NEOTECTONICS, LANDSLIDES AND PLANNING: The Case of Maratea(PZ), Basilicata, Southern Italy

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Thesis presented for the degree of Doctor of Philosophy

Frontispiece: The sackung deformation on the summit of Monte San Biagio, Maratea, southern Italy.

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ABSTRACT

The thesis examines the geology and geomorphology of the town of Maratea, southern Italy, and their efffect on the development of the town.

Maratea is situated at the mouth of a fault-controlled valley surrounded by high limestone mountains of Jurassic and Triassic age. Recent ground movements are associated with a 2km long fault plane scarp which runs along the eastern flank of the valley and the limestone strata above the Town Centre are affected by an excellent example of a deep-seated slope deformation known as a sackung. Six limestone blocks are located in the valley floor below the fault plane scarp and in addition the area is affected by earthquakes associated with the evolution of the Apennine chain.

The area has experienced two phases of neotectonic activity. Evidence from the literature places the first of these at somewhere between 2.0 MY BP and 0.7 MY BP. Subsequently the valley was deepened by a further phase of neotectonic activity, fixed by a U-series date obtained by the author, at 46.4 +/-3.5 x 10^3 yrs BP.

Since then landslide movements have predominated. The fault plane scarp is being exhumed from beneath covering deposits and lichenometric dating, based on the species *Aspicilia calcarea*, shows that up to 15m of scarp face has been exposed in the last 300 - 600 years. The movements are periodically accelerated by earthquake shaking. The limestone blocks are found to be stable features, although a piece of one block, which has broken away from the main block has tilted at various times. The dates of tilting have been determined by sectioning stalactites growing on the block and dating their observed growth phases by a first-order ^{14}C method. Tilting apparently occurred at 2400 +/-300 yrs BP and within the last 400 years.

Finally a questionnaire survey covering all 1008 buildings in Maratea indicated that earthquake shaking, exacerbated by the highly variable sub-surface geology of the valley, is the primary cause of damage.

These preliminary findings reinforce the case for detailed neotectonic research as a prelude to development in unstable tectonic environments.

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ACKNOWLEDGEMENTS

I am indebted to a number of people who have helped me throughout the course of this thesis.

First and foremost, I wish to thank Prof. David Jones of the London School of Economics for a great deal of advice, enthusiasm and encouragement and above all for his detailed criticism of the text out of which has emerged a genuinely better work.

Prof. Judith Rees must also be thanked for taking the risk of allowing me to borrow her car for the journeys to and from Italy.

Thanks must be extended to two of my fellow post-graduates - Roger Foord and Paul Redfern - for enduring some very difficult conditions as field assistants. Roger in particular, spent the whole of one field season in Maratea.

In the UK, Owen Green and his colleagues, at the now closed Department of Geology of Goldsmiths College, are owed a particular thank you for allowing me to use the College facilities and for their help with the XRD analysis. Prof. Claudio Vita-Finzi kindly allowed me to use his ^{14}C dating rig at University College London and helped and guided me through the procedures of tufa dating. I am also grateful to Dr. Marjorie Sweeting and Dr. Vanessa Winchester both of Oxford for their discussions on limestone environments and lichenometry respectively. Dr. Brian Coppins of the Royal Botanic Garden in Edinburgh was kind enough to identify my lichen samples.

In Italy, I am grateful for the help and advice I have received from Prof. Vincenzo Rizzo of the *Consiglio Nazionale della Ricerca* in Cosenza and from Prof. Gregorio Corrado and Dr. Christopher Kilburn of the Department of Seismology, University of Naples.

More than anyone else, my wife, Christine Mudge, deserves thanks for enduring my long absences due to both fieldwork and writing.

On the practical side her weeks of patient work are represented in the coloured damage survey maps which accompany this thesis.

Welwyn Hatfield Council, my present employers, have been kind enough to allow me to use their facilities to finish this thesis. In addition, my friend and colleague at Welwyn Hatfield, Ann Bessant, has painstakingly proof-read the entire work and for this I owe her a particular thank you. I entirely accept, however, the responsibility for any errors that remain.

Last, but by no means least, I must thank Signora Giovanna Giordano and Signora Maria Gianotta, the head teacher and deputy head respectively, of the *Collegio Scuola* in Maratea where I used to return after long days in the field. Both of these ladies where more than kind in allowing me to use the school and its facilities.

I will remember above all, however, the people of Maratea for their friendship and kindness; to single-out names would be to miss many others and so although they are not written here they are not, and never will be, forgotten. A thesis must, of course, stand on its academic content but if there is ever more to it than that, it was surely to be found in southern Italy.

Welwyn Garden City G.R.M.
26 January 1991

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GLOSSARY

The Italian Political System

The Italian political and administrative system is organised on four tiers:

- The National Government
- The Region (Regional Government)
- The Province (Provincial Government)
- The Comune (Town Council)

The **Regione Basilicata** is thus divided into two provinces; Matera (official abbreviation MT; capital Matera) and Potenza (PZ; capital Potenza). Maratea is in Potenza Province and is thus correctly termed Maratea(PZ). The provinces are further sub-divided into ***comune*** (pronounced kom-oo-nay) and the *comune* into smaller units termed ***rione***, which are similar to wards in the UK. Throughout this thesis, when the term *comune* with a lower case 'c' is used, it refers to the whole of the Maratea area governed by the local council - the *Comune di Maratea*. '*Comune*' with an upper case 'c' thus denotes the elected town council.

Commonly Used Italian Words

Lucania: This is the ancient name for Basilicata, derived from the name of one of the earliest peoples to settle the area - the *Lucani*. It was briefly revived by Mussolini but, after the Second World War, Article 131 of the Constitution of the Italian Republic declared Basilicata to be the official name of the region.

Mezzogiorno: Literally the half-day or midday. The name for the south of Italy, most commonly used to refer to the regions of Basilicata, Calabria and the island of Sicily.

Frana:	Landslide	***Centro Storico:***	Historic centre
Torrente:	River	***Chiesa:***	Church

CHAPTER ONE

DEVELOPMENT AND THE LANDSLIDE HAZARD IN THE MEZZOGIORNO: THE CASE OF MARATEA

1.1 The Mezzogiorno

A common saying in Northern Italy is that 'Africa begins at Naples'. The saying conjures up in the imagination scenes of the Third World; vast tracts of barren land, sparse vegetation and burning sun. Villages dotted throughout a landscape where people live in immense poverty dominated by family, religion and the Mafia. A region most graphically described by the Italian writer Carlo Levi in the introduction to his book 'Christ Stopped at Eboli' (Levi, 1945).

> Christ did stop at Eboli, where the road and railway leave the coast of Salerno and turn into the desolate reaches of Lucania. Christ never came this far, nor did time, nor the individual soul, nor hope, nor the relation of cause to effect, nor reason, nor history. Christ never came, just as the Romans never came, content to garrison the highways without penetrating the mountains and forests, nor the Greeks who flourished beside the Gulf of Taranto. No one has come to this land except as an enemy, a conqueror, or a visitor devoid of understanding. The seasons pass today over the toil of the peasants, just as they did three thousand years before Christ; no message, human or divine has reached this stubborn poverty. We speak a different language and here our tongue is incomprehensible. The greatest travellers have not gone beyond the limits of their own world; they have trodden the paths of their own souls, of good and evil, of morality and redemption. Christ descended into the underground hell of Hebrew moral principle in order to break down its doors in time and to seal them up into eternity. But to this shadowy land that knows neither sin nor redemption from sin, where evil is not moral but is the pain residing forever in earthly things, Christ did not come. Christ stopped at Eboli.

The problems of the Italian south - the Mezzogiorno - have long been recognised by planners and politicians alike and particularly in the post-war period a great deal of central government funding has poured into the region. The money has been used for a variety of purposes, agriculture, industrial development and infrastructure to name merely the main headings. This money is being spent in not only in one the poorest regions in Western Europe but also one of the most physically dynamic . In the Mezzogiorno, landsliding, earthquakes and soil erosion are real not academic problems. The severe physical problems of the region have for long been recognised by planners and politicians but all too often misunderstood, underestimated or ignored so that money is made available for major road projects, for example, which cross extensive landslide zones and hence require constant funding for remedial works.

The purpose of this chapter is to bring together the two major problems of the Mezzogiorno - underdevelopment and the difficulties imposed by the physical environment (particularly landsliding) - to outline the response of the Italian authorities to both and to describe the way in which they are interlinked. The final section will focus on the role of the Maratea case study in demonstrating the value of applying geomorphological information at the development planning stage.

The Mezzogiorno is officially defined as encompassing the regions of Abruzzi, southern Latium, Campania, Molise, Apulia, Basilicata, Calabria and the two islands of Sicily and Sardinia. In this region covering two fifths of Italy's land area live 20 million people, which is 35% of the total national population of 56 million. However, the Mezzogiorno is more usually thought of as the three poorest regions in Italy, namely Basilicata, Calabria and Sicily. Statistics such as Calabria having the country's lowest per capita income and Sicily its highest level of unemployment (King, 1985), merely hint at the enormity of the underdevelopment problem. Strong regional policies developed for the Mezzogiorno since 1950 have helped to transform the area from 'a hopeless world of poverty and unemployment' (King,1985,p.141), but why did this world come about and how has it been transformed?

The traditional view on the impoverishment of the Mezzogiorno has emphasised three factors; climate and terrain; lack of natural resources and systems of land tenure, in other words the inherent weakness of the southern economy (Mountjoy,1973). In the regions of Basilicata, Calabria and Sicily mountains or the 'ossa' (backbone) of Italy occupy about 85% of the total land area. Hilltop towns perched above steep, eroding slopes of loosely consolidated Plio - Pleistocene deposits are common; sited there for defence reasons and, more importantly, to avoid the formerly malarial plains known as the 'polpi' or flesh. Very wide, stony, gravel bed rivers are a feature of southern Basilicata as is the calanchi (Plate 1.1) - the heavily disected soil erosion landscape similar to the bad lands of the U.S.A. Harsh winters and long dry summers have produced an arid climate difficult for virtually all types of agricultural activity.

The agricultural difficulties of the region have been exacerbated since Classical times by the system of land tenure. As early as 135 B.C., the Roman Tiberius Cracelius, described a landscape ridden by Malaria and suffering from serious soil erosion (Alexander,1985). These two factors led to Roman landowners moving away from the interior of the Mezzogiorno to the coastal plains. This shift of population led to the rise of a Roman aristocracy (latifondisti) who owned vast areas of low-lying farmland but who lived away from the malarial areas. Thus, the yeoman farmers were replaced by latifundium slave labour under an absentee landlord. The system persisted into the 20th century; as Alexander describes it 'peasants were the mainstay of the system, and in certain parts of Apulia and Basilicata large dormitory villages grew up, with cramped conditions and grossly inflated population sizes for the range of services provided. At Matera [see Fig. 1.1] once known as the 'peasant capital of the south', 12,000 people and 15,000 animals lived in a dense network of haphazard but organic communities based on caves in a limestone ravine that had been inhabited since Iron Age times. Each morning would involve a mass exodus by horse and donkey to the fields and large latifundium farmhouses', (Alexander, 1985, p.125). By its very nature latifundium farming led to poor agricultural practice and the continual existence of a poor and

Plate 1.1: Calanchi scenery near Pisticci in eastern Basilicata.

Figure 1.1: Principal places mentioned in the text.

subservient agrarian population. King (1968), for example, reports that **even up to 1949,** in one Calabrian village - Cutro - 83% of the land belonged to only 2% of the population.

While climate, terrain, outdated land tenure systems and lack of a natural resource base have undoubtedly been primary factors in the underdevelopment of the Mezzogiorno, it is the relationship between the south and the north of Italy that many authors have focused upon to explain the continued impoverishment of the south.

Both Spooner (1984) and King (1987) argue that the 'Questione Meridionale' - the Southern Question - can be explained in terms of regional dualism. As King (1987, p.129) points out 'Italy presents the most classic case [of a dual economy]. It has the distinction of combining one of Europe's most advanced industrial economies, with one of the continents poorest and most depressed areas - the Mezzogiorno.' As noted above this regional dualism has often emphasised the weakness of the south in terms of its poor natural resource base, high migrational outflow and large population, classic symptoms of an underdeveloped economy. In addition before the unification of Italy in 1861 the south played the role of a feudal colony and suffered from its subjugation under the Bourbon Kingdom of the Two Sicilies. Thus the south retained an agrarian peasant culture strongly bound by religion and family, lacking the ability to take effective collective action and stifled by the emergence of the Sicilian Mafia, Calabrian Onorata Societa and Neopolitan Comorra.

However, many commentators (see for example Spooner, 1984) are beginning to argue that northern Italy has been the long standing enemy of the south. Spooner (1984), for example, rather than seeing the unification of 1861 as releasing the south from its feudal ties argues that the opposite was true and that unification merely opened the south to northern exploitation, especially from the industrial area of Piedmont. Furthermore, an alliance between northern industrialists and southern latifondisti was, prior to 1945, the key to the success of the Italian political system, to the detriment of the southern peasantry. This view can be extended into the post war period where the predominant regional partner (the north) continued to sap the subordinate (the south). Indeed, in the 1950s and 1960s the north, particularly the Milan - Turin - Genoa industrial triangle, has drawn on cheap southern labour, this in addition to the south providing a market for northern products.

Political policies towards the south, always important in a highly political country like Italy, have likewise played their part in the underdevelopment of the south. Policies have often been directed towards attempting to maintain a secure political power base for the Christian Democratic Party. Spooner (1984) has argued that the Christian Democrats have underutilised the south's wealth, maintained people in key positions and used short term financial handouts to pacify the electorate. In short, in its relationship with the north the south has become 'a peripheral zone where the regional crisis is not cyclical or short term, but is fundamental and structural' (Spooner, 1984, p.13).

1.2 Regional Policy and the Mezzogiorno

The uncertainty which has existed over the problems of the Mezzogiorno, that is, whether it is merely a rural development problem or one which is more deeply founded in the north - south divide has led to a variety of regional policies for the south.

The early perception of the Mezzogiorno as a rural development problem led to the Land Reforms of the 1950s. The land reform laws began as a response to a rural uprising in Calabria in 1949 when starving peasants occupied absentee owned latifundia land. The land reform laws expropriated land from absentee landowners above a private holding limit of 300ha and redistributed it in small land parcels to landless peasants. However, the reforms were aimed beyond mere expropriation and as King (1987, p.139) points out, also involved 'land improvement, irrigation, settlement and land use planning, education, setting up of co-operatives and marketing of produce.'

The land reform laws of the 1950s achieved varying degrees of success; for example in the Metapontino, the Ionian coast area in the instep of the Italian peninsula, large tracts of land were expropriated and thousands of new farms established. Conversely, in Sicily, non-co-operation by the peasantry and intervention by the Mafia have left the land reform laws in tatters. However, as King (1987) states 'the single most important achievement of the reform was the destruction of the social and economic power of the latifondisti, to the downtrodden peasantry who before 1950 lived in a hopeless world of poverty and unemployment, it brought some relief and the hope of better things to come' (King, 1987, p.141).

The problem of Italy's dual economy was also tackled in 1950 by the setting up of the Cassa per il Mezzogiorno (the Fund for the South). Industrialisation was perceived as the key to the development of the south and the Cassa was established, with national government funding, in order to provide regional incentives to industrial development in the south. In 1984, following a minor political crisis, the Cassa was wound up but in 1986 the founding of the Agenzia per la Promozione dello Sviluppo del Mezzogiorno (with essentially the same powers and funding as the Cassa) ensured that regional development policies for the south would continue.

During the life of the Cassa the emphasis of regional policy has shifted. During the early years (1950 - 1957) regional policy favoured agriculture and infrastructure, particularly water supply and roads. Between 1957 and 1970 the emphasis shifted to a policy of direct grants to industrialists in order to encourage them to locate plant in the south. During this period 70% of all Cassa funding was used for industrial development. Since 1970 much greater autonomy has shifted to the regions of the Mezzogiorno and regional government has taken control of roads, agricultural investment and tourism. The result is that the activities of the current Agenzia are focussed on three areas:

(i) Technical advice to regional government;

(ii) Incentives for industrial and commercial development; and

(iii) A programme of 'special projects' aimed at stimulating local economic development. Among these are the cleaning up of the Bay of Naples, specific agricultural schemes such as the promotion of citrus fruit production and an inter - regional water supply network.

Although the work of the Cassa has achieved some success it has, nonetheless, been criticised on a number of counts primarily relating to its continued emphasis on industrial development. Spooner (1984) argues that three points are of importance:

(i) The industrial projects that have been funded are all large scale but capital intensive; as such they have contributed little to local employment and indeed have been of more benefit to northern industrialists;

(ii) Funding of industrial plant has led to so called "Cathedrals in the Desert", industrial complexes that are not linked to the local economy and provide little in the way of local development; and

(iii) This concentrated pattern of development around a number of industrial poles has exacerbated territorial imbalances within the south.

1.3 Development and the Environment: The Landslide Problem

Whether the view is taken that the underdevelopment of the Mezzogiorno is due to the nature of the physical environment or the south's relationship with the north, it is clear that physical problems continue to be a huge drain on resources and a major cause of suffering. Alexander (1987) has described Italy as a 'Land of Disasters'. Regretfully, this is a highly emotive term, and while drawing attention to the range of physical problems from which Italy suffers, it tends to focus on individual site-specific disaster impacts while ignoring the more important and widespread problems of environmental degradation.

The southern Italian earthquake of 1980 was a disaster, killing nearly 3,000 people in the Mezzogiorno. By contrast, although landsliding in Italy has killed the same number of people in the post war period, only two impacts, namely the 1963 Vajont Dam landslide and the 1985 Val Stava Dam landslide, qualify as disasters. Nonetheless the cost of landsliding in Italy is enormous; for example Cotecchia and Melidoro (1974) have argued that landslides are 'so extensive and serious that they affect economic development' (p.23). In the country as a whole, Arnould and Frey (1978) have put the cost at around US$1140 million per year. The figure is calculated in terms of the loss of housing stock, infrastructure plant and machinery and does not include remedial measures. Similarly, Carrara and Merenda (1976), using the same formula for their calculations, quote losses due to landsliding in Calabria at US$200 million during the period 1972 - 1973. In some towns in Calabria up to 30% of the urban area is threatened by landsliding and in 1973, 200 villages and 5000 people in the same region were affected by landslides after 20 days of rain (Rizzo *pers. comm.;* see also Carrara *et al*, 1977; Carrara and Merenda, 1976).

Numerous examples exist in southern Italy of large ancient orogenic landslides (palaeoslides) thought to be periodically re-activated by earthquake shaking. Many towns in Campania, Calabria and Basilicata have become vulnerable due to this type of landsliding. In many instances these towns are located on hilltop sites (Plate 1.2) or perched on steep sided interfluves composed of Plio - Pleistocene sands and clays. These town sites were originally chosen to avoid attack from marauders and from malaria spreading mosquitoes that bred in the river valleys below, and although both a degree of political stability and the eradication of malaria have subsequently come to the Mezzogiorno, the old settlements still persist. The towns are particularly susceptible to deep seated rotational landslides, Alexander (1981) estimates that 104 settlements in Basilicata are at risk from this type of failure. At Pisticci in the province of Matera (Fig. 1.1), for example, 400 people were killed in 1888 when a seismically induced landslide destroyed a large section of the town. In 1976 landsliding of a similar scale affected the town

Plate 1.2: Rivello in western Basilicata - a typical southern Italian hilltop town

although, on this occasion, with no loss of life. Today the town can be seen perched precariously above the valley floor with the heads of immense gullys edging ever closer to the urban area. Along the western side of the Mezzogiorno, where Maratea is situated (see Fig. 1.1), quite different landsliding problems occur. In this area, formed of high limestone mountains, gravity falls and rock topples are a more common occurrence, although translational and rotational failures have been reported on the argillaceous deposits preserved in tectonic basins (Lazzari, *pers. comm.*).

The identification of landsliding caused by the 23rd December 1980 earthquake is difficult and problematic, for as Alexander (1981) rightly points out, it is often almost impossible to distinguish seismically induced landslides from those that would have occurred anyway. Indeed, it is more likely that most of the landsliding reported immediately following the earthquake was triggered by torrential rain that began four days before the main shock. At Calitri (see Fig. 1.1), for example, Alexander (1981) notes that the Naples newspaper Il Mattino commented favourably on the anti-seismic resistance of its buildings. Perversely, most of Calitri suffered severe damage in early December 1980 due to the reactivation of complex deep seated rotational landslides. The cause of landsliding was primarily high pore water pressures brought about by heavy rainfall but exacerbated by the state road (SS No.399) ascending to the town in a series of hairpin bends that cut across the landslide body at a number of points (see Hutchinson and Del Prete, 1986). Similarly, San Fele (PZ) suffered from a number of shallow bowl shaped slides, at first attributed to the earthquake, but more likely the result of excess pore water pressures brought about by the rain.

In contrast, Tricarico (MT) (Fig. 1.1) which is situated on massively jointed calcarenites, suffered severe damage directly attributable to the earthquake. The street pattern of Tricarico bears no resemblance to the joint pattern and hence many buildings cut across natural fissures. Movement of these joints and cambering failure of calcarenite blocks allied to architectural factors meant that the historic urban centre of

Tricarico suffered severely during the earthquake. Similar reasons are thought to be responsible for massive deep seated failures at Craco (MT). In 1966 landsliding at Craco was so severe that the town had to be partially abandoned. Despite very expensive remedial works landsliding on a huge scale continued and the town has now been entirely abandoned (Plates 1.3, 1.4 and 1.5). Indeed Del Prete and Petley (1982) have argued that ill-informed development and inadequate remedial measures largely contributed to the landslide problem in Craco and were instrumental in bringing about its abandonment.

Similarly at Senise (Province of Potenza), landsliding in 1986 directly attributable to new building work which cut across an old landslide, killed 8 people.

Grassano (MT), sited on an old regressive palaeoslide had damage to 35% of its older buildings caused directly by sub-soil movements generated by the 1980 earthquake. However, continued problems of landsliding in the town have damaged old and new buildings alike. Alexander (1981) notes that of 334 buildings now evacuated as a result of landsliding rendering 1,500 people homeless, 103 are in the *centro storico* (historic centre), 119 in pre-war housing and 112 in a development built in 1950.

Resiting landslide prone villages is the most obvious answer to the problem; reducing vulnerability by moving away from areas of potential hazard. Yet, attempts to do so have been singularly unsuccessful. Craco (MT) which, as noted above, was virtually destroyed by landslides in 1966 was rebuilt as Stazione Craco in a nearby valley location. The new town is tremendously unpopular with its inhabitants, lacking the traditional feel and architecture of the old town. Indeed, so unpopular is this new town that the old Craco is still home to a few dozen people. Similarly, Bisaccia, a town in the Avellino province of Campania, has suffered damage throughout its history from three active landslide zones, to the point where 1,000 homes are now uninhabitable. Despite this the Bisaccia Structure Plan which recommended abandonment and a new safer site, met with enormous

Plate 1.3: The village of Craco in Matera Province, now abandoned because of massive landsliding.

Plate 1.4: Landslide damage to Craco (MT).

Plate 1.5: Landslide damage to Craco (MT).

local opposition and has still not been adopted as a policy document.

Damage to roads from landsliding is also a serious and recurring problem in the Mezzogiorno. Alexander (1981) reports that virtually all of the 29 state roads (strada statali or SS) exposed to serious seismic shaking in the 1980 earthquake were damaged due to landslide activity. In addition, the main Salerno - Potenza road (the Basentana) was damaged due to rockfalls and shallow sliding movements. Fortunately few major roads traversed the area of greatest earthquake intensity and damage was limited. Nonetheless, the infrastructure network in the Mezzogiorno has been the recipient of a great deal of funding both from the Cassa and the E.E.C. and many roads are very high cost capital, projects; the Basentana, for example, could only be built with major funding from the Cassa as it requires major viaducts and tunnels along its route. Setting aside the actual traffic use which these roads get, which in many instances does not justify the cost, it is regrettable that a number of them will always require expensive remedial work because they cross landslide zones that were not identified before construction began. A notable exception was the work of Baldassare and Radina (1980) who investigated stability conditions along the length of the SS 92 running between the towns of San Arcangelo and Senise. Regretfully their findings, largely based on geotechnical observations, only recommended viaducts, cuttings, embankments and defensive works; no attention was apparently paid to road re-alignment to avoid potential landslide zones. As a result many expensive viaducts along the SS 92 are now suffering considerable distress due to slope failures (Plate 1.6).

1.4 Response to the Landslide Hazard

Despite the fact that the landslide hazard in the Mezzogiorno was recognised as long ago as the early part of this century (Almagia, 1907, 1910), few studies on landsliding exist prior to 1980. Exceptions to this are the work of Cotecchia and Melidoro (1974), who carried out a regional survey which attempted to

Plate 1.6: Viaduct on the S.S. 92 abandoned due to a rotational landslide. The road was funded by the Cassa per il Mezzogiorno

correlate landslide type with geological unit, and more particularly Carrara and Merenda (1976) followed by Carrara *et al* (1977, 1982) who established a comprehensive inventory of Calabrian landslides.

It is however, the 23rd November 1980 earthquake and more importantly the large number of landslides associated with it , that has generated the greatest interest in the problems of landsliding in the Mezzogiorno. Numerous works have been published on the slope movements associated with the 1980 earthquake; for example, Crescenti *et al* (1984) on the Bisaccia landslide; D'Elia *et al* (1986) on the Andretta landslide in Campania; Carrara *et al* (1986) and Dramis and Sorriso-Valvo (1983) on the general characteristics of slope movements induced by the earthquake. Geomorphological information is lacking in all of these reports which almost solely concentrate on geological information.

The lack of adequate earth science information that was available for reconstruction projects, in areas that suffered seismic and/or landslide damage resulting from the 1980 earthquake, was recognised by the Italian authorities. In 1981 regional legislation was passed in Basilicata (L.R.20, 20.7.1981) which provided, under Article 16 of the law for the establishment of a regional geological office whose brief was to supply geological reports for both new projects and for earthquake reconstruction. Prior to this, funding by the Cassa per il Mezzogiorno for new development projects had been granted without even this basic level of information being available.

Fulton *et al* (1986) note that earth science information covering geology, hydrology, lithology and geomorphology is now required by law for all new projects. As Fulton *et al* point out, however, it is a failing of the legislation that a large scale geomorphological map is not a requirement, and that a composite map of geology, hydrology and geomorphology is permissible. Hence, the requirement that the Geological Office express an opinion on a development project 'from a geomorphological point of view' is difficult to achieve owing to a lack of detailed geomorphological mapping.

The role that geomorphological mapping and process monitoring can play in the reconstruction process in southern Italy has been well demonstrated by Fulton *et al* (1986) in the case study of Balvano, a town very near to the epicentre of the 1980 earthquake. In other instances where a great deal of time and money has been spent on the stabilisation of landslide zones (for example, Cotecchia *et al* 1980; Paganelli and Puglisi, 1973), geomorphological mapping and process monitoring have been entirely absent.

1.5 The Maratea Case Study

From the foregoing discussion it is clear that a major factor in the sustainable development of the Mezzogiorno and hence the reduction of the north-south divide, is a recognition of the physical problems of the area. Foremost among these physical problems is the landslide hazard, affecting reconstruction, new development and infrastructure. Landsliding is serious, widespread and costly; it is not, however, a problem that can be solved by finding new money for stabilisation works. Indeed Del Prete and Petley (1982) have clearly demonstrated that 'stabilisation' of landslides can contribute to, not reduce, slope instability. Instead, the landslide hazard requires a comprehensive, multi-disciplinary earth-science assessment (not merely a site-specific geotechnical and geological report), incorporating large-scale geomorphological mapping and process monitoring.

The principal aim of this thesis is therefore to investigate the landslide hazard in the Maratea valley. To do this requires a thorough understanding of the processes at work in the area; for example, if there are movements in the Maratea valley what are their age and causal mechanisms? Are movements related to landsliding or neotectonics or both? A secondary aspect of the thesis will be to re-examine development proposals for the area in the light of this work.

The next section is, therefore, inserted for contextual reasons, to give the reader a thorough working knowledge of the site, situation and development background to the study. Chapter Two, which follows, is also contextual and is similarly designed to provide an appreciation of the geological and geomorphological background to the work.

1.5.1 General Site and Situation

Maratea is a coastal town in the region of Basilicata, Province of Potenza. It is the foremost settlement on the scenically attractive, mountainous seaboard that Basilicata has on the Tyrrhenian Sea; the tourist brochures proclaim Maratea to be the premier, and most exclusive, resort in southern Italy. The town is about 100km (161 miles) south of the nearest airport at Naples, but is reasonably accessible by surface transport. The main Naples - Salerno - Reggio Calabria railway line runs through the *comune* and operates a regular stopping service at Maratea. Road access is more difficult because of the terrain, but the *Autostrada del Sole* or 'motorway to the sun', runs parallel to the coast some 15km inland and can be reached within forty five minutes. As a result both Naples and Reggio Calabria are within three hours driving distance (see Fig. 1.2).

Maratea is located at the mouth of a short valley, orientated approximately N.N.E. - S.S.W., which is set between the steep sided, high limestone massifs of Monte Crivo (1277m a.s.l.) and San Angelo (1083m a.s.l.) and drained by a small river - the Torrente Fiumicello (see Fig. 1.3). The inland apex of the valley is situated 4km from the coast and takes the form of a col (600m a.s.l.) in the limestone ridge. This col separates the Maratea valley from a larger lowland area excavated in a tectonic basin - the Lagonegro Basin - and is traversed by the main access road to Trecchina and the Autostrada. From this point the Maratea valley opens out rapidly to the south and also descends

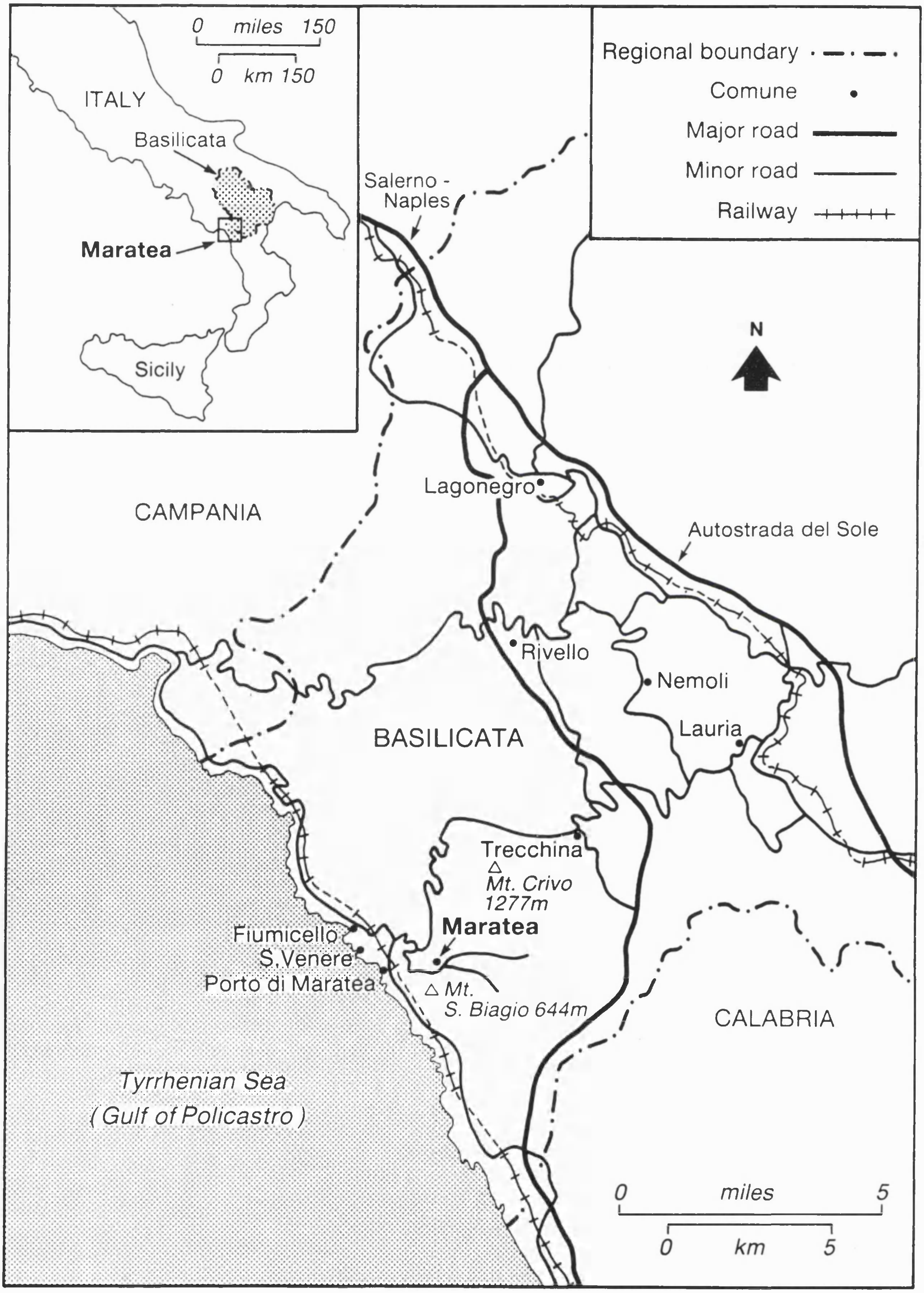


Figure 1.2: Location of Maratea

TOPOGRAPHIC MAP OF THE MARATEA VALLEY

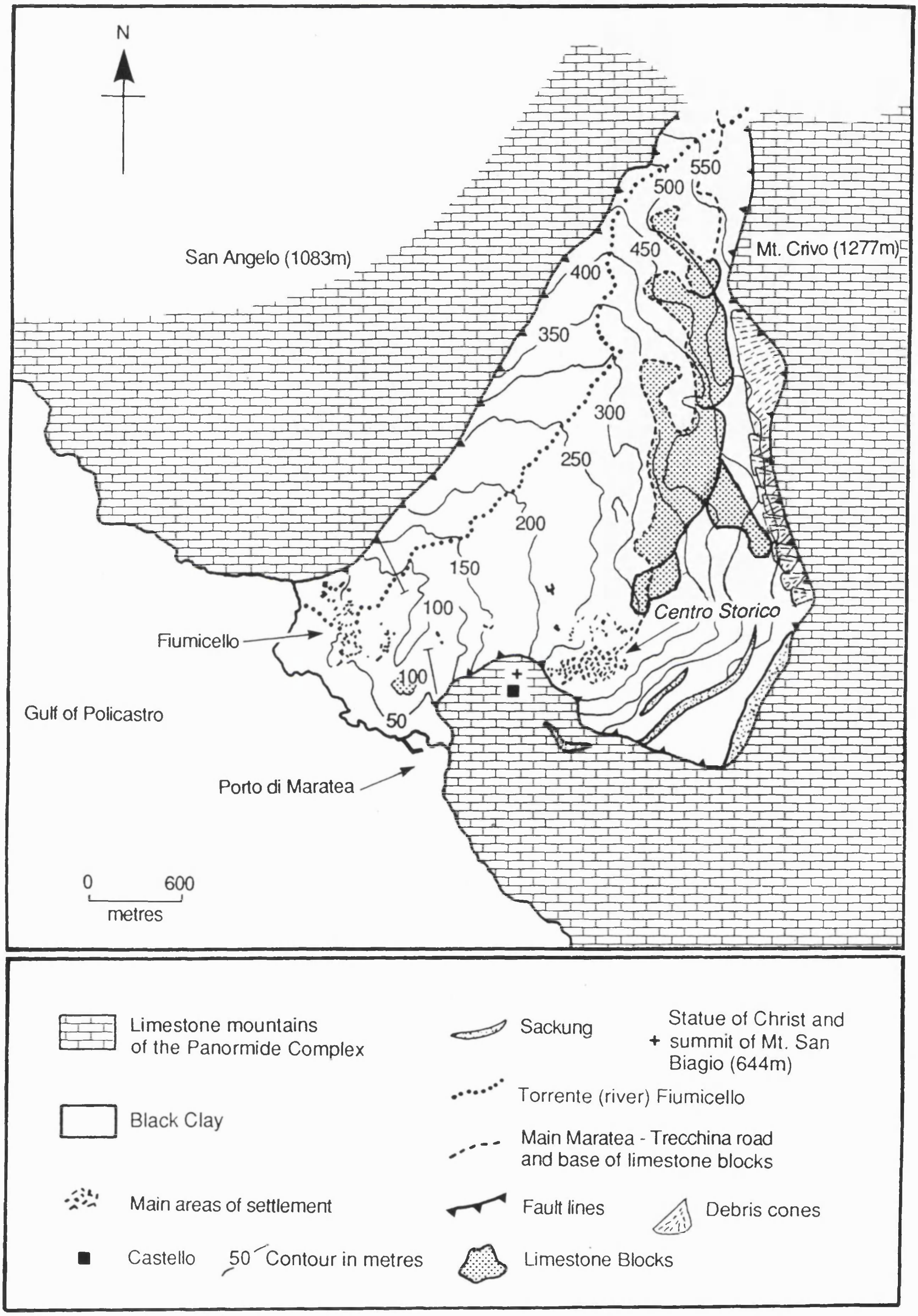


Figure 1.3: Topographic map of the Maratea Valley

quickly to the coast, although the valley floor has considerable morphological complexity and the Torrente Fiumicello occupies an asymetrical position along the north western margin (see Fig. 1.3). The valley is also highly irregular in plan, for the coastal exit is restricted by a north-westward extension of the limestone high ground known as Monte San Biagio (644m a.s.l.) which is bounded by very steep slopes on its northern, western and southern flanks. The valley is dominated by Monte San Biagio, on the summit of which stands a huge statue of Christ (erected in 1963) and the ruins of the first settlement in the area - Maratea Superiore - known locally as the *castello*.

There are three distinct poles of contemporary settlement within the administrative boundary of the *comune* . The old town - *centro storico,* (see Fig. 1.3) - is situated at about 300m a.s.l. on the lower slopes of Monte San Biagio some 300m below the original settlement (Maratea Superiore) and is, as its name suggests, the site of the historic centre of Maratea. By contrast, the Fiumicello di Maratea (see Fig. 1.3) is located at a much lower level (<50m a.s.l.) adjacent to the shore and has few buildings older than about 1950. It is the centre of the 'beach' trade and thrives during the summer months. The Porto di Maratea (see Fig. 1.3), like the *centro storico,* contains a number of very old buildings. For long the major fishing port on this stretch of coast, its activities are now almost wholly centred on the booming tourist trade, catering for small private cruisers at the luxury end of the sailing market. The population of the whole *comune* at the 1980 census was 5083, although this figure more than quadruples during the June - August tourist season.

The topography of the Maratea area clearly reflects the dominant influence of geological structure (see Fig. 1.3). The Maratea valley is underlain by black clays which have been let down within a graben-like trench delimited by two normal faults which converge away from the coast. The overall shape of the valley is therefore fault controlled, as are the boundaries of the Monte Crivo and San Angelo massifs. The surface affects of faulting are readily visible in the landscape, most dramatically on the north-western flanks of the Monte San Biagio ridge immediately above the *centro storico*, where the limestone strata are being affected by a type of deformation known as a 'sackung', (from the German, meaning literally 'sagging'; Varnes, 1978). The sackung consists of a number of major vertical breakages which exist as bluffs and cliffs (Plates 1.7 and 1.8: Plate 1.7 is also reproduced as one of a stereo pair of aerial photographs in the back pocket of this thesis). The main dislocation can be traced inland in a narrow arc of about 0.75km length at which point it trends into a clear fault plane scarp approximately 2.08km long (Plate 1.8). The fault plane scarp runs along the base of the Monte Crivo massif and is easily distinguished as a steeply inclined, smooth grey-coloured rockface not more than 40m in height. Grooves scored down the rockface are slickenside ridges which are diagnostic features of fault plane scarps. The smoothness and light colour of the fault plane suggest recent exposure through neotectonic movements of the scarp, landsliding or a combination of the two. The physical expression of the fault line ends at the inland extremity of the valley where the fault plane scarp disappears. Directly beneath the fault plane scarp occur extensive talus deposits which form a series of coalescent debris cones which rest, in turn, upon six limestone blocks of varying size. The talus accumulations resting on these blocks have slopes of between 20° - 30°, while the front 'leading' edges of the blocks fall away much more steeply (50° - 60°). Beneath, and to the north, of these blocks lies the valley floor proper which is about 800m wide at the coast but narrows inland.

North-west of the *Torrente Fiumicello* - lie the slopes of San Angelo. A second normal fault runs along the base of the San Angelo massif (Lazzari, *pers. comm.*), but unlike the fault scarp on the south-east side of the valley, has no surface expression. Apart from a minor rockfall in 1985 at the coastal end of the fault, there is no evidence of any landslide movements affecting this side of the valley in historical time.

In contrast, clear evidence for movement exists along the south eastern side of the valley. Displacements associated with the

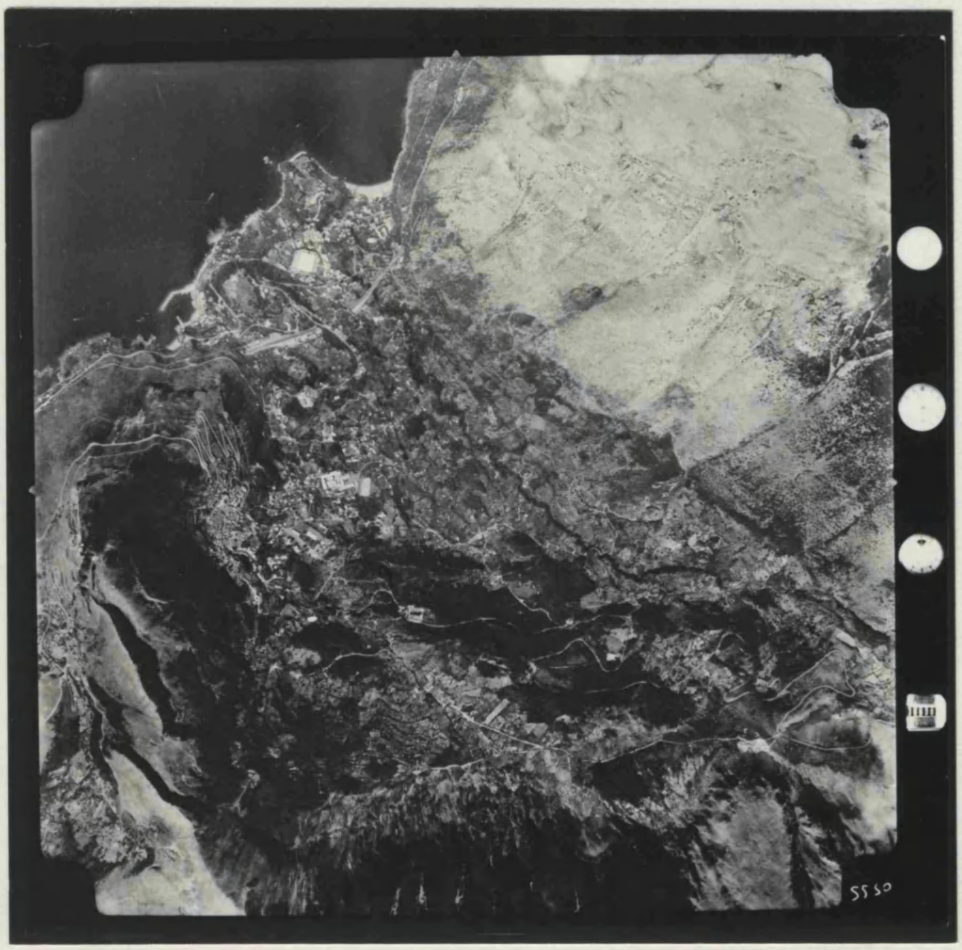


Plate 1.7: Aerial photograph of the Maratea valley - north is on the right. A major north - south trending normal fault and a north-east - south-west normal fault separate the limestone high ground from the valley. The historic centre of the town is on the centre - left of the photograph beneath the summit of Monte San Biagio. The major breaks of the sackung are at the bottom left. Photograph 46420 flown on 20 November 1974 - courtesy of the Istituto Geografico Militare, Florence. This photograph is one of a stereo pair which are included in the back pocket of the thesis.

Plate 1.8: Photograph of the Maratea valley, looking north from Monte San Biagio. The sackung is on the right and the fault plane scarp can be seen running through the centre of the photograph.

sackung have caused considerable damage to the *centro storico* from the earliest known historical records in the 11th century to the present day. Similarly, there are clear signs of recent movement along the fault plane scarp; as noted above its smooth surface morphology, limited weathering etching and pale colour suggest recent exposure. Moreover at the base of the fault plane scarp there is often a narrow (<1m) band of very pale grey colouration, referred to here as the "white line". This "white line" phenomena indicates a zone of minimal weathering and thereby suggests very recent exposure.

Since 1978, when a plan was prepared by the local town council (the Comune di Maratea or Comune) outlining the future development strategy for the area, a great deal of geological and geotechnical work has been carried out in Maratea. Almost exclusively this work has been concentrated on the centro storico and sackung, with only passing reference to other areas of the valley. Indeed it is important to note that prior to the commencement of this thesis in 1984 there was virtually no awareness of the existence of the fault plane scarp or the possibility of differential movements.

1.5.2 Major Structural Features of the Maratea Valley

The valley of Maratea has three major visible structural features noted in section 1.5.1. These are (see Plate 1.9):

(i) the sackung deformation;

(ii) the fault plane scarp on the south-east margin of the valley and;

(iii) the limestone blocks below the area of talus deposition.

- **The Sackung**

As noted in section 1.5.1, the slopes of the Monte San Biagio, immediately above the *centro storico*, are affected by a major

Plate 1.9: Major structural features of the Maratea valley. The fault plane scarp is a clear light coloured band under Monte San Biagio. The sackung is on the extreme right and the limestone block field, is the heavily vegetated area below the fault.

deformation known as a sackung. The outward expression of the sackung is a series of nine vertical breaks or tears of varying size, the largest being approximately 100m from crest to base and the smallest 1m - 2m high. The sackung has been a major source of interest in the valley since the historical records began about 800 years ago. Three reasons exist for this; first, its unique beauty, unusual character and impressive scale in the landscape; second the damage which movements said to be associated with it have caused to the *centro storico* and third, its interest to academics. This last point has led to a number of published papers on the sackung; these will be discussed fully in Chapter Three section 3.2.1 with particular reference to the relevance of the information they contain to other sections of the valley.

- **Fault Plane Scarp**

Next to the sackung the 2km long fault plane scarp at the base of Monte Crivo is the most impressive structural feature in the valley although, as noted previously, there was little knowledge of its existence or significance before work began on this thesis. This is despite the fact that the fault plane scarp appears to be a northward continuation of the largest break of the sackung, leading to the initial supposition that the fault scarp and sackung are part of the same structural feature. In contrast to the sackung, little work has been carried out on the fault plane; the work that has is examined in section 3.2.2.

- **Limestone Blocks**

Air photograph interpretation and geomorphological mapping of the valley by the author revealed the extent of six major blocks of limestone positioned below the fault plane scarp. These heavily vegetated features are described as "blocks" because they each have definable boundaries, in particular the presence of a distinct scarp or 'cliff' on their valley facing side. This would not be expected if the blocks were merely accumulations of limestone material derived from weathering processes taking place on the Monte Crivo ridge. In this instance the blocks would appear as large mounds of coalescent material with no definable boundaries.

Five blocks are immediately below the zone of talus deposition adjacent to the fault plane scarp, the sixth is near to the coast and has scarp faces on all four sides. The largest block is about 700m long by 200m wide with a visible depth of about 120m and the smallest 150m X 150m X 100m; all these figures are approximate values determined from the air photographs. The depth of each block buried below talus accumulations is not known.

Again, prior to the commencement of this thesis, there was virtually no knowledge of the origin of the blocks or their significance to future development in the valley, although their presence had been recognised (Guerricchio and Melidoro, 1979). The limestone blocks will be discussed in detail in section 3.2.3.

1.6 Maratea: Planning for Future Expansion

In 1978 a draft Structure Plan for the Maratea area was published by the Comune. This document was in its final discussion stages when on the 21 March 1982 an earthquake of VI - VII on the Modified Mercalli Scale, struck the area causing widespread and serious damage. One side effect of the earthquake was that the Structure Plan was temporarily shelved in favour of post-earthquake reconstruction. The result is that many of the Structure Plan recommendations are only now being implemented. Many of those recommendations will be affected by, and will themselves affect, the natural environment in the Maratea area, principally the hillslope conditions. It is one of the intentions of this thesis to examine the Structure Plan in the light of physical restraints imposed by ground conditions prevailing in the area.

1.6.1 Introduction

The most famous biographer of the Italian south, Carlo Levi remarked that 'no one has ever come to this land except as an enemy, a conqueror, or a visitor devoid of understanding', (Levi, 1945; p.12, 1984 English translation). Today the Italian people are, perhaps, more willing to excuse the intellectual capacity of those who travel to the Mezzogiorno provided they are not visitors devoid of foreign currency.

Italian planners also perceive that one of the ways of helping to correct the regional imbalance, dicussed earlier in this chapter, is the encouragement of tourism in the Italian south, although here too, there exists a high degree of regional disparity (see White, 1987). The Tyrrhenian coast of Basilicata has much to offer those for whom sun and sea provide the ideal holiday environment. During the main Italian holiday season of August, Maratea attracts considerable numbers of Italian, German and Swiss tourists. If the planned expansion of Naples' Capodichino Airport and that of La Mezia Terme (in Calabria) go ahead, many more tourists from other parts of Europe can be expected. To cope with this expansion Maratea will need to improve its infrastructure base; at the same time, in order to maintain its position in the tourist market place, it must keep alive the feel of the 'typical' southern Italian town and provide modern tourist facilities (for example the new Pianeta Maratea hotel constructed on the southern flanks of Monte San Biagio). The success of Maratea is of first importance to both the town and the Region of Basilicata. The Pianeta Maratea, for example, was built by a consortium of companies based in the north of Italy; these companies invested in Maratea for commercial reasons. If this project in Maratea can be seen to be a commercial success, further investment may well be attracted to both Maratea and other possible tourist locations in Basilicata, possibly leading to eventual investment in industry.

This section will examine the ways in which Maratea has set about solving the development problem. It will look first at the historical basis for settlement in Maratea, as it is around this legacy that future development must take place. It will then move on to look at the problems of land availability and existing tourist development. Section 1.7 will look in detail at the draft solution to these problems contained in the 1978 Structure Plan.

1.6.2 Historical Basis for Settlement in Maratea

There is little archaeological evidence to suggest that there were any prehistoric settlements on the Maratea coastline, although the nature of the coastline and its obvious fishing potential, argue that there might well have been.

Evidence for a strong Greek presence in the area, from about the VI century B.C., is provided by a study of the linguistic evidence (Stoppelli, 1982). Place names such as Calicastro, Racia, Profiti and Santa Venere, which are located on the coast between Maratea and Praia a Mare to the south, are all Greek in origin.

However, neither the Greek nor Roman period was marked by an urban settlement, indeed the first recognisably urban development was not until the VIII century A.D. on the summit of Monte San Biagio. This settlement became known as the *castello* (Plate 1.10). The selection of Monte San Biagio was an obvious one; a hilltop site, easily defended, allowing good visibility for early warning and yet within reach of agricultural land in the Fiumicello valley. The founding of the settlement is dated by the *Chiesa di San Biagio*, which had contained the remains of the patron saint of Maratea since A.D. 732, and by the earliest known document on the town - a Papal bull of Alfano I, Bishop of Salerno, dated 1079.

In the early XV century a small settlement began to grow around the *Chiesa di San Vito* in what is now the old town of Maratea (the *centro storico* or as it is known locally the *borgo*, literally 'the village'). This settlement maintained its defensive advantages being hidden from the sight of sea-going

Plate 1.10: The statue of Christ on the summit of Monte San Biagio. The ruins of the *castello* are on the left.

vessels by Monte San Biagio but, at the same time, allowed an easier access to the agricultural land. The initial building phase was a haphazard collection of houses around a number of narrow streets and squares. The second phase of building during the XV - XVI centuries, saw the addition of more squares and open spaces and a shift in the focus of the town to the *Chiesa Santa Maria Maggiore* (the *Chiesa Madre* or Mother Church). The third phase of expansion in the XVII century, witnessed the building of more roads and some larger, artistically grander, buildings.

The importance of the *centro storico* at this time is apparent from the fact that it became administratively independent of the *castello;* it was allowed its own census and there was even a split in names. The *castello* became *Maratea Superiore* and the *centro storico* was known as *Maratea Inferiore.* In 1736 the *centro storico* became the headquarters of one of the four *ripartimenti* into which the region (then known as Lucania), was divided.

Sieges of Maratea (both the *castello* and *centro storico*), during the XV - XIX centuries, had important consequences for the development of the town (Vassalluzzo, 1987). In 1441 Maratea took arms with the Anjevin King of Naples in a war against the Aragonese of Sicily. The victory of the Anjevins against the forces of Count Sanseverino di Lauria guaranteed that the privileges of land ownership enjoyed by the people of Maratea were confirmed, thereby ensuring that Maratea did not become part of the feudal *latifundium* system of land tenure. It ensured that, to the present day, wealth created by the community stayed within Maratea and did not go to a feudal landlord.

The last siege of Maratea occurred during the Napoleonic wars. In 1806 the *castello* was razed to the ground by the French General Lamarque despite the efforts of the much eulogised Colonel Mandarini of Maratea.

Towards the end of XIX century the railway came to Maratea; the coastal road was built in the 1920s and opened in 1930, the harbour constructed after the Second World War, and the textile factory opened in the late 1950s.

1.6.3 Population

Historical records of the principal church in Maratea, note that in 1523 there were 1800 inhabitants in the *comune*, by 1648 this had risen to 2570. Plague in 1656 reduced numbers to 1300 but they had risen again to 3800 by the end of the XVIII century. Mass emigration in the early 1900s of about 25% of the population, mainly to Venezuela, reduced the population to 2603 in 1910. A drift back of population after the Second World War saw the figures rise to 5067 in 1960; the latest (1980) census put the population at 5083 (Vassalluzo, 1987).

The development of Maratea since the mid XX century has largely been the result of the sons of emigrants returning to Maratea as wealthy men. In particular five families prospered and returned. These families, known as the *Venezualani*, have played an important part in the recent expansion of Maratea. The heads of the families - Vitolo, Trotta, Iannini, Sisinni and Limongi - have all attained important and influential positions within the *comune*. Biagio Vitolo is president of the very influential *Azienda Autonoma Soggiorno e Turismo* (the local tourist board); all the principal supermarkets (Supermercato Trotta, Papaleo and Zaccaro) are either owned by the Trotta family or Trotta women have married into the families that own them. In addition Aldo Trotta is the president of the local Chamber of Commerce. Iannini owns all the bars and cafes in the *centro storico*. Fernando Sisinni has been mayor of Maratea since 1975, taking over from his father and the Limongi family have become the organisers and patrons of all the musical and cultural events within the town. These families provide a great deal of money to the town and their collective voice is a powerful force in shaping its future development. Trotta, for example, invested large sums of money in the new 'Europa' football stadium, built just off the main Maratea - Trecchina road about 1.5 miles from the *centro storico* (Plate 1.11), and also sponsors the Maratea team. This stadium was one of the main investment projects proposed in the 1978 Structure Plan.

Plate 1.11: The Maratea valley looking towards the summit of Monte San Biagio, with the centro storico beneath the summit and the 'Europa' football stadium in the foreground.

1.6.4 Tourism

Because of the absence of a latifundium system of land tenure and because large sums of money were coming back from Venezuela, Maratea has enjoyed a quite separate development from the rest of southern Italy. Today it has a much more affluent look about it than any other town in Basilicata. Looking to future development, the *Comune* are eager to conserve both the historical and cultural heritage of the town and preserve its 'picture postcard' appeal.

Unplanned tourist development has placed an increasing strain on these aims. Vassalluzzo (1987) reports that 'during the summer season the population grows by up to eight times its normal size: in July 1985....the number of registered tourists was 29,209, rising in August of the same year to 43,069' (Vassalluzzo, 1987, p.30); note that these figures are for whole months. Hotels, pensiones and the campsite manage to accommodate most of these tourists (the hotel, *Pianeta Maratea* - 'Planet Maratea' - which is located on the south facing slopes of Monte San Biagio on the opposite side of the mountain to the *centro storico,* was opened in 1985 with space for a thousand guests). The major problem is that in excess of 90% of all tourists bring their cars with them (Comune di Maratea, *pers. comm.*), creating enormous problems on the complex network of narrow roads (Plate 1.12) and severe congestion in the centre of the *centro storico.*

Thus, a high seasonal population causes a number of problems. Among these are traffic blocking the narrow streets of the *centro storico* and bringing with it pollution and parking difficulties and the enormous pressure on existing hotel and community facilities. For example, during the 1987 summer season, the fire brigade provided a temporary crew, housed in a school in Fiumicello, to cope with a greater fire risk generated by high levels of tourism. Even this caused problems as heavy traffic and on-street parking often prevented the fire tender from leaving its barracks.

Plate 1.12: The main street of the *centro storico*.

1.6.5 Land Availability

The shortage of available building land in Maratea poses a serious problem for developers. The existing physical situation of a narrow valley floor has been exacerbated by unplanned development, mostly in the form of weekend holiday homes built by Neopolitans. Many of these people have inherited plots of land in Maratea and, under Italian law, have a legal right to build. In addition there are large numbers of abandoned houses in the area. These were left by former emigrants many of whom have now been forgotten, but their land and their houses can still pass to the family and the *Comune* is not empowered to touch them.

Nonetheless the major problem by far is the physical lack of suitable building land. Very little is left on the valley floor, none in the *centro storico* and none in Fiumicello or the Porto. The only land available is between the base of the coalescent talus cones, adjacent to the fault plane scarp, and the leading edge of the limestone blocks (see section 1.5.2). It is in this area that future developments will have to be concentrated (see Fig. 1.4).

1.7 Maratea Structure Plan

The problems of controlling unplanned tourist expansion while expanding the tourist industry and preserving the natural beauty of the area, were addressed in the 1978 Structure Plan (De Fiore and Brando, 1978), hereafter referred to as the 'Plan'. The Plan had six aims:

(i) 'The re-building or restoration of edifices which have been destroyed or highly damaged, with the reconstruction of the urban and social structure, **except in areas which are geologically unsuitable**.

(ii) The reconstruction of special buildings for use by the public, mainly for touristic and cultural purposes, according to the historic character of Maratea.

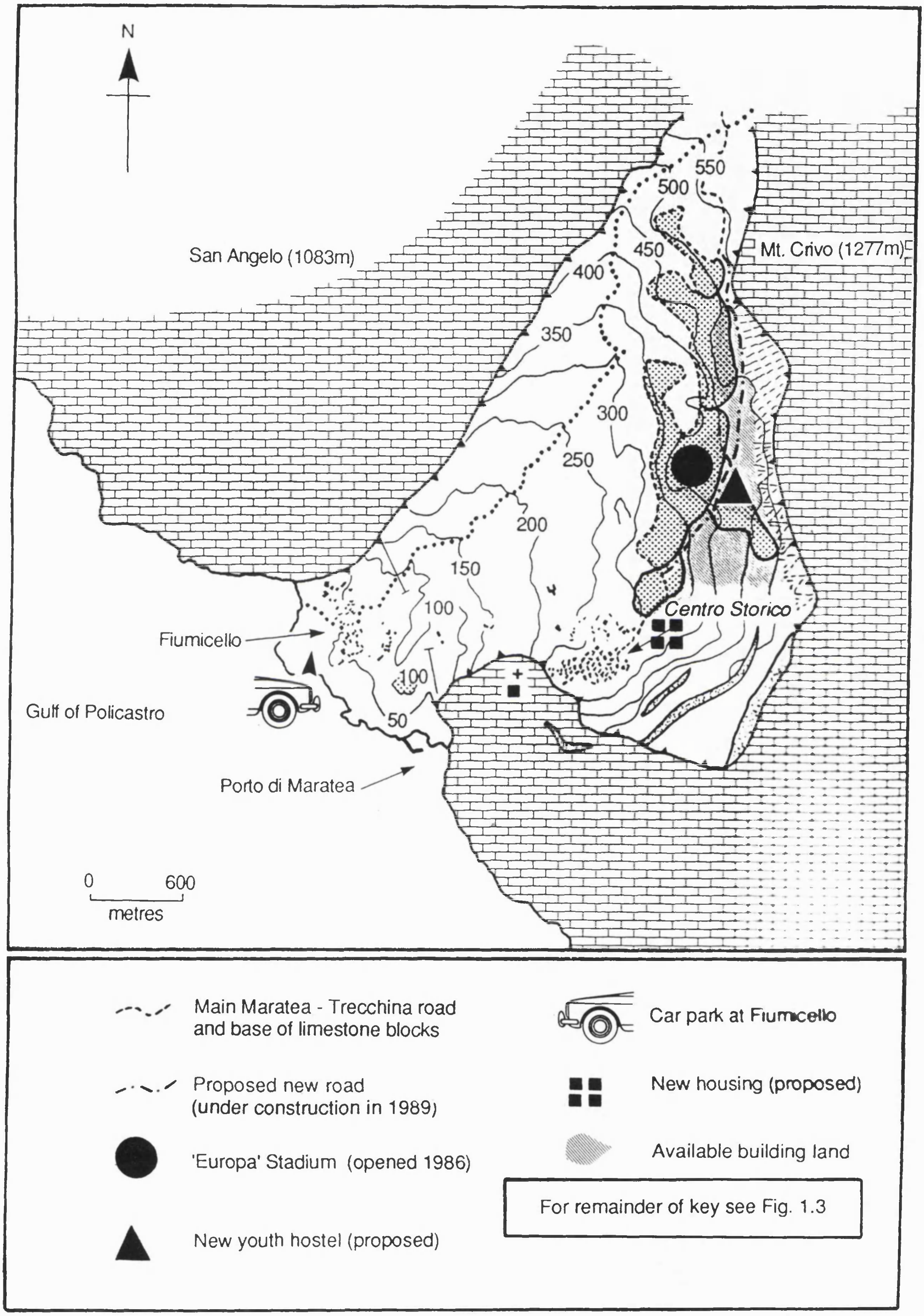


Figure 1.4: Works proposed in the Maratea Structure Plan 1978 Source: De Fiore and Brando (1978)

(iii) The creation of public gardens within the town, providing the necessary breaks in the urban structure.

(iv) The provision of roads for both pedestrian and vehicle use, taking into account the location of; arts and crafts work, tourist shops, culturally important buildings and hotels in the centre. The provision of car parks which are adequate for the demands of tourism but which are sympathetic to the conservation of the *centro storico*.

(v) The creation of a sports centre.

(vi) Construction of new buildings for both residential and tourist use.'

In this way the *Comune di Maratea*, sought to achieve a balance between what they considered to be the three key issues, namely; the preservation of the cultural identity of Maratea, its art, monuments and historic buildings; the promotion of local arts and crafts; the development of tourism. The Plan stresses 'the necessity to uphold a policy of investment aimed at the growth of commercial activities with the emphasis on the tourist industry'.

Estimates of the size and cost of the Plan are shown in Table 1.1a & b. The Plan did not specify a time scale for these works, nor did it give any details of their site. At the time of writing (July 1988) the works carried out have been:

(i) Construction of a new car park on the sea front at Fiumicello.

(ii) Construction of the *Pianeta Maratea*.

(iii) Construction of a new soccer and athletics stadium, the 'Europa Stadium', opened in 1986.

(iv) Work is in progress on a new road link. The road runs along the line of an old track on top of the limestone blocks at the base of the talus. For the moment the road will join the old Maratea - Trecchina road about 1km from

ESTIMATES FOR THE MARATEA STRUCTURE PLAN

● (a) Area Involved

Type of Construction	Existing Area m^3	Estimated Area m^3
● Residential	526,000	
● Non - Residential	63,300	30,200
● Hotel Space	4,230	11,700
● Urbanisation Works		
Roads	9,600	2,100
Car Parks	2,600	2,500
Public Green	0	25,000
Primary School	250	0
Secondary School	1,950	0
Churches	1,850	0
Covered Market	0	400
Open-Air Market	350	1,250
Social Centre	0	3,100
Youth Hostel	0	1,200
Sports Ground	0	10,000

Table 1.1(a): Size estimates for the 1978 Structure Plan for Maratea
From De Fiore and Brando (1978).

ESTIMATES FOR THE MARATEA STRUCTURE PLAN

(b) Expenditure

● Primary Works	Size	Total Cost (£m)
Roads	21 km	1.05
Car Parks	2,500 m^2	0.25
Sewers	Sufficient	
Water Works	Sufficient	
Illumination	Sufficient	
Telephones	Sufficient	
● Secondary Works		
Schools/Cultural	4,300 m^2	1.50
Sports Facilities	10,000 m^2	0.25
Markets	400 m^2	0.10
Public Green	1,250 m^2	0.10
Compensation		1.35
Planning Expenses		0.05
Total		4.68

Table 1.1(b): Expenditure estimates for the 1978 Structure Plan for Maratea
From De Fiore and Brando (1978), based on 1978 estimates and assuming an average exchange rate of L2000/£.

the *centro storico*. Ultimately, it is planned to drive the road through the sackung to the *Pianeta Maratea*.

A sketch of the location of these and other proposed works is shown in Fig. 1.4.

A social and cultural centre and a new youth hostel are planned within two years. One again, building is planned at the base of the area of talus deposition adjacent to the new road described in (iv) above.

The principal weakness of the Plan, is the total absence of any provision for the funding of geological, geomorphological or geotechnical investigations. This omission is surprising given Maratea's position within the framework of the Southern Apennines (see Chapter Two, section 2.3.3), and the problems of landsliding in southern Italy discussed earlier in this chapter. Two geotechnical reports were commissioned after the publication of the Plan (De Stefano, 1978; Regione Basilicata, 1978) and these will be summarised in the following sections. That they were commissioned after the publication of the Plan is significant in that it illustrates how ground investigations were viewed as merely an appendix designed to lend credibility to the document. In part, this results from the fact that the Structure Plan does not provide detailed plans of future works, either their positioning or physical construction, except to note that they must be in areas which are not geologically unsuitable. Where these areas are, or how they are to be defined, is not stated. As such the Structure Plan is more a statement of future intent than a clear policy statement. Part of the problem stems from the fact that the authors of the Plan are architects. It contains some very detailed information on such matters as the type and positioning of street lights and the colour of rendering to be used on restored buildings, but ignores the wider issues including hazard evaluation. On the positive side, however, publication of the Plan stimulated other earth scientists to look at the area. As noted earlier these authors were principally concerned with the sackung as the most striking feature in the area. The danger is that the recommendations of the Plan are now being acted upon; major schemes are in the pipeline and some, such as the relief road described above, are underway. These schemes are being progressed with an inadequate understanding of the processes at work or their rate of operation.

CHAPTER TWO

GEOLOGICAL STRUCTURE OF SOUTHERN ITALY

2.1 Introduction

Before proceeding to the specific problems of Maratea it is necessary to examine the wider setting of the study area. The reasons for this are self-evident; landslide type, magnitude and frequency largely reflect geological conditions, including seismicity. As noted in Chapter One, landsliding in Basilicata and in the Southern Apennines in general, is a widespread and serious problem often exacerbated by seismic activity, (see for example Alexander, 1981, 1983; Carrara *et al*, 1986). Alexander (1987) reports, for example, that in 1968 no fewer than 104 of the 132 *comuni* in Basilicata were threatened by landsliding; twenty two years on, this figure is probably very much higher. In addition, many of the larger landslides in southern Italy have often been interpreted as ancient features (palaeoslides) initiated during the tectonic evolution of the Southern Apennines (see Nossin, 1973; Carraro *et al*, 1979; Guerricchio and Melidoro, 1979; Crescenti *et al*, 1984; Carton *et al*, 1985) and repeatedly reactivated by recent earth movements (neotectonics). A major fault line in Maratea, for example, was regarded as a Pleistocene relic along which no activity had taken place since its formation (Lazzari *pers. comm.*). It is clear, therefore, that an essential prerequisite of the understanding of the ground conditions of both the Maratea valley and southern Italy, and the hazards imposed by them, is a grasp of the processes involved in the formation of the Southern Apennines and its subsequent modification by neotectonic activity.

Similarly, the extent and degree of earthquake damage is related to the surface and sub-surface conditions, for as Costa and Baker (1981) argue 'the extent of earthquake vibration damages to structures is partly controlled by the characteristics of the ground upon which the buildings are located'. In southern Italy this assertion has been demonstrated by Calcagnile *et al* (1977).

The authors attempted to construct a composite seismic hazard map of Basilicata based on an analysis of the 119 earthquakes recorded in southern Italy between 1550 and 1973. Their completed work, which will be discussed in detail in section 2.5 below, illustrated a seismic hazard map closely related to the geological make-up of the region. As Calcagnile *et al* assert 'in fact the seismicity of a region cannot be defined taking into account only the number and intensity of shocks, but also at least the areal distribution of the seismic energy radiated by the source must be considered'. Quite clearly the affects of seismic energy will be heavily dependent on the geological structure through which they are radiated.

This chapter is inserted, therefore, to provide the reader with an understanding of the geology of the Southern Apennines, its subsequent modification by neotectonic movements and seismic activity, and the varying terrains encountered across the area. The chapter is thus purely contextual in nature, aimed at giving the reader a general introduction to the area. A detailed account of the geological structure of Italy is in Appendix A.

2.2 The Geological Framework of Italy

The geological fabric of Italy is both young and extremely complex. Good summaries of the major structural characteristics of Italy can be found in Desio (1973, in Italian) and Squyres (1975, in English). Italy is geologically part of the Alpine system in that its deformational history is essentially Cenozoic, although in the Southern Apennines, Mesozoic (especially Cretaceous) tectonic features can be identified. In very general terms the Italian peninsula can be sub-divided into three major structural domains; the Alps, the northern basins and the Apennine chain.

The northern basins comprise the Po Valley (or Padan Plain) and the Venetian Plain, both of which are intermontane basins which were filled with up to 10,000 metres of Neogene and Quaternary sediments (roughly 38my - 1my). The basins form a foretrough to the Alpine system which is part of a late Tertiary mountain belt extending from the Maghrebids of Tunisia (part of the Tunisian Atlas) through the Apennines, Alps, Dinarids and Hellenides to the Turkish Alps and Zagros Mountains of Iran.

The Apennine chain is an extension of the Alpine orogen, and can be sub-divided into the Northern and Southern Apennines along the Anzio-Ancona Line (Fig. 2.1) which has been successively a flexure, normal fault and wrench fault (Caire, 1975). The Northern Apennines are an arcuate mountain belt (the Umbrian arc). Jurassic schists, Cretaceous and Oligocene/Miocene flysch outcrop. Flysch is a term applied to sediments produced from developing fold structures, later deformed by the further development of the same fold structure (see section 3.2.2 for a full definition). In Italy flysch sediments are generally marine clays and sands. Middle Miocene flysch fans are found in the more external areas of the Northern Apennines (Marches and Umbria). During the Alpine orogeny these units were displaced and re-sedimented into the Alpine thrust belt.

Only two sets of basement deposits are encountered - crystalline and metamorphic basement rocks outcroping in the Alps and in the Calabria-Peloritani Arc and the limestone basement of the Apulia and Gargano peninsulas.

2.3 The Southern Apennines

2.3.1 Introduction

The Southern Apennines are part of a late Tertiary mountain belt, delimited in the north by the Anzio-Ancona Line (see section 2.2) and in the south by the Sangineto Line - a north-east - south-west thrust fault (see Fig. 2.1). This mountain belt has been interpreted as the contact zone between either a northern extension of the African plate, known as Adria, or an Apulian (Adriatic) microplate and the European plate, (see Fig. 2.2 and Appendix A, section A.2.3).

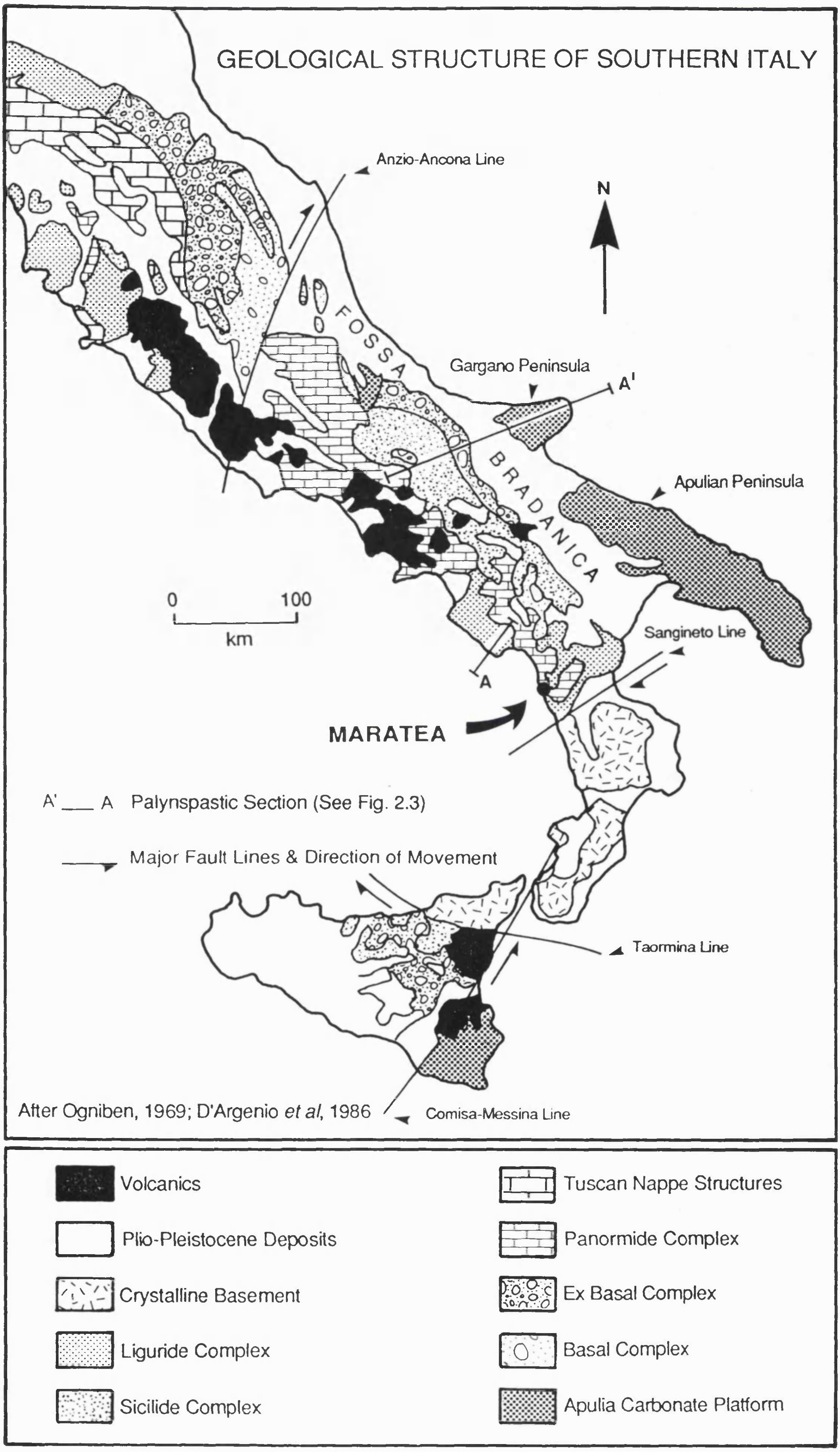


Figure 2.1: Geological structure of southern Italy.

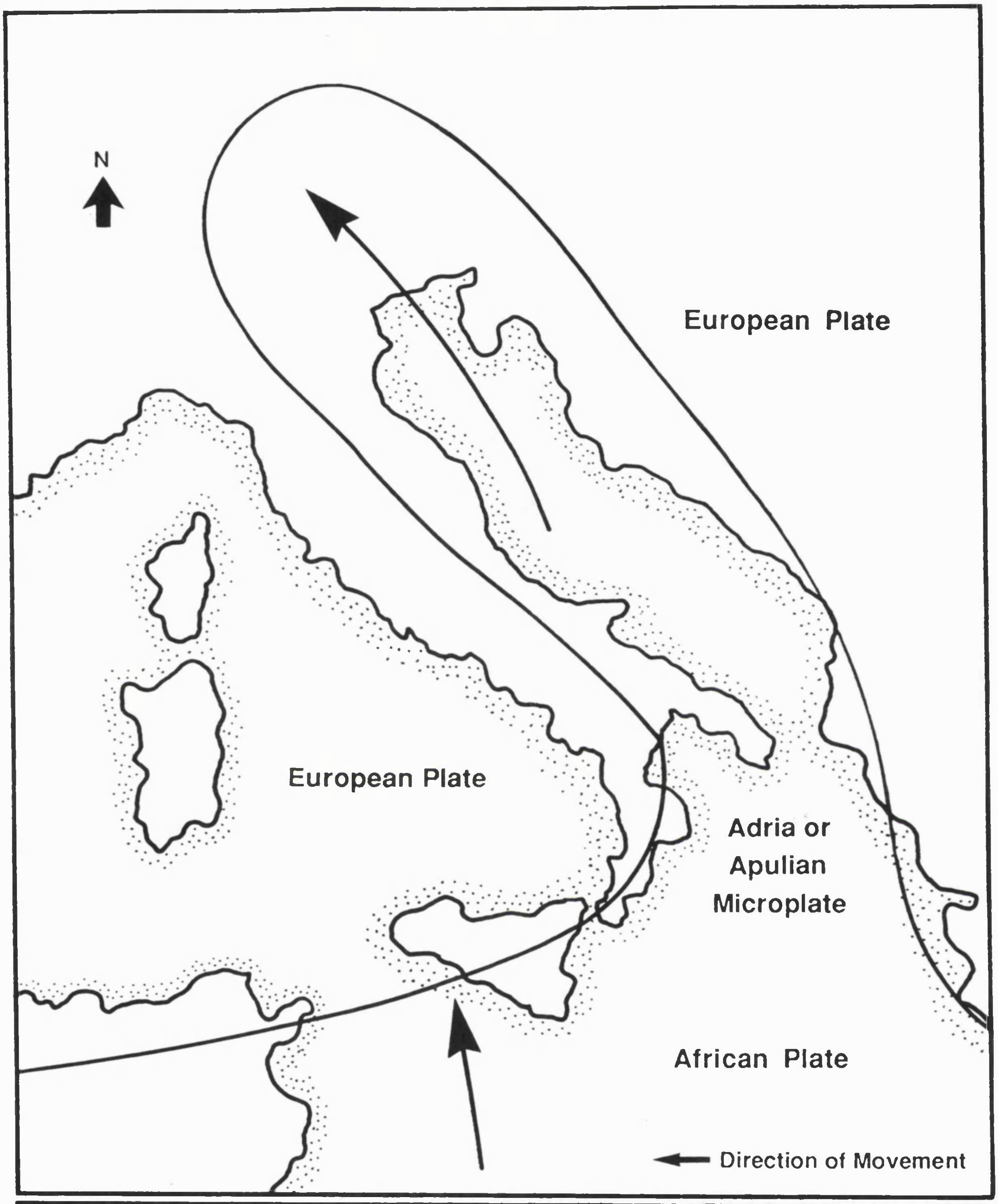


Figure 2.2: Possible plate boundaries in Italy and the Adriatic with the direction of movement. The diagram is from McKenzie (1972, p.135) who argues that ' the seismicity is too weak to define the plate boundaries, and the fault plane solutions are too scattered to show the motion clearly. Hence this arrangement of plate boundaries is compatible with the [seismic] data, but may well be incorrect'. In the diagram the Adriatic is shown as a northern extension of the African Plate, although it may well form a separate microplate (see Appendix A), once again the seismicity is too weak to define it with certainty.

The sedimentary rock bodies forming the Southern Apennines, range in age from mid-Triassic (about 200my) to late Pliocene (about 2my - 3my). These rocks were deformed and incorporated into the mountain belt during the late Tertiary (Neogene) when a continent-continent collision closed the southern margin of the Tethys ocean (Fischer, 1975a). Apart from the crystalline basement rocks of the Calabria-Peloritani arc (Fig. 2.1) the Southern Apennine thrust belt is formed entirely from sediments deposited from the middle Triassic to early Cretaceous.

The present-day landscapes of southern Italy, derive from the deformation of sediments laid down in three sedimentary basins and two intervening carbonate (limestone) platforms, formed by rifting, first under continental conditions and then in an oceanic environment over the period middle Triassic to early Cretaceous. Fig. 2.3 illustrates the stages in the formation of the pre-orogenic basin and platform topography of the Southern Apennines. This figure is an important illustration of the evolution and deformation of the Southern Apennines and will be referred to throughout this chapter. From west to east, the sedimentary basins are known as the Lagonegro, Molise and Irpinian Basins and the platforms termed the Latium-Campania-Lucania and Abruzzi-Campania Platforms, with a further platform, the Apulia Carbonate Platform, surviving in the extreme east where it forms the tablelands of the eastern seaboard and acts as a foreland to the Southern Apennines mountain chain. Orogenic deformation from the late Oligocene to the early Pliocene, represented by a series of nappe structures, (Ogniben and Vezzani, 1975; see Plate 2.1), incorporated these elements (domains) into the Apennine thrust pile (see Fig. 2.3). Before the onset of the Apennine orogeny the stratigraphical relationships of these domains was essentially similar, for example, the sedimentary sequence of the Lagonegro and Molise basins is early-middle Jurassic - early Cretaceous. However, their position in the nappe pile is dependent upon the time of their deformation and incorporation into the thrust belt, so that sequences of the same age may be superimposed one above the other and even separated by older deposits.

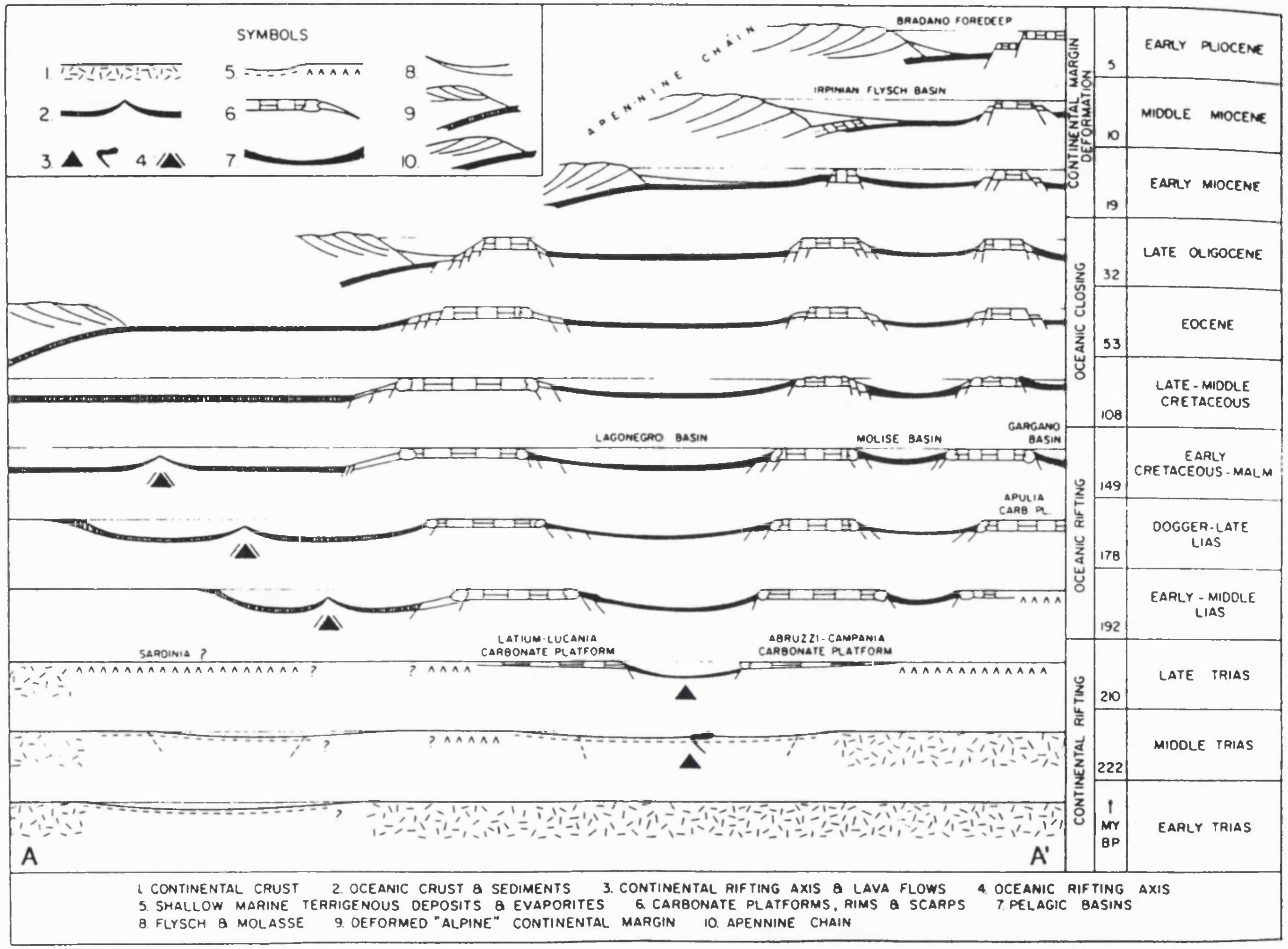


Fig. 2.3: Palaeogeographic reconstruction of the imbricate thrust belt showing the stages in the evolution and deformation of the Southern Apennines. After D'Argenio and Alvarez (1980).
For location of composite profile see Fig 2.1.

Plate 2.1: Nappe structure in well consolidated Plio-Pleistocene sandstones near Aliano

Deformation proceeded from west to east with the westernmost elements thrust over and the eastern elements thrust under the growing nappe pile. As a result, the further west a domain was originally located, the higher its position in the imbricate thrust pile and the greater its degree of deformation. The deformation of the thrust belt resulted in the formation of a number of foredeep basins along the eastern margin of the evolving mountain chain of which the Bradano Foredeep (or Fossa Bradanico) has the largest areal extent (see Figs. 2.1 and 2.3). This basin was subsequently filled with sediments of Plio-Pleistocene age.

From the middle Pliocene onwards, the compressive tectonics that led to the formation of the Southern Apennine thrust belt, gave way to vertical tectonic movements. Compression, during the Apennine orogeny, delimited a number of large fault blocks and it is along these boundaries that recent (neotectonic) movements in the Southern Apennines have been concentrated (see section 2.4). In particular, large fault-bounded blocks have collapsed along the western margin of the chain, a situation which will be clearly illustrated in the case of Maratea. The distribution of contemporary seismic activity in southern Italy is largely the response to these vertical neotectonic movements located to the west of the Apennine belt (see section 2.5). Seismic activity in the area of the Calabrian Arc is a separate and more problematic issue (see section 2.5.).

2.3.2 Landscapes of the Southern Apennines

The deformational history of the Southern Apennines thrust belt has produced a variety of terrains in southern Italy. Eight major relief regions can be identified, all of which are represented in Basilicata. These regions are, very broadly, aligned north-west - south-east along the peninsula, and reflect the trend of the compressive tectonics that have led to the deformation and uplift of the Southern Apennines. It is helpful to consider the terrains of the Southern Apennines in terms of these regions, which are illustrated on the generalised relief map of Basilicata (derived from ridge top levels) shown in Figure 2.4. From east to west the regions can be defined as:

- Apulia Carbonate Platform
- River valleys of Bradano, Basento, Cavone, Agri and Sinni
- Low-lying coastal areas of the Metapontino
- Deeply dissected Plio-Pleistocene deposits of eastern Basilicata
- 'Lucanian Dolomites' ridge of south-central Basilicata
- Low rounded hills of Potenza and central Basilicata
- Limestone mountains of Maratea, Pollino and western Basilicata
- Monte Vulture Volcanics

Apulia Carbonate Platform

The Apulia Carbonate Platform is an extensive area of limestone shelf deposits formed during early-middle Lias - early Cretaceous times during a period of continental rifting (see Fig. 2.3). The Platform was not deformed during the Apennine orogeny and acts as a foreland to the main thrust belt. It outcrops for a length of about 300km along the whole of the Apulian peninsula and has an average width of approximately 50km. It forms an area of low-lying relief 300m - 500m above sea level although Monte Caccia in Apulia rises to 680m and Monte Calvo in the Gargano (see Fig 2.1) attains a height of 1056m. Along the eastern coast of southern Italy and in the 'heel' of Italy - the Salentina peninsula - the platform is submerged. The higher, central, areas of the Platform form a natural barrier between the coastal lowlands around Bari, Brindisi and Taranto and the valley of the River Bradano to the west, hence the colloquial name for the Apulia Platform - *le Murge* or the 'wall'.

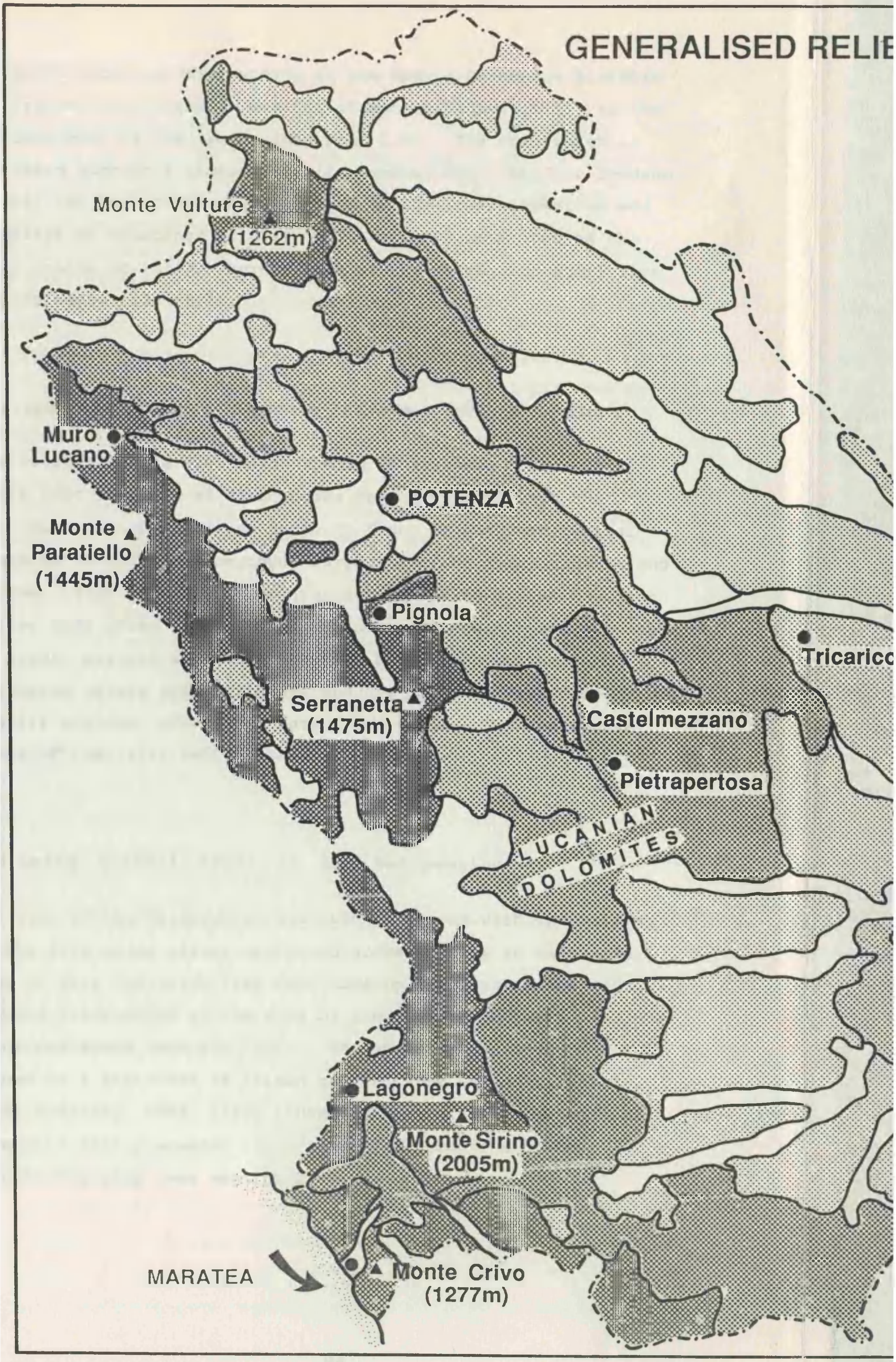
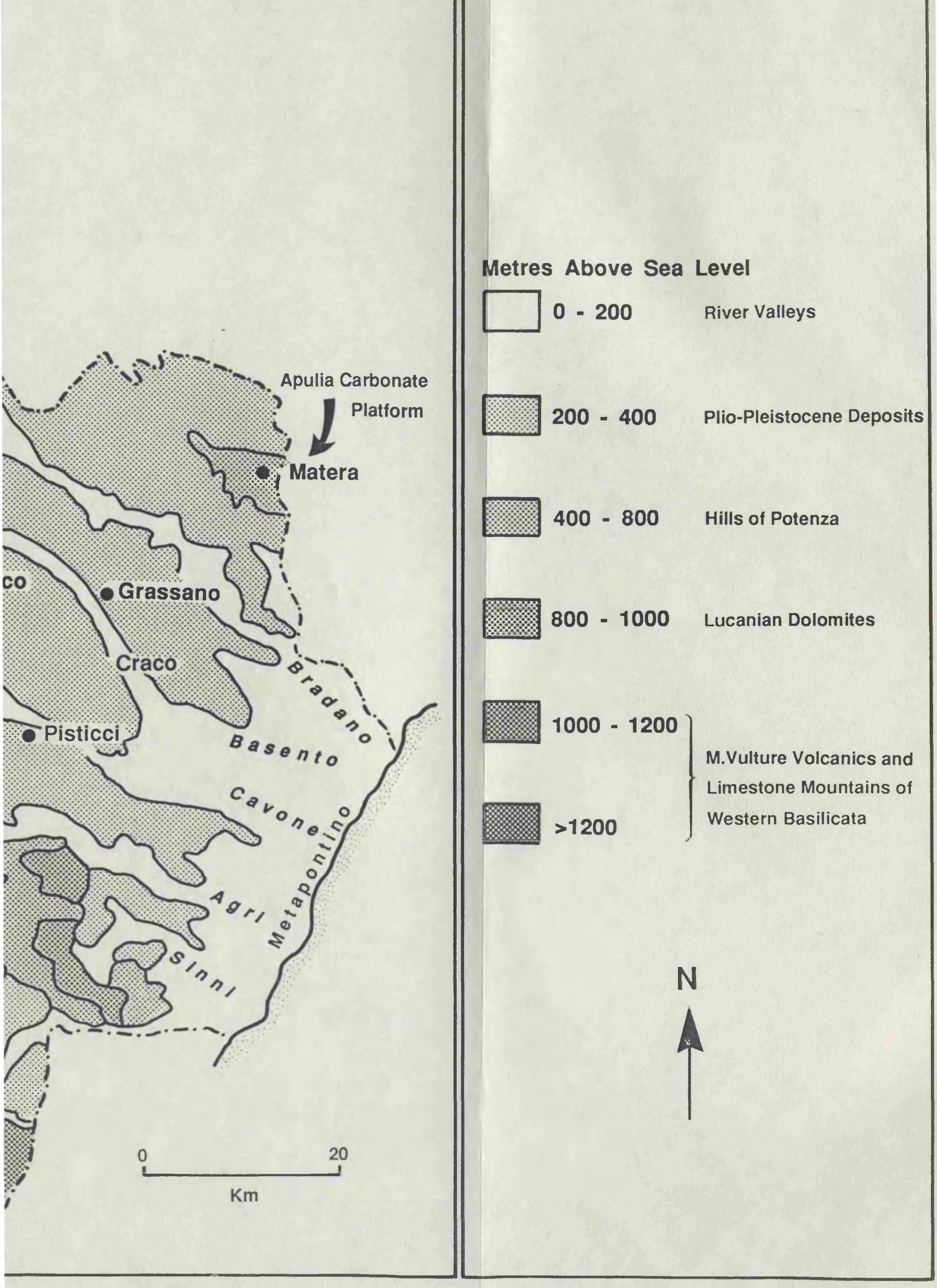


Fig. 2.4: Generalised relief map of Basilicata

IEF MAP OF BASILICATA



In Basilicata the only outcrop of the Apulia Carbonate Platform is around the provincial capital of Matera (401m a.s.l.) in the extreme east of the region (see Fig. 2.4). The town which is situated high on a limestone cliff looking down into the Bradano gorge, has been partly hollowed out of the local limestone and displays an abundance of cave dwellings marking it out as the only centre in Italy, where some of the population still live a troglodyte life-style.

Valleys of Bradano, Basento, Cavone, Agri and Sinni

The valleys of the five major rivers in southern Italy which drain into the Gulf of Taranto are deeply incised into the extensive Plio-Pleistocene deposits found in east and central southern Basilicata; the three largest are the Agri, Basento and Cavone. High levels of discharge in the spring months have cut valley beds often 1km - 2km wide and brought down large volumes of sands, gravels and clays. During the summer months, discharge levels are negligible and the river valleys display a heavily braided, gravel bed form. The valleys form extensive areas of low-lying relief (see Fig. 2.4).

Low-lying Coastal Areas of the Metapontino

The area of the Metapontino has much in common with the valleys of the five major rivers mentioned above. It is an extensive area of very low-lying flat land made-up of clays, sands and gravels transported to the area by the drainage network described above (see Fig. 2.4). The whole of the Metapontino is formed of a staircase of raised beaches (see Cotecchia *et al*, 1969; Brückner, 1982, 1983) caused by the vertical (neotectonic) movements that proceeded the compressive tectonics of the Apennine orogeny (see section 2.4).

Plio-Pleistocene Deposits of Eastern Basilicata

During the final phases of compressive tectonics that led to the uplift of the Apennine chain a large foredeep basin formed along the eastern margin. Figure 2.3 shows this process in detail as the Apennine chain was thrust over an earlier (early-middle Miocene) flysch basin known as the Irpinian basin during the early Pliocene. From this time onwards the foredeep known as the Bradano Foredeep or Fossa Bradanico has filled with thousands of metres of loosely consolidated sands, clays and conglomerates of Plio-Pleistocene age. These deposits have been deeply dissected, as noted above, by the five main rivers of southern Italy which drain into the Ionian Sea (Gulf of Taranto).

The extensive Plio-Pleistocene deposits of the *Fossa Bradanico* now with a general elevation of 200m - 400m a.s.l., form the interfluves between the major rivers (see Fig. 2.4). The loosely consolidated deposits are highly susceptible to mass movement and in this area piping and associated gully retreat, mud flows and massive rotational landslides are common.

Approximately 1% (2,500km^{2}) of the Plio-Pleistocene deposits are covered by *calanchi* (badlands), particularly in the most eastern areas around Pisticci, Tricarico, Grassano, Aliano (Plate 2.2) and Stigliano (Alexander, 1982a & b). These settlements are characteristic 'hilltop' towns sited, as their name suggests, high above the river valleys, and are suffering serious mass movement problems resulting from the rill and gully landscapes of the *calanchi;* Alexander (1982a), for example, notes that some slope angles in the *calanchi* are of the order 60° - 80° and some stream headcuts are advancing at more than 2m/year.

Lucanian Dolomites

The Lucanian Dolomites are an area of high relief along a 6km ridge which is an eroded monocline, and has an area of about 6km^2 (Alexander and Rendell, *pers. comm.*). The ridge is to the west of the Plio-Pleistocene deposits and is situated in central

Plate 2.2: Plio-Pleistocene deposits of eastern Basilicata. The town is Alianello seen from Aliano - the two are
are being separated by the landslide in the centre of the photograph.

Basilicata; the two main settlements in the area are Pietrapertosa and Castelmezzano (see Fig. 2.4 and Plate 2.3).

The Lucanian Dolomites are composed of sediments laid down during the middle Miocene; mainly jointed, massively bedded sandstone, thinly bedded fractured sandstone and slates, shales, marls and mudstones (see Plates 2.4 and 2.5). The ridge follows the north-west - south-east Apennine trend and comprises steeply dipping strata which have been eroded into high relief. Landsliding is a common and widespread occurrence in the area; debris slides, rockfalls, rock topples and rock slides have all been noted in the area (Alexander and Rendell, *pers. comm.*).

Potenza and North-Central Basilicata

This area is characterised by low-rounded hills formed in marine sediments of late Cretaceous to early Miocene age, mostly marly clays and calcarenites. The regional capital of Potenza (646m a.s.l.) is in the west central section of the belt which extends north to Altilla in a broad (approximately 10km) band and south to Corletto Perticara.

Limestone Mountains of Maratea, Pollino and Western Basilicata

These limestone mountains are formed of Triassic dolomites, Liassic limestones, Jurassic limestones and Cretaceous calcarenites and comprise all the areas of high relief along the western border of Basilicata (Plate 2.6). Among the highest mountains are Monte Paratiello (1445m a.s.l.), Serranetta (1475m), Monte Sirino (2005m) and Monte Crivo above Maratea, (1277m; see Plate 2.7).

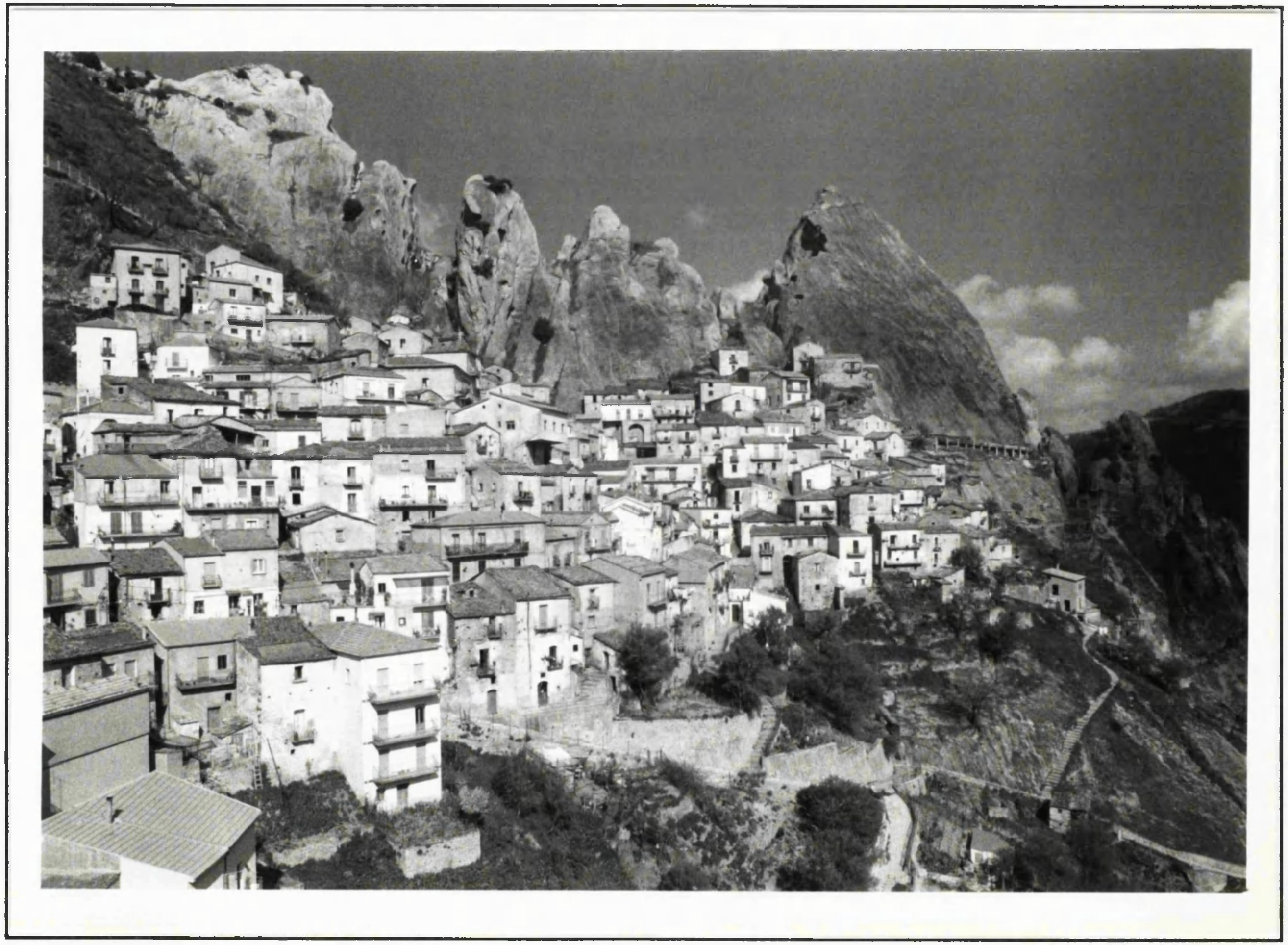


Plate 2.3: Castelmezzano in the Lucanian Dolomites.

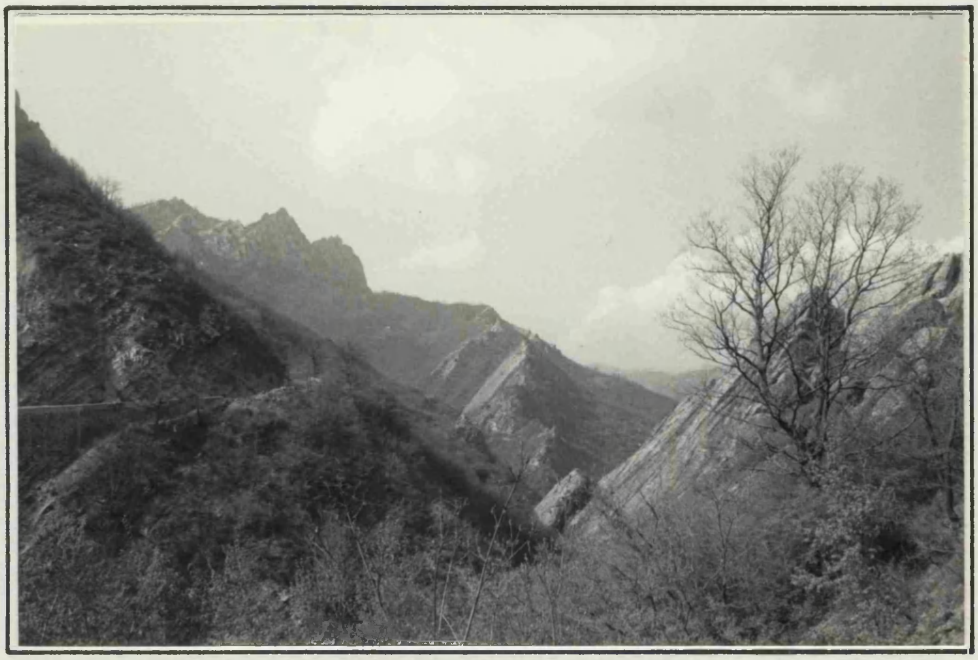


Plate 2.4: Landscapes of the Lucanian Dolomites near Pietrapertosa.

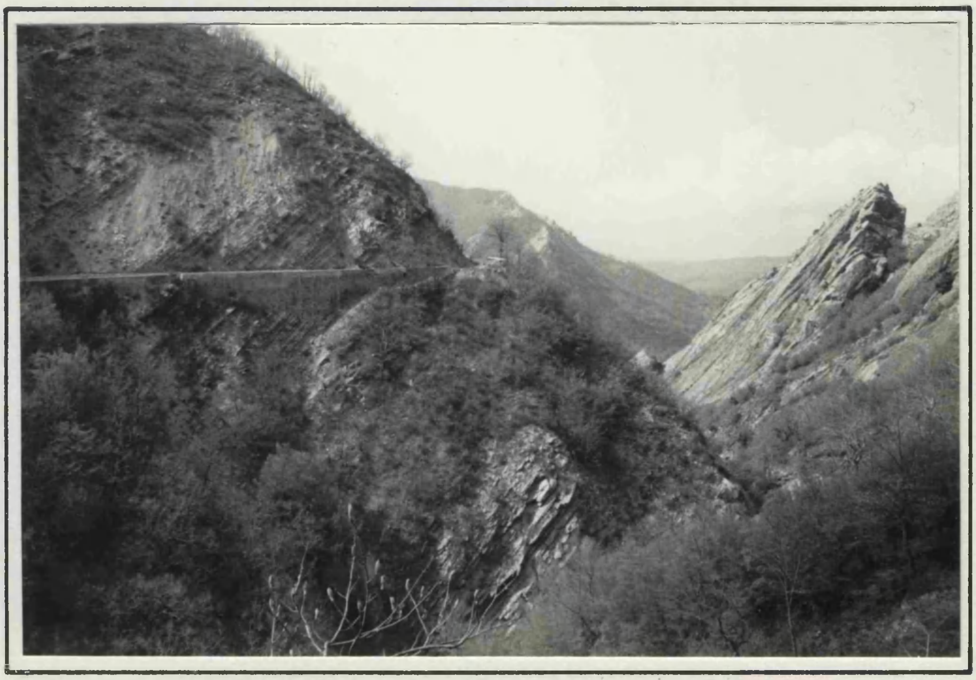


Plate 2.5: Steeply dipping limestone strata of the Lucanian Dolomites.

Plate 2.6: Thrust fault near Marsico Vetere in western Basilicata.

Plate 2.7: The Maratea valley on the western coast of Basilicata. The summit of Monte Crivo is in the centre of the photograph. One of the normal faults can be seen at the base of the mountain.

Volcanics

The volcanics developed extensively in southern Italy from the middle Pleistocene onwards. In Basilicata the main outcrop is at Monte Vulture (1262m) in the north of the region (see Figs. 2.1 and 2.4).

2.3.3 Position of Maratea in the Imbricate Thrust Belt

Maratea lies on the extreme western edge of the Southern Apennines imbricate thrust belt. The rocks forming this area are shallow water Triassic dolomites and Jurassic limestones derived from the deformation of the Latium-Campania-Lucania Carbonate Platform and are collectively known as the 'Panormide Complex'. They outcrop along the whole of the western boundary of Basilicata (see Fig. 2.1). The domains of the Latium-Campania-Lucania Carbonate Platform were among the earliest to be incorporated into the Southern Apennines thrust pile (see Fig. 2.3). Hence they are some of the highest and most severely deformed elements within the imbricate belt.

In the Maratea area, resting unconformably over the Triassic dolomites and Jurassic Limestones, are black shales and clays deriving from the deformation of the most external sectors of the thrust belt, probably the domains of the former Lagonegro Basin. In the Maratea area, both the carbonate formations and clays were affected by neotectonic activity when the compressive tectonics that led to the formation of the Southern Apennines, gave way to vertical movements during the middle-late Pliocene. The Maratea valley area has been downfaulted along two converging normal faults (Plate 2.7) resulting in clays and shales on the valley floor, lying unconformably over carbonate formations which also form the surrounding mountains.

2.4 Neotectonic Evolution of the Southern Apennines

2.4.1 Introduction

About 5 million years ago, the compressive tectonics that led to the deformation of the Southern Apennines began to subside and be replaced by vertical movements. Vertical movements have dominated since 2 - 3 MY BP, although the area is still under some compression. During the phase of compressive tectonics, transverse faulting occurred which delimited a number of large fault blocks in Southern Italy. Seismic activity is largely the response to movements along these existing fault boundaries and hence to vertical deformation. As such the uplift zone has moved from west to east as compression continues to build the Apennine chain and the Tyrrhenian basin deepens. Vita-Finzi (1986) has broadly defined neotectonic as 'the study of late Cainozoic deformation' (p.14). In this thesis the word is used to describe 'recent' earth movements in the Southern Apennines, that is, movements that have occured since compressive mountain building tectonics began to subside about 5 MY years ago. Thus, while the term neotectonic is employed throughout this thesis, in order to be consistent with the Italian literature, epeirogenesis may be a more exact description of the widespread movements that can be observed throughout the southern Italian peninsula.

The most complete synthesis of the neotectonic evolution of southern Italy is contained in the Neotectonic Map of Southern Italy (Carta Neotettonica dell'Italia Meridionale). The synthesis of the neotectonic evolution of southern Italy, outlined below, is based on the present authors English translation of this work (Ciaranfi *et al*, 1983). This atlas and accompanying publication is the summary of a three year (1978 - 1980) project - Progetto Finalizzato Geodinamica - carried out by various authors under the auspices of the Italian National Research Council (Consiglio Nazionale delle Ricerche, or CNR). For the purposes of the research project, southern Italy was divided into a number of regions, based on 1:100,000 map sheets published by the Italian cartographic body the Istituto

Geografico Militare. Researchers were each allocated a region; for example one group worked along the Salerno, Sorrento, Amalfi area (1:100,000 map sheets 172, 185, 196 and 197). A full account of each group's research findings is contained in three project publications (number 155 for 1978, 251 for 1979 and 356 for 1980) and summarised in Ciaranfi *et al* (1983) to which the reader is requested to refer for a full bibliography.

The research methodology of the project involved the recognition in the stratigraphical record of deposits of marine and continental origin whose ages ranged from the late Pliocene to the Holocene. Of these deposits, Pleistocene marine sediments were the most useful as their well preserved facies and palaeontological record enabled accurate assessments to be made of their age and depth of deposition. By correlating the various phases of deposition and erosion observed in these deposits it is possible to describe the sequences of uplift and subsidence which characterise the neotectonic evolution of the area.

Ciaranfi *et al* (1983) describe a five phase evolutionary pattern related to both the geological sequence and the Italian biostratigraphical succession.

- **Interval 1**

The phase of compressive tectonics and continental margin deformation from the early Miocene (19 MY BP) to the early Pliocene (5 MY BP) is represented by the formation of the Irpinian Basin in the middle Miocene and its closing and subsequent formation of the Fossa Bradanico in the early Pliocene. The interval is represented by the presence of evaporites and the disappearance of the foraminifera *Globorotalia conomiozea* from the Italian biostratigraphical succession.

- **Interval II**

This interval covers the early Pliocene, that is 5.2 MY - 3.8/3.5 MY BP. It is marked by the disappearance of the foraminifera *Globorotalia margaritea* from the Italian biostratigraphical succession. The interval is also marked by the appearance of *Sphaeroidinellopsis spp.* and divided at about 4.5 MY by the first signs of *Globorotalia puncticulata.*

- **Interval III**

This interval extends from 3.8/3.5 MY BP - 0.7 MY BP which includes the middle and upper Pliocene and the lower and middle Pleistocene. The length of this phase and marked biostratigraphical phases within it have caused Ciaranfi *et al* to divide it thus:

- **Interval IIIa**

Characterised by the foraminifera *Globorotalia bonoriensis, Globorotalia crassaformis* and *Globorotalia inflata,* this sub interval extends from the end of the early Pliocene (3.8 - 3.5 MY) to the beginning of the upper Pliocene. The period corresponds with the continental faunal assemblage of the lower Villafranchian.

- **Interval IIIb**

This sub interval extends from 2.0MY BP (the early Pleistocene) to 0.7 MY BP and is characterised by *Globorotalia cariacoensis* and *Globorotalia truncatulinoides excelsa.* The beginning of the period coincides with the appearance of fauna and vertebrates of the upper Villafranchian.

- **Interval IV -V**

The separation between the two intervals is placed at 0.018 MY BP although there is considerable doubt as to whether there should be one or two intervals. They are difficult to separate in the biostratigraphical classification and for the purposes of the Neotectonic Map of Southern Italy they were regarded as one phase, extending from 0.7 MY BP to date, that is the middle Pleistocene through the Holocene.

2.4.2 Neotectonic Movements

- **Interval II (See Fig. 2.5a and Legend)**

During this phase the Southern Apennines thrust belt was still largely experiencing compression along a zone to the west of the main Apennine ridge. The line of compression followed a north-west trend from Trebisacce on the Ionian coast through to Muro Lucano and Benevento passing 10 km due west of Potenza.

West of this compression line there was a major zone of uplift with the exception of the Cilento (Vallo di Lucania) area which formed a smaller zone of lesser uplift, bounded to the east by the Cilento fault. The major uplift zone covered all the high limestone mountains of the Panormide Complex, namely the Pollino, Picentini, Maratea and Matesa mountains. Both the Bay of Naples and the Salerno Gulf (Sele Plain) were areas of strong subsidence.

Most of the major fault lines followed the trend of the Southern Apennines and the compression line, namely south-east - north-west, although an important transverse fault system ran from Diamante through Verbicaro and Mormanno. The Sangineto fault which forms the boundary between the Southern Apennines thrust belt and the Calabrian arc, runs from a point 5 km north of Cetraro south-west - north-east to Trebisacce and was probably formed during this period.

NEOTECTONIC MAP OF SOUTHERN ITALY

Legend

1. Linear Elements

Dip Slip Faults (Arrow Indicates Direction of Relative Movement; Dash Indicates Fault Direction)

Known Fault

Probable Fault

Underground Fault

Probable Underground Fault

Normal Fault

Reverse Fault

Not Known

Strike Slip Fault

Phase of Deformation

Extension

Compression

Anticline

Syncline

Convex Fold

Concave Fold

Flexure

Apennine Front

NEOTECTONIC MAP OF SOUTHERN ITALY

Legend

2. Areal Elements

— —	Subsidence
– –	Probable Subsidence
+ +	Uplift
+ +	Probable Uplift
V V	Minor Alternating Subsidence and Uplift
√ √	Major Alternating Subsidence and Uplift
– c	Probably Stable but with a Tendency to Subside
c c	Probably Stable
+ c	Probably Stable but with a Tendency to Uplift
	Areas of Differential Uplift (Arrow Indicates Direction)
	Volcanics
	Volcanic - Tectonic Horst

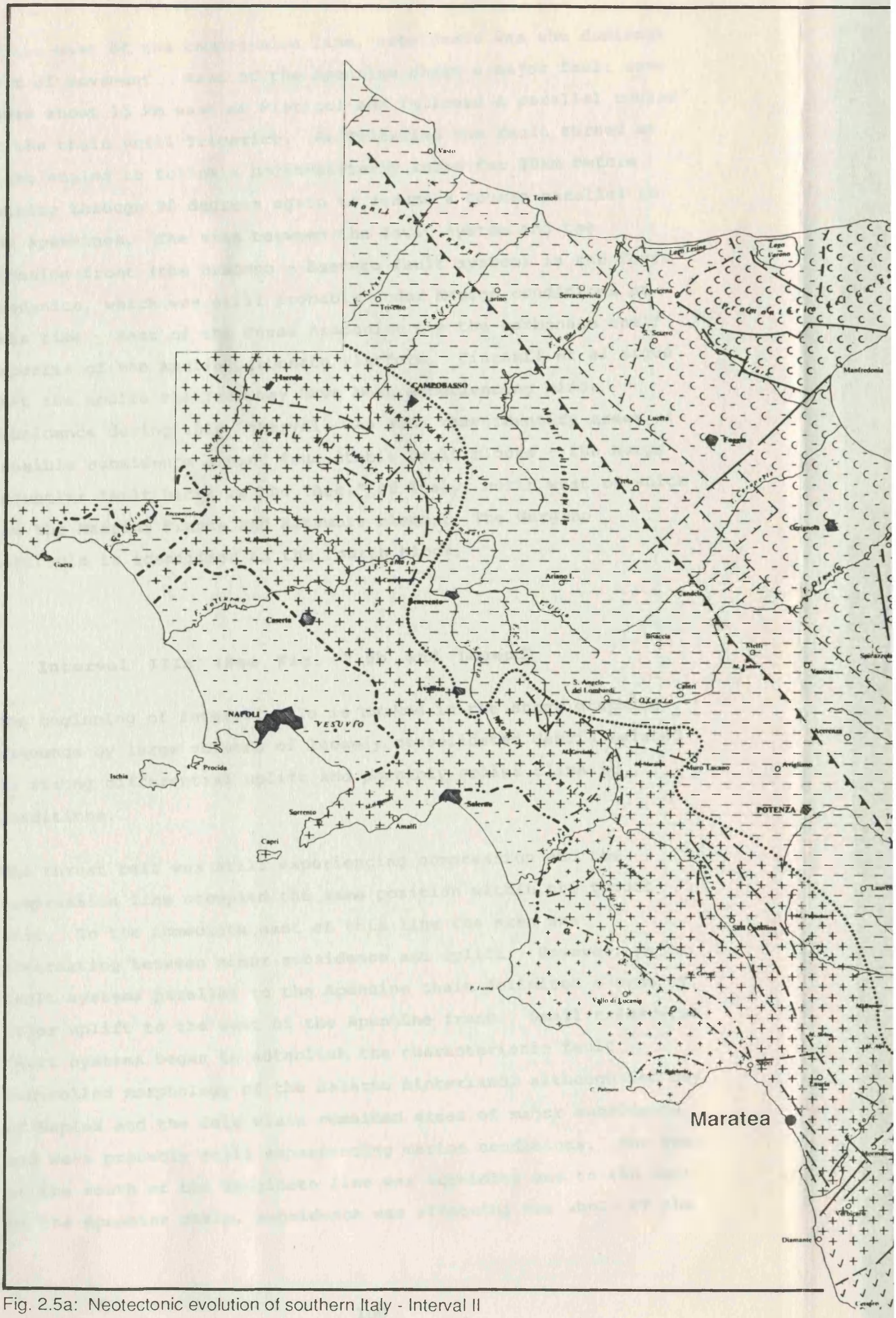
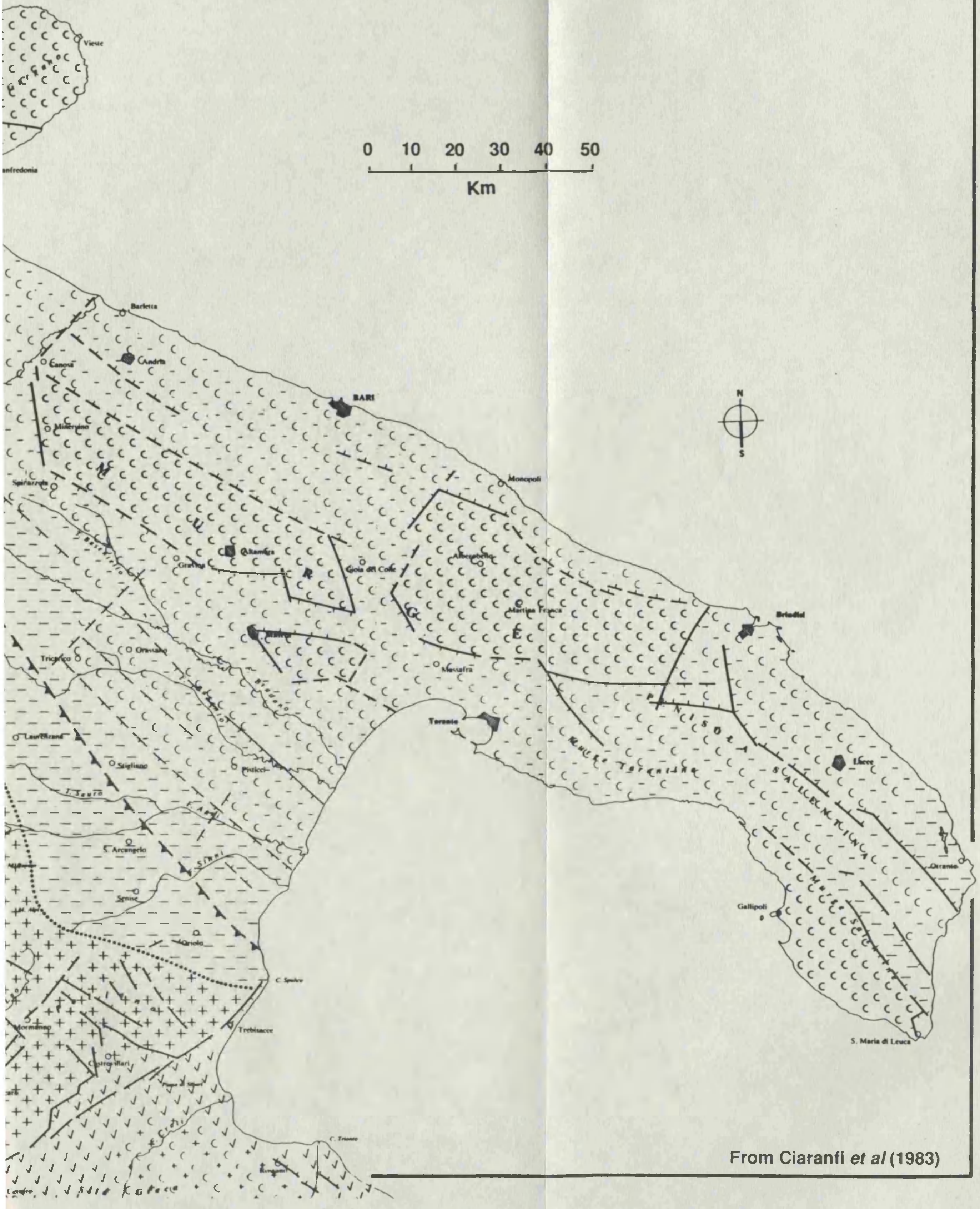


Fig. 2.5a: Neotectonic evolution of southern Italy - Interval II

NEOTECTONIC MAP OF SOUTHERN ITALY

Interval II

5.2MY - 3.8/3.5MY BP



From Ciaranfi *et al* (1983)

To the east of the compression line, subsidence was the dominant form of movement. East of the Apennine chain a major fault zone began about 15 km east of Pisticci and followed a parallel course to the chain until Tricarico. At Tricarico the fault turned at right angles to follow a north-easterly route for 20km before turning through 90 degrees again to resume a course parallel to the Apennines. The area between the fault system and the Apennine front (the Bradano - Basento fault system) is the Fossa Bradanico, which was still probably under marine conditions at this time. East of the Fossa Bradanico are the carbonate shelf deposits of the Apulia Carbonate Platform. Ciaranfi *et al* argue that the Apulia Platform may have been experiencing minor subsidence during this interval. As such they identify areas of possible subsidence around four stable fault blocks - the Murge Salentina fault block in the "heel" of Italy, north west of which are the Martina Franca and Altamura blocks. The Gargano peninsula is identified as the fourth block.

- **Interval IIIa (See Fig. 2.5b and Legend)**

The beginning of Interval IIIa is marked in the stratigraphical sequence by large volumes of loosely consolidated debris related to strong differential uplift and possibly cooler climatic conditions.

The thrust belt was still experiencing compression and the compression line occupied the same position within the thrust belt. To the immediate east of this line the area was alternating between minor subsidence and uplift. However, major fault systems parallel to the Apennine chain delimited a zone of major uplift to the west of the Apennine front. Small transverse fault systems began to establish the characteristic fault controlled morphology of the Salerno hinterland, although the Bay of Naples and the Sele Plain remained areas of major subsidence and were probably still experiencing marine conditions. The area to the south of the Sangineto line was subsiding and to the east of the Apennine chain, subsidence was affecting the whole of the

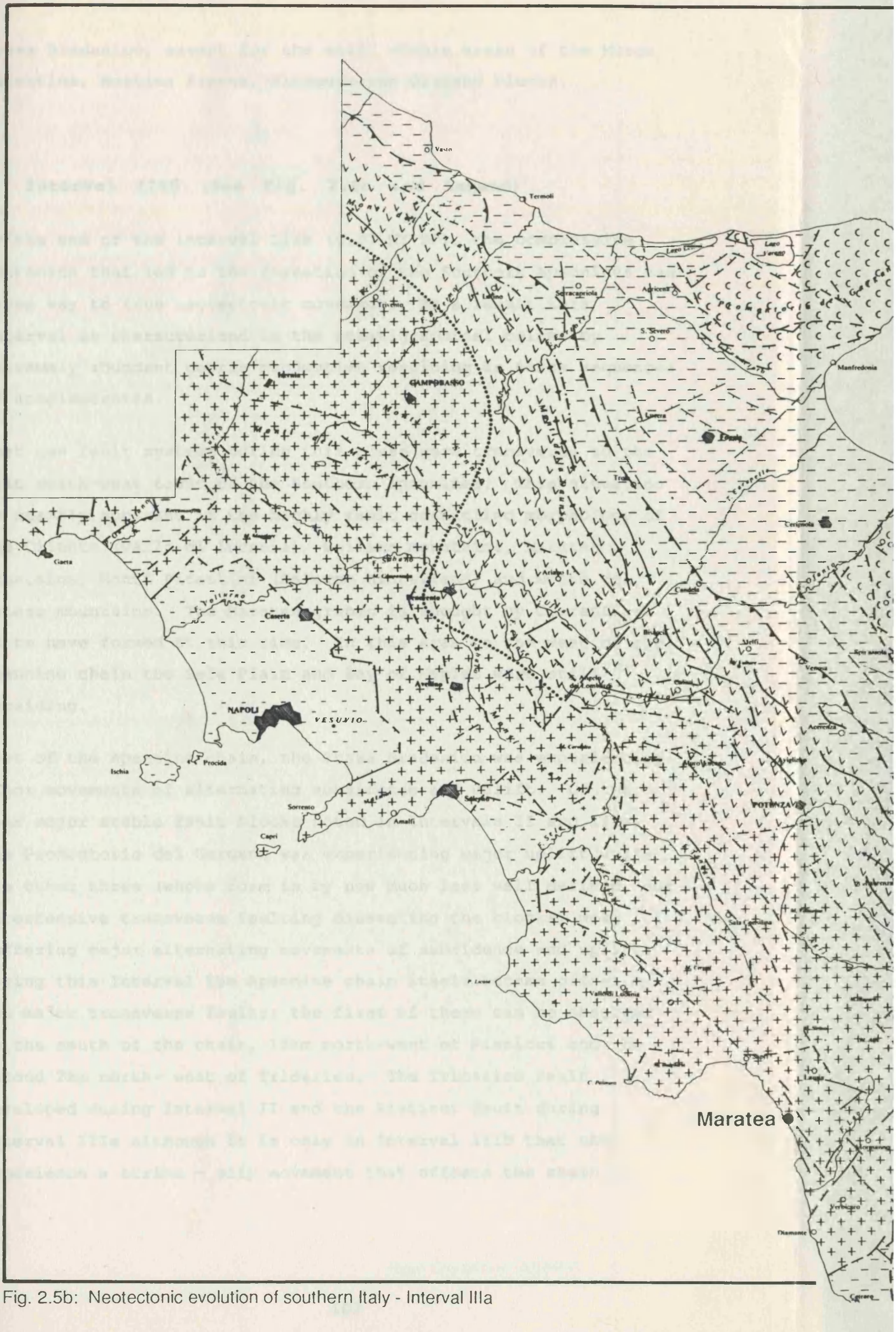


Fig. 2.5b: Neotectonic evolution of southern Italy - Interval IIIa

NEOTECTONIC MAP OF SOUTHERN ITALY

Interval IIIa

3.8/3.5MY - 2.0MY BP

From Ciaranfi *et al* (1983)

Fossa Bradanico, except for the still stable areas of the Murge Salentina, Martina Franca, Altamura and Gargano blocks.

- **Interval IIIb (See Fig. 2.5c and Legend)**

By the end of the Interval IIIb (0.07 MY BP), the compressive tectonics that led to the formation of the Southern Apennines had given way to true neotectonic movement. As a result this interval is characterised in the stratigraphical column by extremely abundant debris production resulting in thick sequences of conglomerates.

Most new fault systems during this phase were transverse to the main north-west trend of the Southern Apennines. This situation is readily apparent in the highly fault controlled morphology of the Cilento (Vallo di Lucania), Pollino mountains, Maratea mountains, Monti Picentini (Salerno hinterland) and Monte del Matese mountains. The Maratea graben is thought by Ciaranfi *et al* to have formed at this time. In this area to the west of the Apennine chain the Sele Plain and Bay of Naples were still subsiding.

East of the Apennine chain, the Fossa Bradanica was experiencing minor movements of alternating subsidence and uplift. Of the four major stable fault blocks noted in Intervals II and IIIa, the Promontorio del Gargano was experiencing major uplift while the other three (whose form is by now much less well defined, due to extensive transverse faulting dissecting the blocks) were suffering major alternating movements of subsidence and uplift. During this Interval the Apennine chain itself became offset by two major transverse faults; the first of these can be observed in the south of the chain, 15km north-west of Pisticci and the second 2km north- west of Tricarico. The Tricarico fault developed during Interval II and the Pisticci fault during Interval IIIa although it is only in Interval IIIb that they experience a strike - slip movement that offsets the chain.

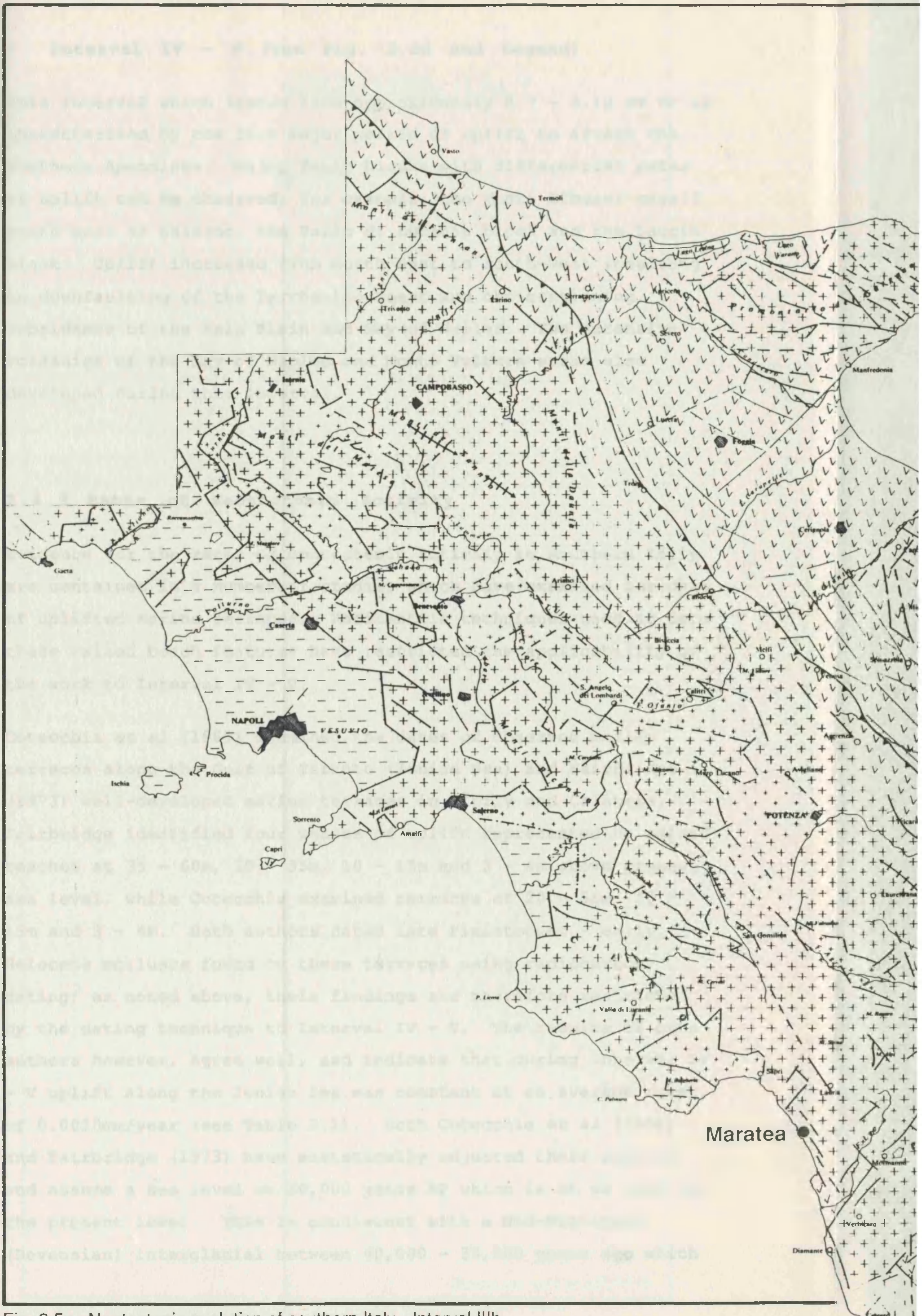
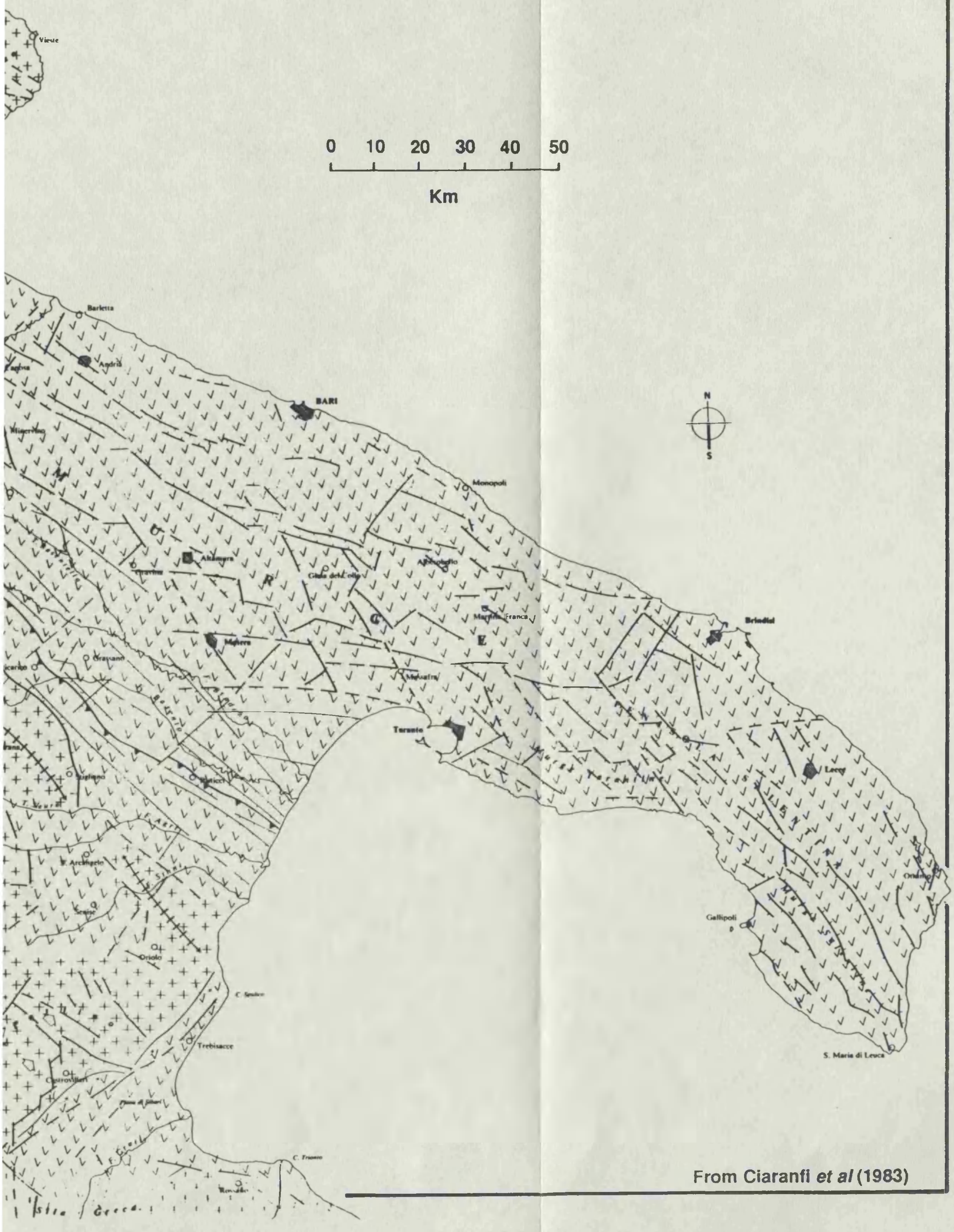


Fig. 2.5c: Neotectonic evolution of southern Italy - Interval IIIb

NEOTECTONIC MAP OF SOUTHERN ITALY

Interval IIIb

2.0MY - 0.7MY BP



From Ciaranfi *et al* (1983)

- **Interval IV - V (See Fig. 2.5d and Legend)**

This interval which lasted from approximately 0.7 - 0.12 MY BP is characterised by the last major period of uplift to affect the Southern Apennines. Major fault blocks with differential rates of uplift can be observed, for example, the Monti Alburni massif south-east of Salerno, the Vallo di Lucania block and the Lauria block. Uplift increased from north-east to south-west resulting in downfaulting of the Tyrrhenian coast and the continuing subsidence of the Sele Plain and Bay of Naples. The extensive volcanics of the Bay of Naples and Monte Vulture areas also developed during this Interval.

2.4.3 Rates of Neotectonic Activity

Evidence for the rates of neotectonic activity in southern Italy are contained in a number of studies which have examined the date of uplifted marine terraces. Radiometric techniques used to date these raised beach features have restricted the applicability of the work to Interval IV - V.

Cotecchia *et al* (1969) examined the dates of observed marine terraces along the Gulf of Taranto (Ionian Sea) and Fairbridge (1973) well-developed marine terraces in Sicily and Calabria. Fairbridge identified four phases of uplift represented by raised beaches at 35 - 60m, 20 - 35m, 10 - 15m and 3 - 4m above present sea level, while Cotecchia examined terraces of 20 - 35m, 10 - 15m and 3 - 4m. Both authors dated late Pleistocene - early Holocene molluscs found on these terraces using radiocarbon dating; as noted above, their findings are therefore restricted by the dating technique to Interval IV - V. The results of both authors however, agree well, and indicate that during Interval IV - V uplift along the Ionian Sea was constant at an average rate of 0.0020mm/year (see Table 2.1). Both Cotecchia *et al* (1969) and Fairbridge (1973) have eustatically adjusted their results and assume a sea level at 30,000 years BP which is at or near to the present level. This is consistent with a Mid-Wisconsin (Devensian) interglacial between 40,000 - 30,000 years ago which

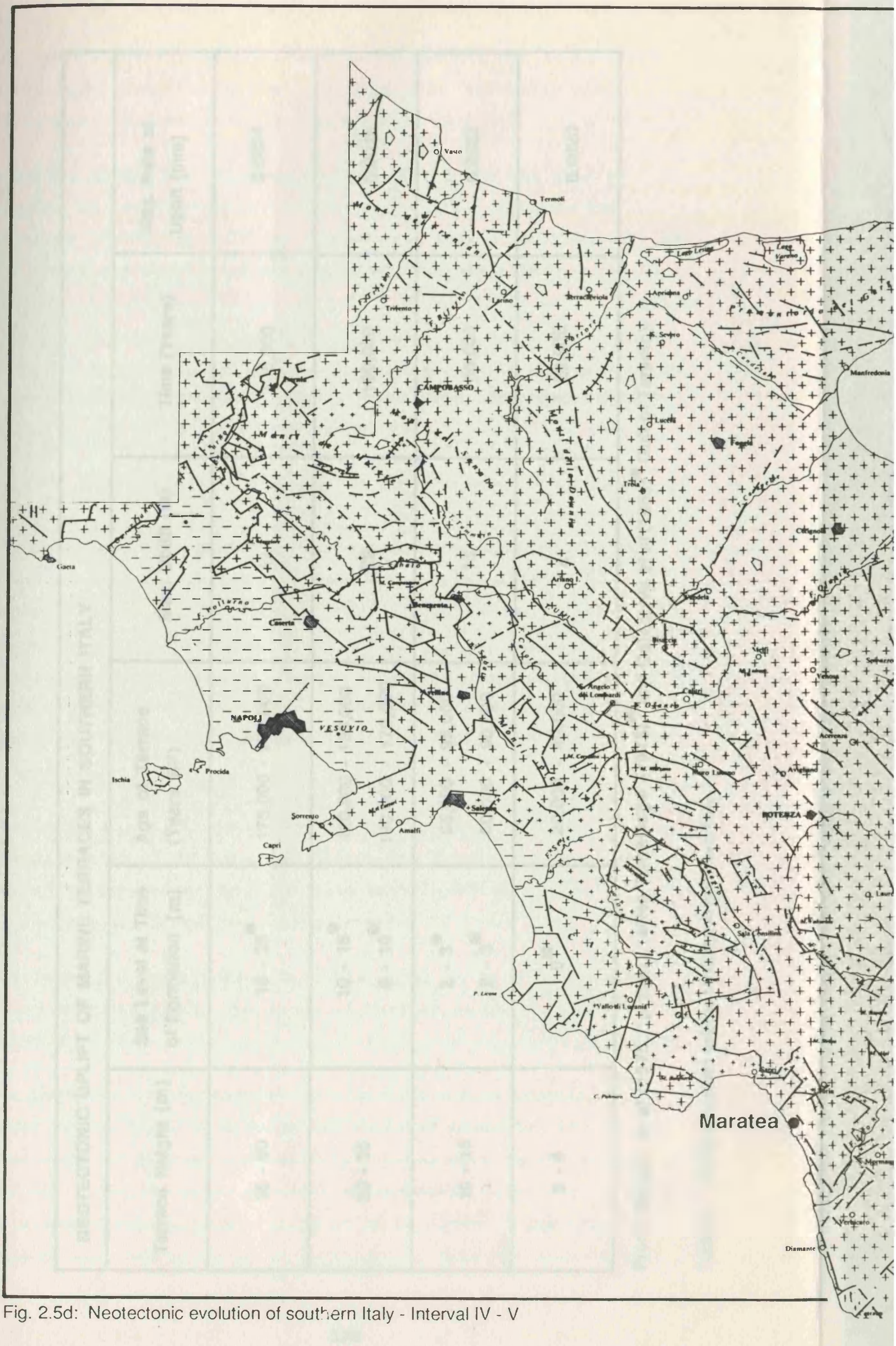


Fig. 2.5d: Neotectonic evolution of southern Italy - Interval IV - V

NEOTECTONIC MAP OF SOUTHERN ITALY

Interval IV - V

O.7MY - 0.018MY BP & 0.018 MY - Date

From Ciaranfi *et al* (1983)

NEOTECTONIC UPLIFT OF MARINE TERRACES IN SOUTHERN ITALY					
Terrace Height (m)	**Sea Level at Time of Formation (m)**	**Age of Terrace (Years BP)**	**Max. Uplift (m)**	**Time (Years)**	**Max. Rate of Uplift (mm)**
35 - 60	18 - 25●	175,000 - 230,000	42	175,000	0.0024
20 - 35	10 - 15● 6 - 10■	120,000 - 135,000 160,000 - 170,000	29	160,000	0.0018
10 - 15	2 - 3● 2 - 3■	65,000 - 95,000 60,000 - 90,000	13	60,000	0.0022
3 - 4	0■	20,000 - 40,000	4	20,000	0.0020

From Brogan *et al* (1975, p.326), after Fairbridge (1973)■ and Cotecchia *et al* (1969;● Gulf of Taranto).

Table 2.1: Dates of raised marine terraces in southern Italy

raised sea-level from about 140m below present sea level. Sea level again fell during the Late Wisconsin Regression which immediately preceeded the Holocene Trangression.

Brückner (1982) has extended the chronology for the Gulf of Taranto by the identification of eleven Pleistocene marine terraces (named TK1 - TK11). Brückner's TK1 is equivalent to the 3 - 4m raised terrace of Cotecchia *et al* (1969); TK2 to the 10 - 15m terrace; TK3 to the 20 - 35m terrace and TK5/6 to the highest terrace of Fairbridge (1973) at 35 - 60m. In addition to these, however, Brückner lists a further six Pleistocene terraces which detail the uplift sequence of the Metapontino from the 636,000 years BP (TK11) to 314,000 years BP (TK6).

Of more significance to the Maratea area, however, is the work of Carobene *et al* (1986). The authors identified a number of raised beaches along the Tyrrhenian coast between Maratea and Cetraro. These old sea levels are represented by deposits of biocalcarenite with the foraminifera *Cladocora caespitosa* filling fractures in it. Carobene *et al* (1986) carried out $^{230}Th/^{234}U$ dating on these samples and the mollusc *Spondylus* on raised marine terraces at 13m - 14m, 8m -9m and 2m - 5m above present sea level; they termed these ancient sea levels A,B and C respectively (see Table 2.2).

Sea Level A: Is characterised by the presence of *Cladacora caespitosa* at 13.5m a.s.l. at Grotta del Prete 20km south of Maratea. The beach has been dated at >350,000 years BP indicating its formation during interval IV - V.

Sea Level B: The evidence for this level is an 8 - 9m raised beach at Punta Iudia, 8km south of Maratea, dated to >350,000 years BP.

Sea Level C: Is represented by a 2 - 5m raised shoreline at Torre Talao, Punta di Cirella and Punta di Diamante, 25, 30 and 35km south of Maratea respectively. Dates were in the range 250,000 - 300,000 years BP which approximates to a rate of uplift of around 0.0012mm/year. Carobene *et al* (1986) argue that this rate is very low and even if approximate, does not account for

N° éch.	Espèce (*)	Localisation (voir fig. 1)	Altitude (m a.s.l.)	Aragonite (%)	Calcite (%)	Poids éch. daté (g)	Rendements chimiques U (%)	Th (%
LB66	Cl	Punta Iudia	9	85	15	10,22	90	94
LB66	Sp	Punta Iudia	9	85	15	64,17	61	70
LB65	Cl	Grotta del Prete	13.5	75	25	9,51	23	97
LB27	Cl	Torre Talao	5	97	3	12,48	90	48
LB1	Cl	Punta di Cirella	2	95	5	9,38	84	99
LB69	Cl	P^{ta} di Diamante	5	90	10	9,29	78	96
LB25	Sp	Punta La Testa	32	90	10	43,80	91	93

N°	[U] ppm	$^{234}U/^{238}U$	$(^{234}U/^{238}U)_0$	$\frac{^{230}Th}{^{232}Th}$	$^{230}Th/^{234}U$	Age $\frac{^{230}Th}{^{234}U}$ (ka BP)
LB66Cl	1,670 ± 0,040	1,126 ± 0,038	-	245 ± 36	1,105 ± 0,034	> 350
LB66Sp	0,658 ± 0,016	1,130 ± 0,039	1,194 ± 0,070	285 ± 39	0,738 ± 0,023	143^{+16}_{-13}
LB65Cl	1,440 ± 0,053	1,059 ± 0,053	-	306 ± 57	1,100 ± 0,045	> 350
LB27Cl	2,046 ± 0,048	1,148 ± 0,038	1,302 ± 0,162	269 ± 51	0,930 ± 0,030	252^{+70}_{-40}
LB1Cl	1,973 ± 0,048	1,087 ± 0,037	-	209 ± 28	1,011 ± 0,031	≧ 300
LB69Cl	1,870 ± 0,046	1,108 ± 0,038	-	118 ± 12	1,020 ± 0,032	≧ 306
LB25Sp	0,517 ± 0,012	1,158 ± 0,038	1,236 ± 0,072	293 ± 49	0,738 ± 0,023	142^{+15}_{-13}

$^{230}Th/^{234}U$ Dates for the Coast of Basilicata and Calabria.

From Carobene *et al* (1986)

Cl = Cladocora Caespitosa
Sp = Spondylus

(Quoted errors are 1∂ uncertainties due to Nuclear counting statistics only)

Table 2.2: Dates of raised marine terraces on the coast of Basilicata and Calabria.

the high 'Sicilian Terraces' which the authors contest exist at around 150 - 200m a.s.l. along the coast 2km south of Maratea, or at 300m a.s.l. between Cirella and Diamante (35km and 40km south of Maratea respectively). For terraces at this height to be 250,000 - 300,000 years old requires a rate of uplift of the order 0.67mm - 1.0mm/year. The authors accept that these rates are rough estimates but nonetheless argue that uplift in this zone has diminished by 10 - 20 times over the last 250,000 years.

At Cetraro (Punta la Testa), Sea Level A has been identified by the authors at 32m instead of the 14m along the coast between Scalea and Cirella. The tectonic line which separates the coast at Cetraro (Capo Bonifati) is the Sangineto Line; the line divides the Pollino - Apennine zone to the north (a zone of uplift) from the Alpine folds of the Catena-Costiera to the south (a zone of major uplift).

The uplift is more apparent to the south of the line and is characterised by the presence of the foraminifera *Strombus bubonius*. The altitudes at which this level is found diminish from north to south. Maximum rates of uplift in the area are therefore found at Reggio Calabria (Boretto) with rates of the order 0.98mm/year. Carobene *et al* also argue that in Calabria there is a consistent tendency for uplift rates to have accelerated since the upper Pliocene - lower Pleistocene. This is in line with the work of Ghisetti (1981) who argues for an uplift rate of 0.06 - 0.63mm/year at 1.5 MY BP in southern Calabria rising to 1.5mm/year at 0.08 MY BP.

2.5 Seismicity and Recent Neotectonic Activity

Brogan *et al* (1975) have argued that the 'tectonic setting in which [the] large earthquakes of southern Italy have been generated appears to be an inclined seismic zone (Benioff Zone) along which the African Plate might be subducted beneath the European Plate', (Brogan *et al*, 1975, p.235). This explanation is probably too simplistic, and more recent plate tectonic reconstructions are of greater complexity. Platt *et al* (1989), for example, have argued that kinematic data suggest that since about 70 MY BP, the motion history of Adria has been separate from the European and African Plates. As a consequence, the Adriatic should be regarded as a microplate moving north-west relative to Europe and not a northern extension of Africa as the assertions of Brogan *et al* indicate.

Calcagnile *et al* (1977), detail 119 seismic events to have affected Basilicata, southern Campania and northern Calabria during the period 1550 - 1973 (see also Giorgetti and Iaccarino, 1971). When plotted on a map (Fig. 2.6 - see also Table 4.1) it is clear that virtually all seismic activity is located to the west of the Southern Apennine ridge along the boundary of the old Latium-Campania-Lucania Carbonate Platform - the Panormide Complex which now forms all the high limestone areas of western Basilicata of which the Maratea mountains are a part. The distribution of seismic activity in the region and published fault plane solutions (McKenzie, 1972) are, as McKenzie points out 'consistent with an Adriatic microplate and suggest that the motion between Africa and Eurasia is not taken up by thrusting on an east-west feature at the southern end of the Adriatic but by normal faulting in Italy and thrusting in Yugoslavia', (McKenzie, 1972, p.135). This scenario would suggest that the compressional tectonics which formed the Apennine chain are now over and have been replaced by tensional forces, a view shared by Richter (1958). Richter similarly argued that folding and thrusting in the Apennine zone has finished and that the chain is being 'broken into blocks along comparatively new fractures', (Richter, 1958, p.32). Fault plane solutions for the last major earthquake to have struck Italy - the 23 November 1980 earthquake - also suggest tensional forces. Deschamps and King (1983) found that the fault movement which caused the 1980 earthquake extended along a 40km strike and came to within 5km of the surface. The fault had a plane dipping at 60° and was approximately 15km deep.

It is clear, therefore, that the distribution of seismic activity in the Southern Apennines is related to tensional forces along a contact zone which marks the boundary between a possible Adriatic microplate and the European Plate. The seismicity of the region

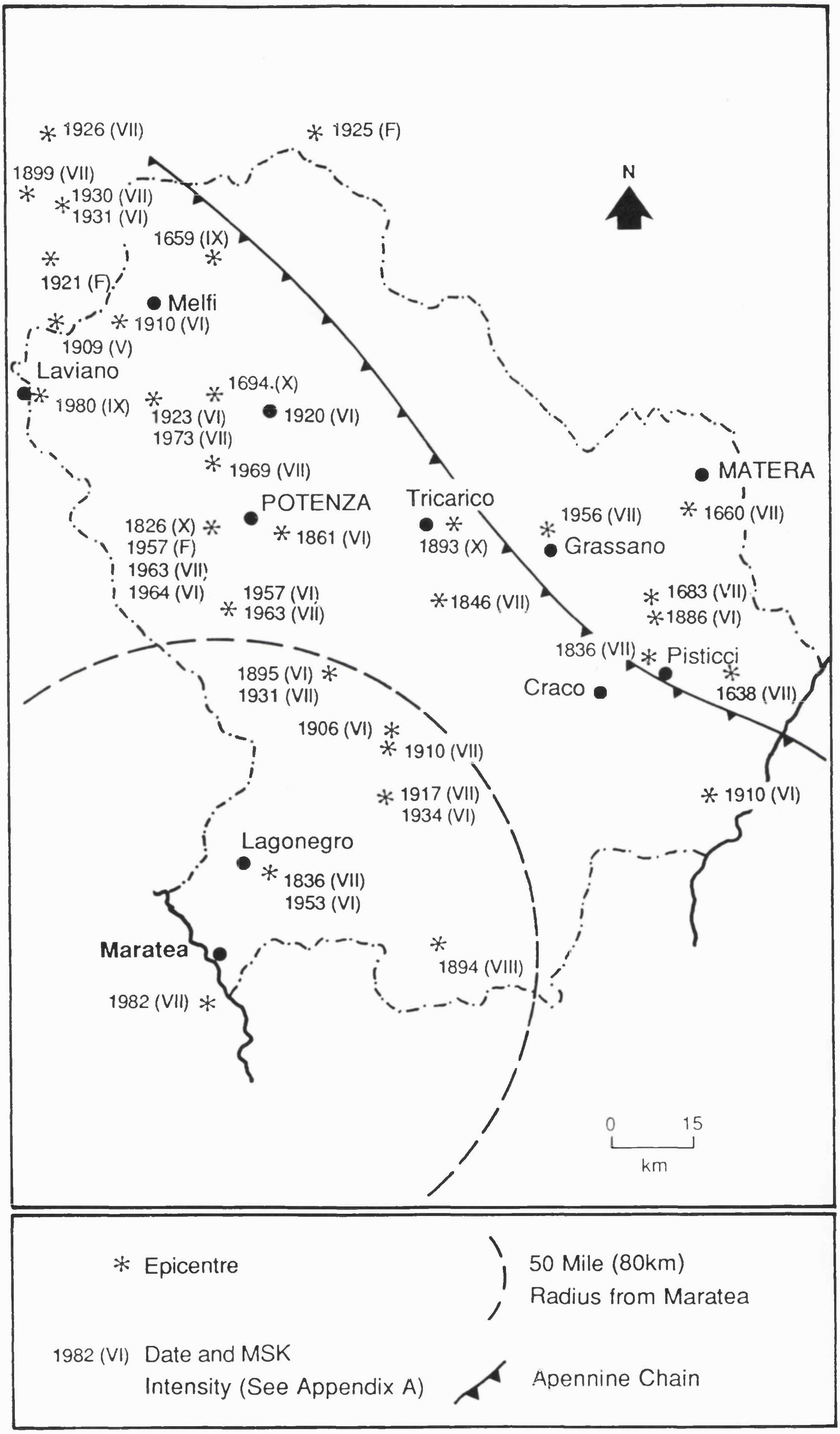


Fig. 2.6: Map of earthquake epicentres in Basilicata, southern Campania and northern Calabria. Data from Calcagnile *et al* (1977). See also Table 4.1.

is, however, as Mckenzie (1972) pointed out, too weak to confirm or deny this interpretation with any real certainty. Seismic activity in the area of the Calabrian Arc is, however, a separate and more problematic issue. McKenzie (1972) argues that the distribution of seismic shocks in this area is probably related to a fragment of the African Plate which has broken away from the main plate and is now sinking.

Similarly, the evidence for ground deformation during seismic events is scarce. The 'Great Neopolitan Earthquake' of 16 December 1857 (see Mallet, 1862) is the largest to have struck the Southern Apennines in historical time, having an estimated Richter magnitude of 6.84. No faulting that broke the surface was reported at the time of the earthquake. Since 1862, the largest earthquake to have affected the region is the 23 December 1980 event and, as with the 1857 earthquake, no faults were reported to have ruptured the surface at the time although Dramis *et al* (1982) reported surface fractures. However in 1984 clear evidence of surface faulting was reported (Westaway and Jackson, 1984). Shepherds in the Laviano area (the earthquake epicentre) and San Gregoria Magno areas, reported that an observed surface rupture had not existed prior to the earthquake. At first the fault had been obscured by the severe snow of the 1980 winter and later dismissed as a superficial surface feature by Cinque *et al* (1981) and Carmignani *et al* (1981). Observations of this fault by Westaway and Jackson (1984) and Boschi *et al* (1990) confirmed that earthquake associated faulting in southern Italy 'takes place in the upper 10 - 15km of the earths crust on steep planar faults which break the surface', (Westaway and Jackson, 1984, p.436).

Guerricchio and Melidoro (1979), attempted to argue that an observed 'renewal of movement' (p.13) along the Maratea fault was due to neotectonic movement. Later the same authors, however, (Guerricchio and Melidoro, 1981) argued that many 'large gravitational movements in the Southern Apennines are often interpreted erroneously as active tectonic processes because they take place in geological structures controlled by faults' (Guerricchio and Melidoro, 1981, p.252; see also Bousquet, 1973).

Among areas where these erroneous interpretations are said to occur are Maratea, Monte Le Falconara in the Pollino Mountains, and two cases in the Sele basin - Lauria and Senerchia. The authors argue that these examples which involve a characteristic 'refreshening' of fault scarps in limestone areas, are not the result of active tectonic processes but rather caused by large slow moving landslides. They contest that in historical time at least, no seismic events, which would induce ground deformation, have been reported along these fault lines.

Thus, in the Maratea example as in other areas throughout southern Italy, it is clear that there is often little information on particular faults. Observed movements in these areas may be interpreted as active tectonic processes or landslide movements. It is to this question in the Maratea valley that this thesis will now turn.

CHAPTER THREE

THE MARATEA VALLEY

3.1 Introduction

Chapter One discussed the background to the development problems of southern Italy, with particular reference to the landslide hazard, and Chapter Two, focussed on the principal geological features, terrains, neotectonic evolution and seismicity of the Southern Apennines. Thus, these chapters have provided the reader with an introduction to both southern Italy and more specifically to Maratea.

The thesis will now turn its full attention to the Maratea study area. In this chapter the geological and geomorphological investigations that were carried out in the valley prior to the present author beginning work are summarised, and in the following chapters (Four to Ten), the work of the author is presented and discussed.

3.2 Geological Setting

Maratea is situated on the western side of the Southern Apennine imbricate thrust belt. In Basilicata this margin is formed from Mesozoic limestones of the Panormide Complex (see Appendix A) described by Ogniben (1969); this complex is equivalent to the Monti della Maddalena and Monti Foraporta elements (two of the Intermediate Tectonic Elements - see Appendix A) described by D'Argenio *et al*, (1986). They are derived from the deformation of the Mesozoic Latium-Campania-Lucania Carbonate Platform (see Chapter 2, section 2.3.1).

In the south of Basilicata, resting tectonically on the Panormide Complex, are the Liguride Units (together with the Sicilide Units forming the Higher Tectonic Elements of D'Argenio *et al*, 1986; see Appendix A). These units are represented by black shales

(Crete Nere Formation), calcareous clays (Saraceno Formation) and marly clays (Albidona Flysch); see Appendix A.

All the areas of higher relief surrounding the Maratea valley are formed of limestones of the Panormide Complex (namely, Monte San Biagio, Monte Crivo and San Angelo). In contrast, the valley floor and basal slopes of the mountains are covered by deposits of the Liguride Complex. In the Maratea valley, the Liguride Complex has been downfaulted along the two normal faults described in Chapter One, section 1.5.2. In the valley floor the complex is still thought to rest on Panormide Complex deposits which themselves have been downfaulted. Again, in the valley floor, the Liguride Complex has been covered by alluvial deposits from the Torrente Fiumicello and by detrital material weathered from the surrounding limestone mountains. Some small depressions in the *centro storico* area have been filled with Pleistocene red clays - *terra rossa*.

3.2.1 The Panormide Complex

As noted above, the limestone mountains surrounding the Maratea valley are part of the Panormide Complex. Brancaccio *et al* (1979) argue that deposits of the Lower Lagonegro element (see Appendix A) lie below the Panormide Complex. Del Prete (*pers. comm.*) goes further and suggests, more specifically, that Galestri Flysch (part of the Lower Lagonegro element) is beneath the carbonate sequence. Regrettably until more detailed stratigraphical information is available, the views of Del Prete must remain an hypothesis.

Samples were taken from the area of the fault plane scarp, sectioned, stained and then thin sectioned. Sample thin sections show a dolomitic limestone containing 30% - 40% dolomite (Plate 3.1). The dolomitic crystals are sub-hedral and rhomb-shaped and occur unstained surrounded by pink stained, unaltered, calcium carbonate. The concentration of dolomitic crystals indicates that the fault plane scarp should more properly be termed 'dolomite' rather than limestone.

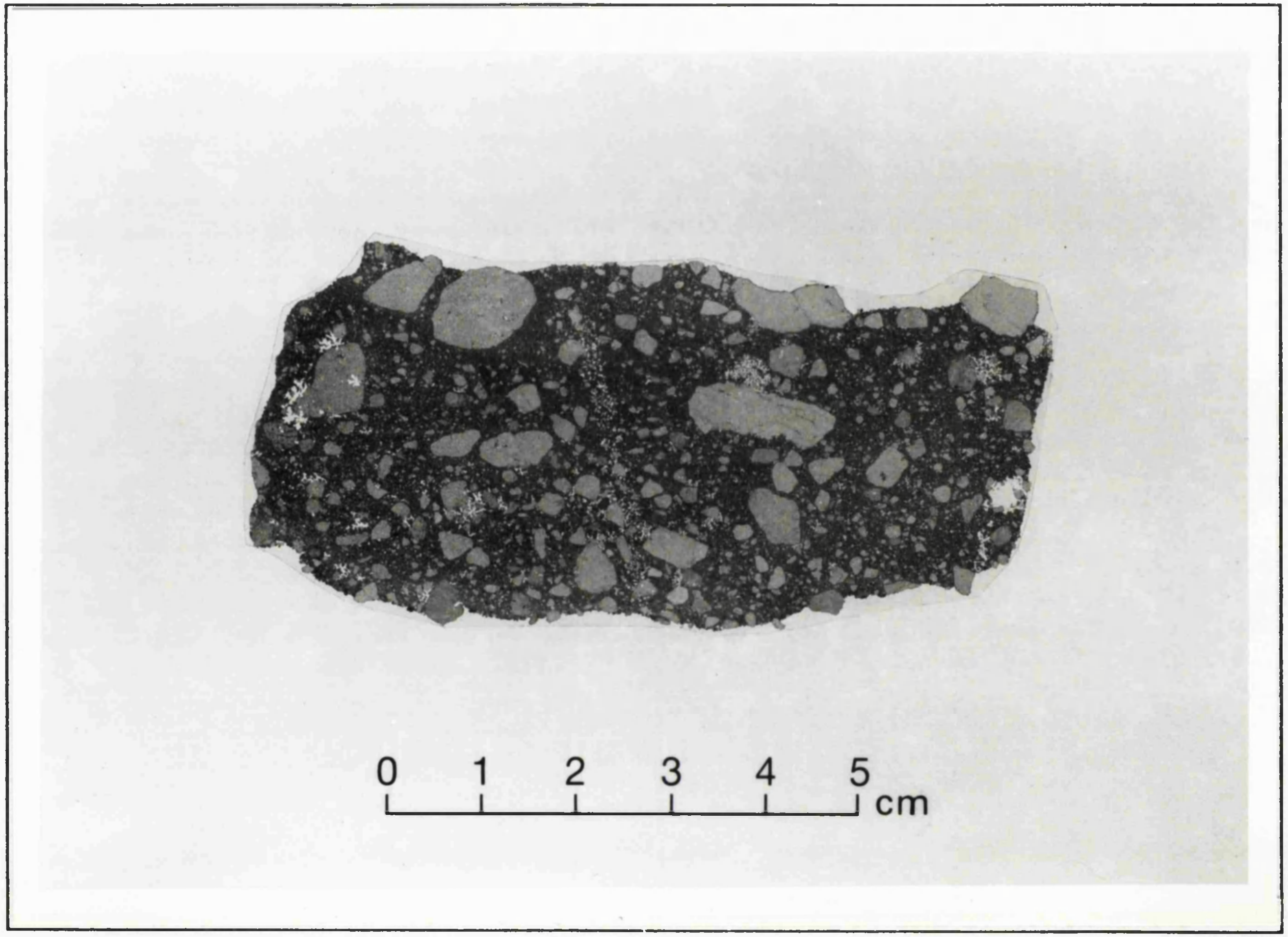


Plate 3.1: Thin section of the limestone from the fault plane scarp. The large white particles are dolomite.

3.2.2 The Liguride Complex

The Liguride Complex (see Appendix A) is made up of three sets of deposits; black shales (Crete Nere Formation), calcareous clays (Saraceno Formation) and marly clays (Albidona Flysch). Only the black shales of the Crete Nere Formation outcrop under the floor of the Maratea valley and in the vicinity of the *centro storico*. In southern Basilicata the Liguride Complex is indistinguishable from the Frido black clays (see Appendix A), so some doubt exists as to its identification.

Regione Basilicata (1978) argue that the Crete Nere or Frido Formation is an altered black clay - a flysch. Whitten and Brooks (1985) define flysch as follows:'a term which originated in Switzerland and is strictly applicable only to sediments associated with the Alpine orogeny. It is used to describe sediments produced by the erosion of uprising and developing fold structures, which are subsequently deformed by later stages in the development of these same fold structures. In Switzerland, such sediments are marine and consist of argillaceous rocks, impure sandstones, breccias and conglomerates', (Whitten and Brooks, 1985, p.180). The origin of the Liguride Complex is not clear (see Appendix A) and because of this cannot be described as a flysch *sensu stricto*. Consequently, the Crete Nere Formation at Maratea should more properly be termed a black clay rather than a flysch (Ogniben, 1969). The Maratea black clays appear to be identical to deposits of the Crete Nere Formation found at Lauria and Nemoli in the nearby Lagonegro tectonic basin (see Appendix A).

Limited geotechnical investigations of the black clay have been undertaken by De Stefano (1978) and Regione Basilicata (1978). A granulometric analysis by De Stefano (1978) indicates a fine-grained sandy clay (Fig. 3.1 and Table 3.1). Triaxial compression tests have similarly been carried out by De Stefano (1978). These are important to determine the shear strength of the black clay, that is the resistance of the material to shear stress. This is related to the amount of grain interlocking (determined by the angularity of the particles) and their degree

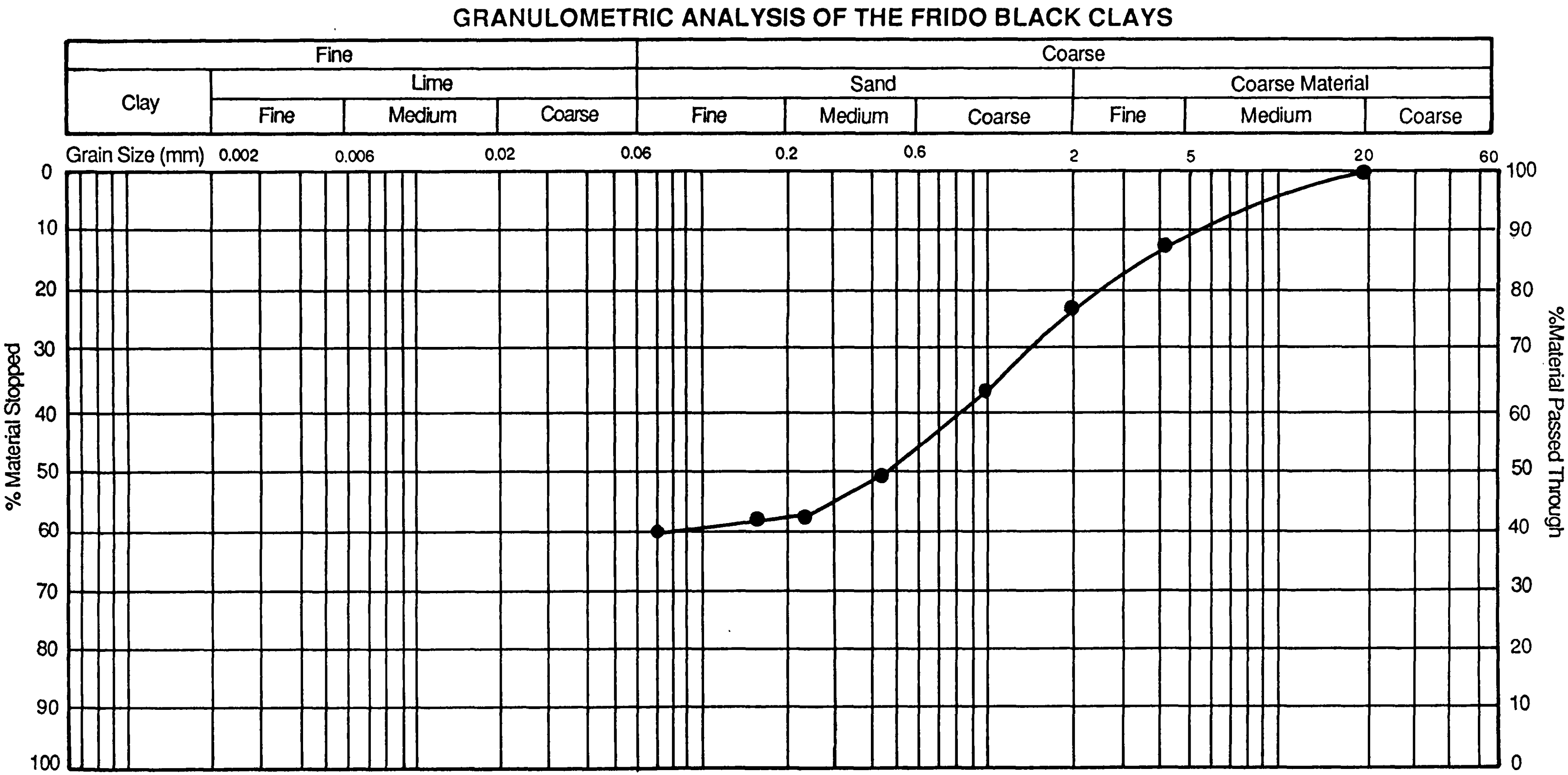


Fig. 3.1: Granulometric analysis of the Frido Black Clays. From De Stefano (1978).

GRANULOMETRIC ANALYSIS OF THE FRIDO BLACK CLAYS

Aperture Size (mm)	% Material Passing Through Sieve
12.70	100.0
9.50	94.5
4.76	87.5
2.00	76.8
1.00	64.8
0.42	49.7
0.25	43.2
0.177	42.7
0.074	40.8

Table. 3.1: Granulometric analysis of the Frido Black Clays. From De Stefano (1978).

of consolidation. These, in turn, determine the angle of shearing resistance which, in addition, is a function of the effective pressure between particles and their cohesion. These relationships can be described by the equation:

$$s = c' + \sigma' \tan \phi' \qquad \text{(Equation 3.1)}$$

Where:

s = shear strength

c' = effective cohesion

σ' = effective pressure between particles

ϕ' = angle of shearing resistance

The results of two triaxial compression tests carried out by De Stefano (1978) on the black clays are detailed in Table 3.2. Table 3.3 compares the angles of shearing resistance derived from the black clays with those of other 'typical' clay soils (Kenney, 1984). The significance of this comparison is to demonstrate that the Frido black clays are normally consolidated clays with a high residual shear strength approaching that of other normally consolidated, freely drained clays.

The geotechnical investigations of De Stefano (1978) were commissioned by the *Comune di Maratea* as a parallel study to the 1978 Structure Plan for the area. Unfortunately it was a 'one off' commission with no proviso for follow-up work. The results presented above are based on too little empirical evidence for them to have any real significance or value. A number of potentially useful experiments (such as the placing of deep piezometers) were never carried out either because of a lack of funding or neglect. Such work would have been of immense value in determining the changing pore water pressures in the sub-soil. Pore water pressures, which change the normal stress acting on a soil and the residual shear strength of the soil by altering both internal cohesion and the effective pressure between particles, could have been related to the values of shear strength derived for the black clays. If this work had been carried out, areas of potential slope failure within the black clay outcrop could have been established.

SHEAR STRENGTH VALUES FOR THE BLACK CLAYS

TEST 1

Sample Number		1	2	3	4
Initial Water Content	% (w)	17.8	18.0	17.6	16.5
Weight	g/cm^2 (γ)	2.18	2.16	2.17	2.18
Vertical Pressure	kg/cm^2 (σ)	0.881	1.495	2.117	3.086
Vertical Deformation at Rupture	mm (δ)	0.43	0	0.48	0.36
Transverse Deformation at Rupture	mm (δ_1)	2.50	4.00	5.00	4.50
Shear Strength	kg/cm^2 (τ)	0.46	0.75	1.10	1.55
Final Water Content	% (w_f)	18.1	17.3	15.8	14.6

TEST 2

SAMPLE NO.		1	2	3	4
Initial Water Content	% (w)	16.3	16.5	16.8	16.0
Weight	g/cm^2 (γ)	2.16	2.14	2.19	2.15
Vertical Pressure	kg/cm^2 (σ)	0.881	1.512	2.117	3.086
Vertical Deformation at Rupture	mm (δ)	0.02	0.08	0.20	0.44
Transverse Deformation at Rupture	mm (δ_1)	0.19	0.70	0.80	1.70
Shear Strength	kg/cm^2 (τ)	0.87	1.30	1.62	2.12
Final Water Content	% (w_f)	19.0	18.0	18.9	18.1

Angle of Shearing Resistance (ϕ) TEST 1 27° TEST 2 29°

Cohesion (c') TEST 1 0.05 kg/cm^2 TEST 2 0.40 kg/cm^2

Source De Stefano, 1978

Table 3.2: Shear strength values of the Black Clays.

Soil	W_L (Liquid Limit) %	W_P (Plastic Limit) %	ϕ'
London Clay, Brown	82	30	20°
London Clay, Blue	72	29	19°
Upper Lias Clay	60	28	23°
Cucaracha Shale	59	32	23°
Oslo Clay	41	21	32°
Labrador Clay	32	22	31°
Frido Black Clay 1	30	17	27°
Frido Black Clay 2	-	-	29°

Table 3.3: Comparison of Liquid and Plastic Limits for Frido Clays and other 'typical' clays. After Kenney (1984).

More general criticisms of De Stefano's report are that it was written in extremely technical language and probably was not understood, or even read, by the administrators of the *Comune di Maratea*. In addition, his sample borehole locations for the triaxial compression tests, were not identified.

3.2.3 Distribution of Geological Units

The limestone units of the Panormide Complex comprise all the high areas surrounding the Maratea valley. In contrast the distribution and depth of the black clays, detrital material and *terra rossa* is more problematic.

Two reports commissioned by the *Comune di Maratea* have sought to clarify the stratigraphical relationships and areal extent of these deposits. Regione Basilicata (1978) sunk twelve boreholes in the vicinity of the *centro storico*. Eight boreholes were located at the base of Monte San Biagio (boreholes S1 - S7, and S12) and the other four distributed through the old town (for locations see fold out sheet in the back pocket of this thesis). The eight in the centro storico at the base of Monte San Biagio were in two groups; S1 - S3 and S7 were in one group in the south-east sector, S4 - S6 and S12 in another along the Via Mandarino in the south-west sector. One of the weaknesses of the Regione Basilicata (1978) investigation is that no rationale for the siting of the boreholes is specified in the report. The absence of this rationale poses a major problem in the interpretation of the resulting borehole data. The sub-surface geology cannot be mapped and no interpretation can be placed on the areal extent of the sub-surface deposits. All that can be safely said is that one borehole differs from another. This is because, as noted above, many of the boreholes occur in groups and there is limited spatial spread of information. A more rigorous sampling procedure, based for example on a sampling grid, would have achieved a more even coverage of information.

A diagrammatic representation of the stratigraphical record from each borehole is shown in Fig. 3.2a - 1. The main feature of

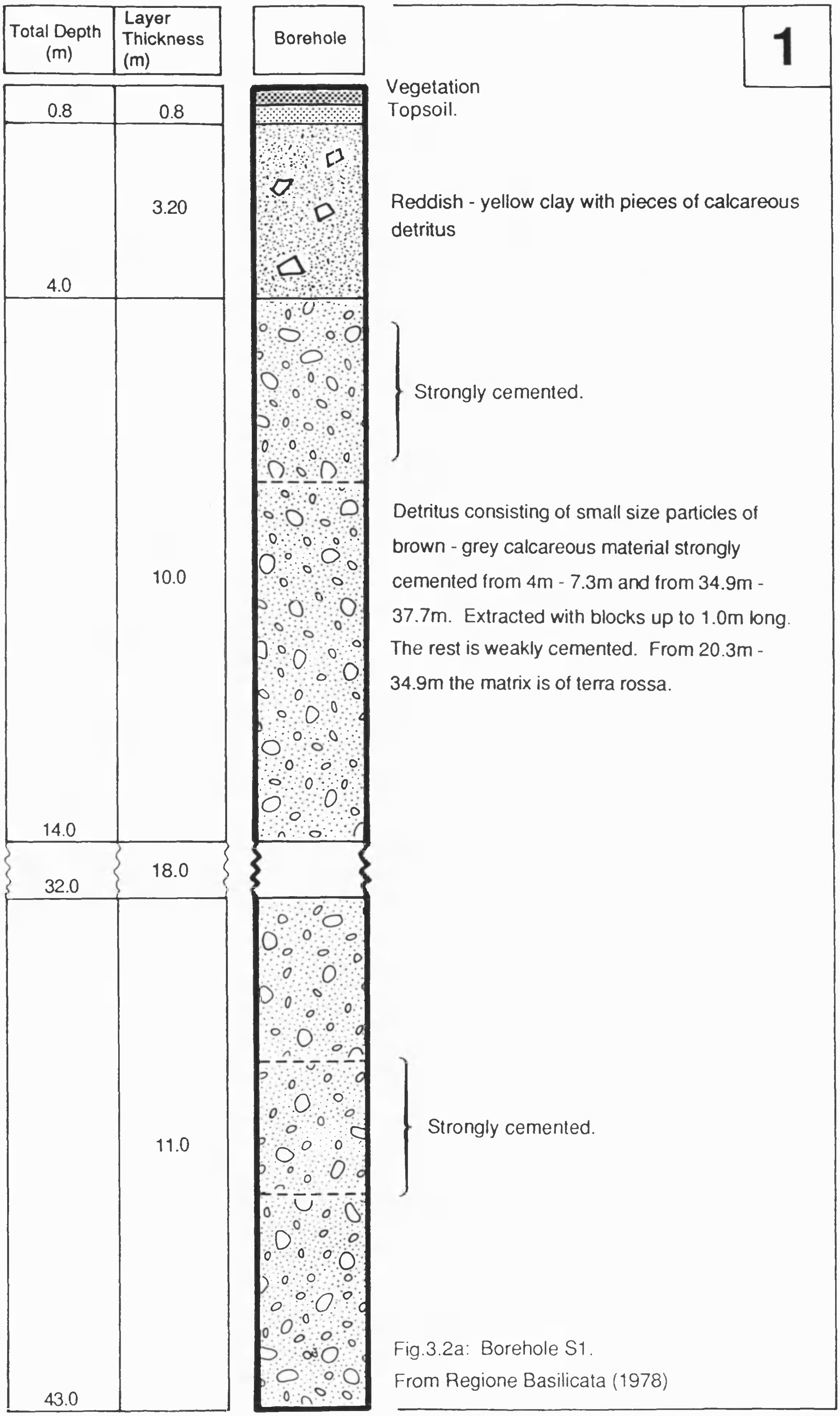


Fig.3.2a: Borehole S1.
From Regione Basilicata (1978)

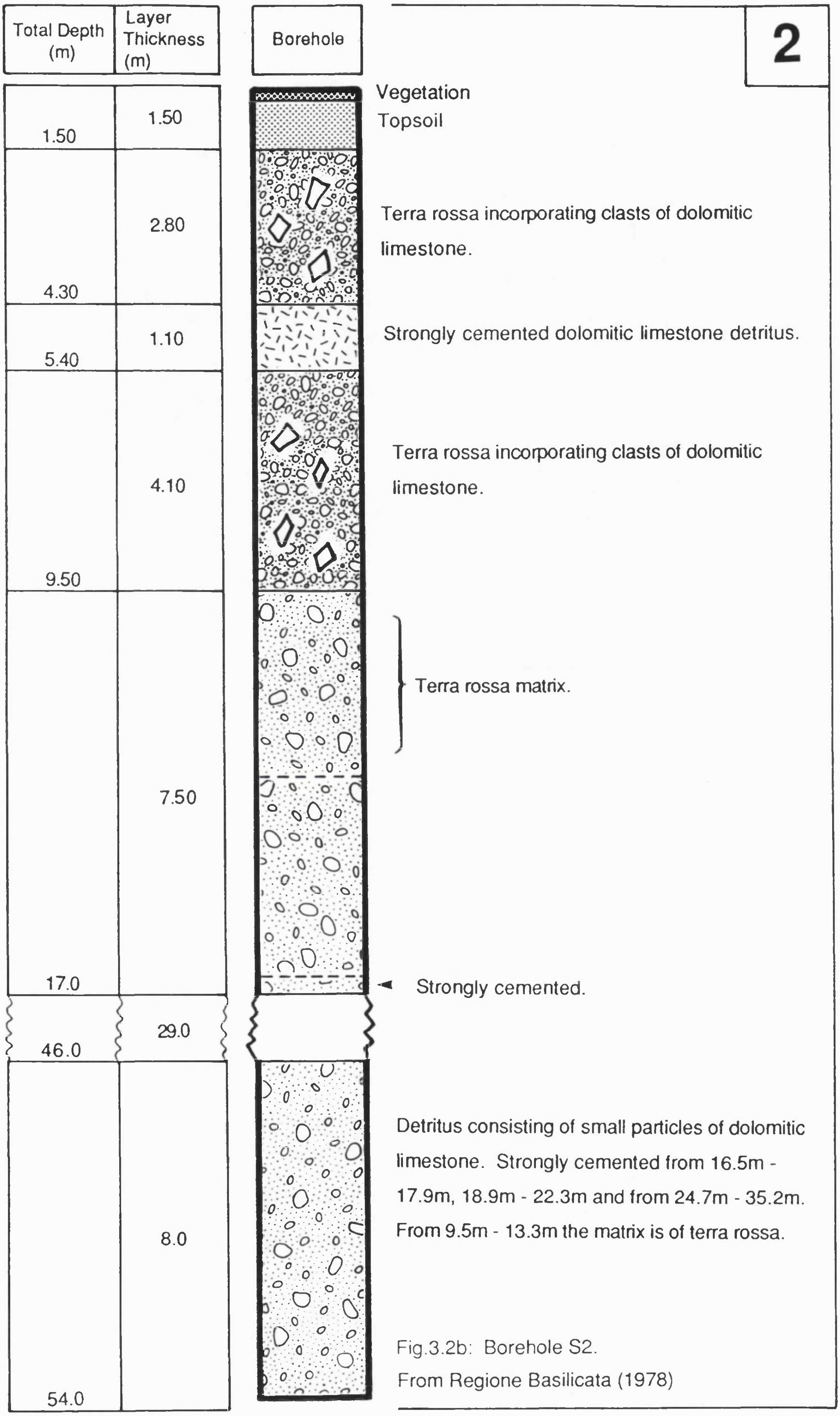


Fig.3.2b: Borehole S2.
From Regione Basilicata (1978)

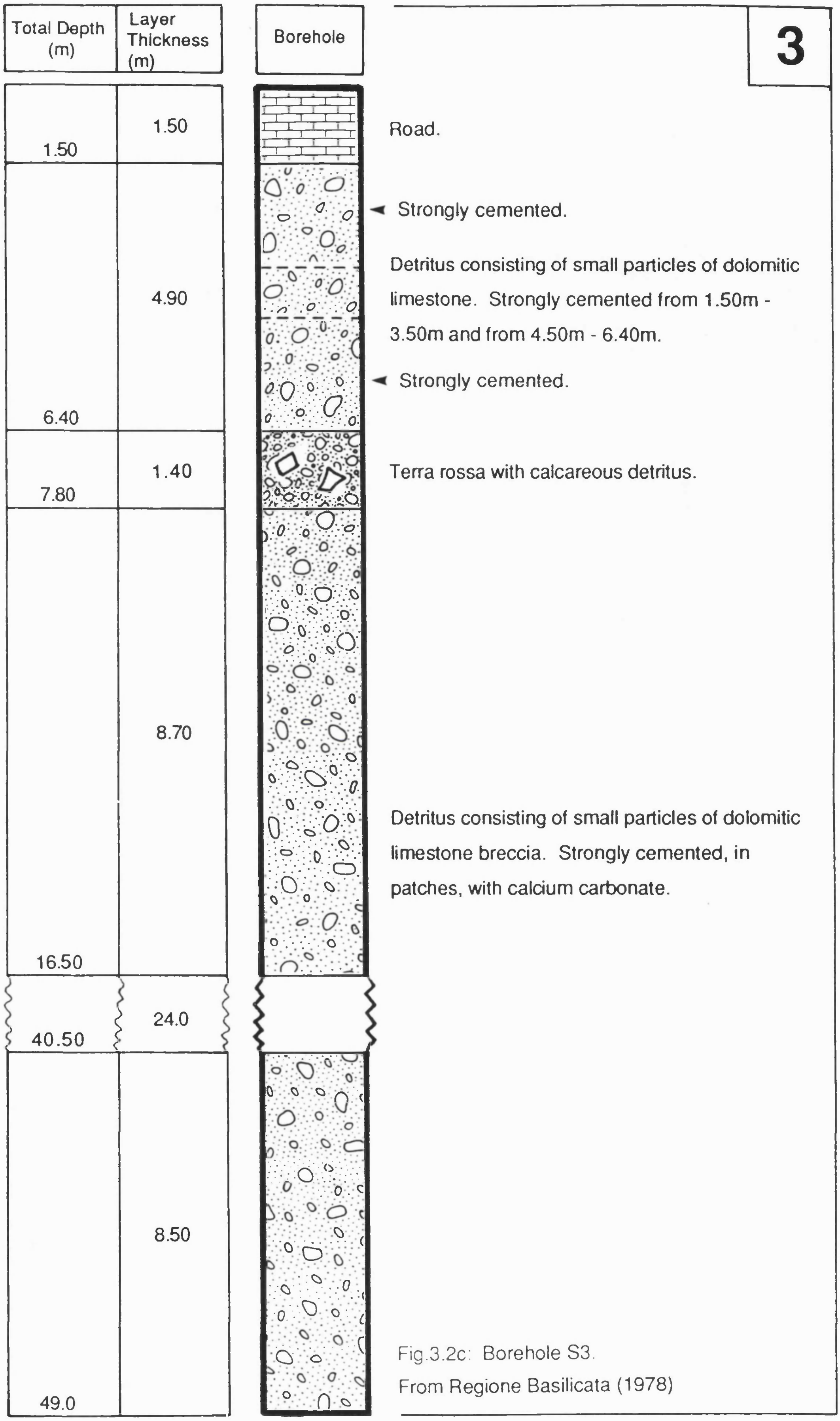
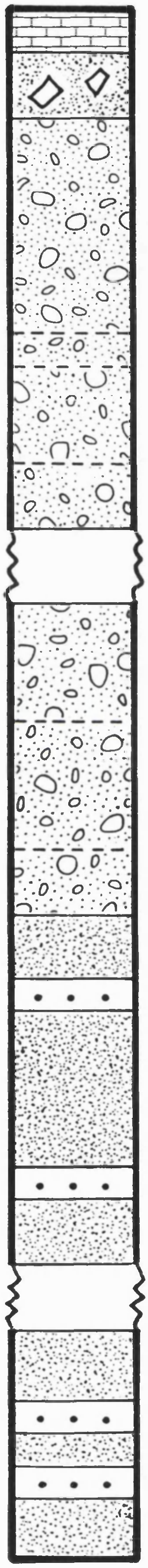


Fig.3.2c: Borehole S3.
From Regione Basilicata (1978)

Total Depth (m)	Layer Thickness (m)
1.10	1.10
2.20	1.10
8.0	5.80
15.0	7.0
20.0	5.0
25.50	5.50
32.50	7.0
38.10	5.60

Borehole



4

Road.

Reddish - grey clay with calcareous clasts

◄ Strongly cemented.

◄ Strongly cemented.

Detritus with small particles of dolomitic limestone. Strongly cemented from 2.20m - 5.50m, 6.0m - 7.0m, 8.0m - 12.7m, 13.6m - 14.5m and 16.8m - 19.0m. Whitish calcareous matrix of calcium carbonate.

◄ Strongly cemented.

Grey - black and grey coloured clay and shales with odd clasts of calcarenite and horizontal bands of grey - black loam about 400mm thick with a sub-horizontal stratigraphy.

Fig.3.2d: Borehole S4.
From Regione Basilicata (1978)

Total Depth (m)	Layer Thickness (m)	Description
1.50	1.50	Road.
6.80	5.30	Reddish - grey clay with calcareous clasts
15.0	8.20	Clayey shales with a strong grey colour, sometimes grey - black or yellowy grey, with horizontal bands of grey calcareous material and calcareous loam. The bands are about 200mm wide and the loam often contains calcareous fragments.
21.0	6.0	
30.7	9.70	

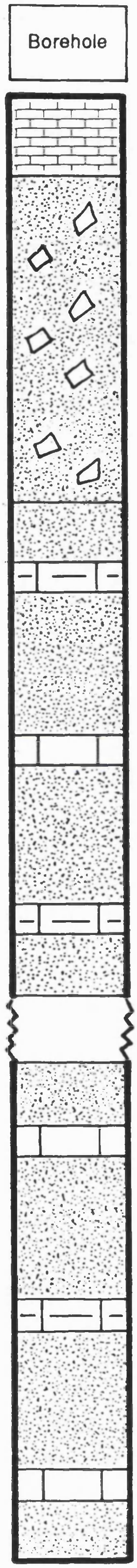


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Fig.3.2e: Borehole S5.
From Regione Basilicata (1978)

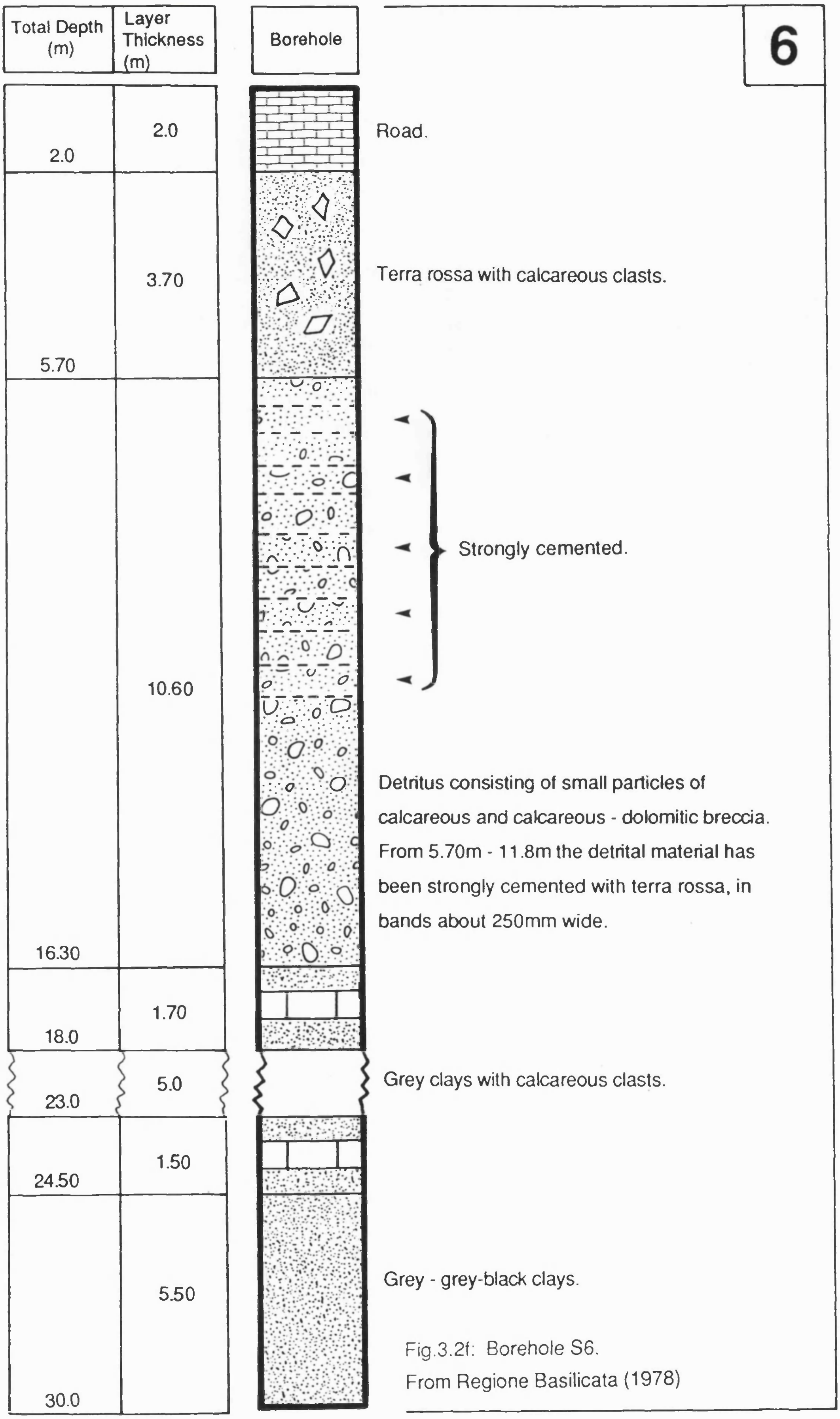


Fig.3.2f: Borehole S6.
From Regione Basilicata (1978)

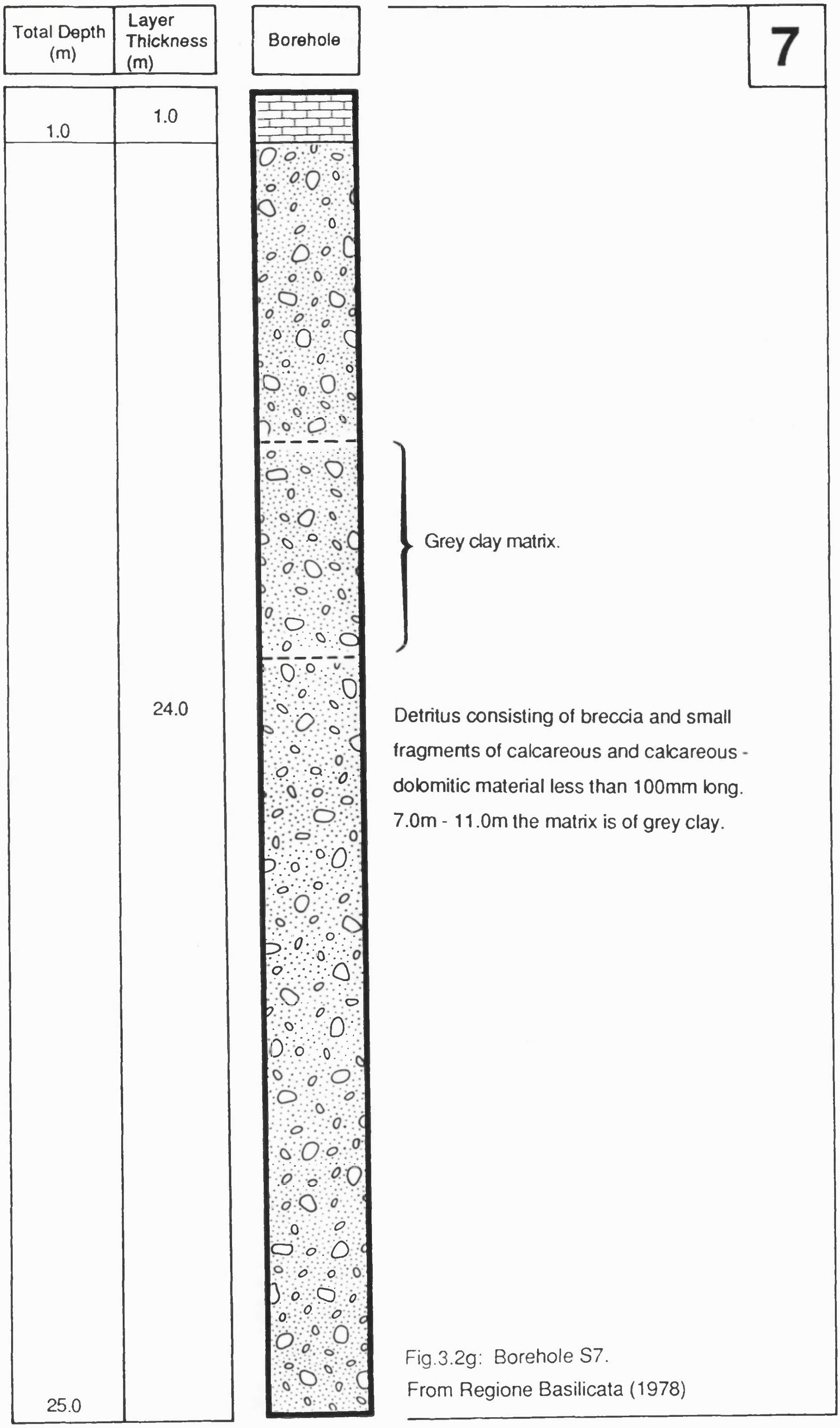


Fig.3.2g: Borehole S7.
From Regione Basilicata (1978)

8

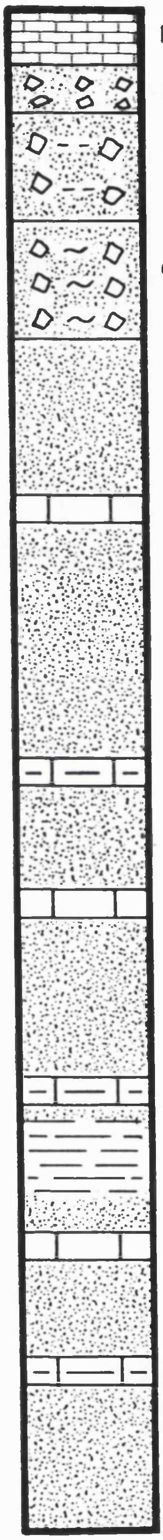
Total Depth (m)	Layer Thickness (m)	Borehole	
0.50	0.50		Road.
1.60	1.10		Reddish - brown clay with calcareous clasts
3.70	2.10		Reddish impure terra rossa with calcareous clasts
5.50	1.80		Greyish - yellow clay with clasts of dolomite.
22.0	16.50		Grey - black to grey coloured clay with some thin bands of calcareous material and grey black calcareous loam abundant from16.8m - 17.4m. From 78m to the bottom of the borehole, there are regularly spaced bands of calcareous material about 300mm thick which display a distinct horizontal form.

Fig.3.2h: Borehole S8.
From Regione Basilicata (1978)

Total Depth (m)	Layer Thickness (m)	Borehole	9
0.50	0.50		Road.
3.30	2.80		Impure terra rossa. Reddish - brown colour with calcareous clasts.
26.30	23.0		Detritus consisting of breccia and calcareous clasts, grey - brown in colour and generally unconsolidated.

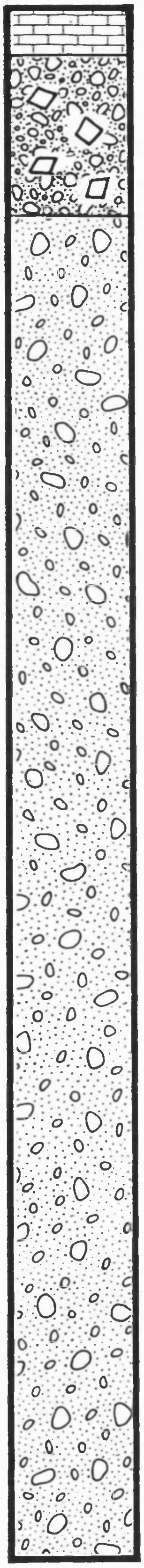


Fig.3.2i: Borehole S9.
From Regione Basilicata (1978)

Total Depth (m)	Layer Thickness (m)	Description
1.50	1.50	Superficial detrital layer mixed with reddish clay and small pebbles
3.50	2.0	Reddish - brown clay with small calcareous clasts
5.50	2.0	Terra rossa.
17.60	12.10	Detritus consisting of calcareous breccia browny - grey in colour, mixed with reddish - brown clay between 15.6m - 16.5m and large calcareous clasts between 16.5m - 17.6m.
25.0	7.40	Terra rossa.
26.0	1.0	Calcareous detritus.

Borehole

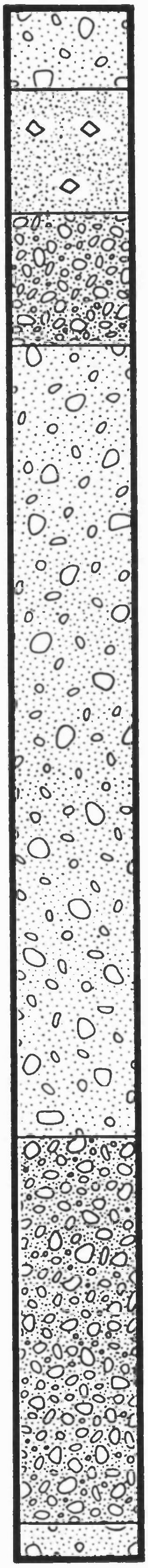


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Fig.3.2j: Borehole S10. From Regione Basilicata (1978)

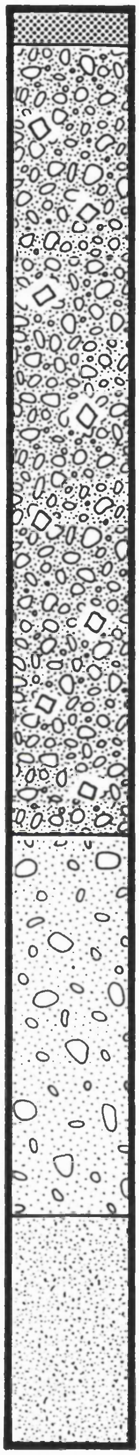
Total Depth (m)	Layer Thickness (m)	Borehole	11
1.0	1.0		Topsoil.
12.0	11.0		Reddish - brown clay with many small calcareous clasts
17.50	5.50		Detritus consisting of generally well cemented calcareous breccia.
21.0	3.50		Yellowy - grey clay with whitish veins of dickite

Fig.3.2k: Borehole S11.
From Regione Basilicata (1978)

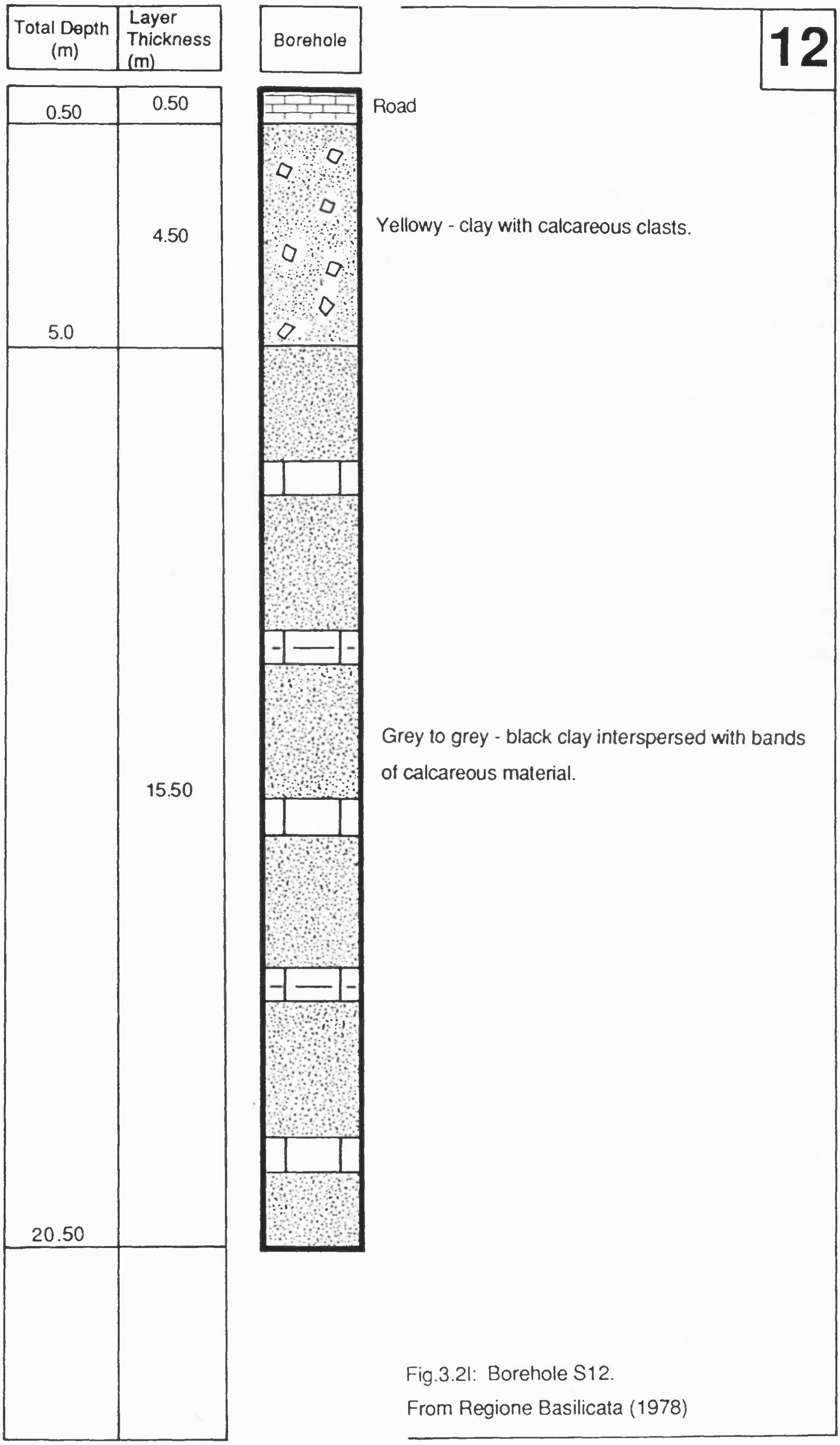


Fig.3.2l: Borehole S12.
From Regione Basilicata (1978)

note is the high variability of the sub-surface geology. Black clays were found in five boreholes (S4 - S6, S8 and S12). In S4 it appears at 20m depth; S5 at 6.80m; S6 at 16.30m; S8 at 5.50m and in S12 at 5.00m. The corollary is that the depth of the detrital cover is also very variable as is the occurrence and depth of *terra rossa*. For example, boreholes S2 and S3 are less than 200m apart and yet S2 has 6.90m of *terra rossa* and S3 none; clearly S2 has penetrated a small depression infilled with *terra rossa*.

The report of De Stefano (1978) commissioned by the *Comune di Maratea* also contained a borehole survey. This too, was limited to twelve boreholes although their position is less clear, there being no location map attached to the report. As the author himself admits 'sadly, the boreholes carried out on the basis of research for the solution of specific problems do not allow the whole geological picture to emerge', (De Stefano, 1978, p.4, translated from the Italian by the author). Even more sadly, the author does not define the 'specific problems' that he was trying to solve.

The principal conclusion to emerge from the reports of De Stefano (1978) and Regione Basilicata (1978) is that the sub-surface geology of the Maratea valley is highly variable. A major problem with both is that the depth of borehole information is limited. De Stefano gives no indication of the depth of his boreholes and the deepest borehole of Regione Basilicata is only 54m.

This section has been highly critical of the reports of De Stefano (1978) and Regione Basilicata (1978) commissioned by the *Comune di Maratea* as a parallel study to the 1978 Structure Plan which has been discussed in detail in Chapter One. A number of general criticisms have been highlighted; lack of detail regarding borehole locations; inadequate design of the borehole sampling pattern; inadequate depth of borehole information; presentation of highly technical reports with no attempt to link them to the framework of the 1978 Structure Plan.

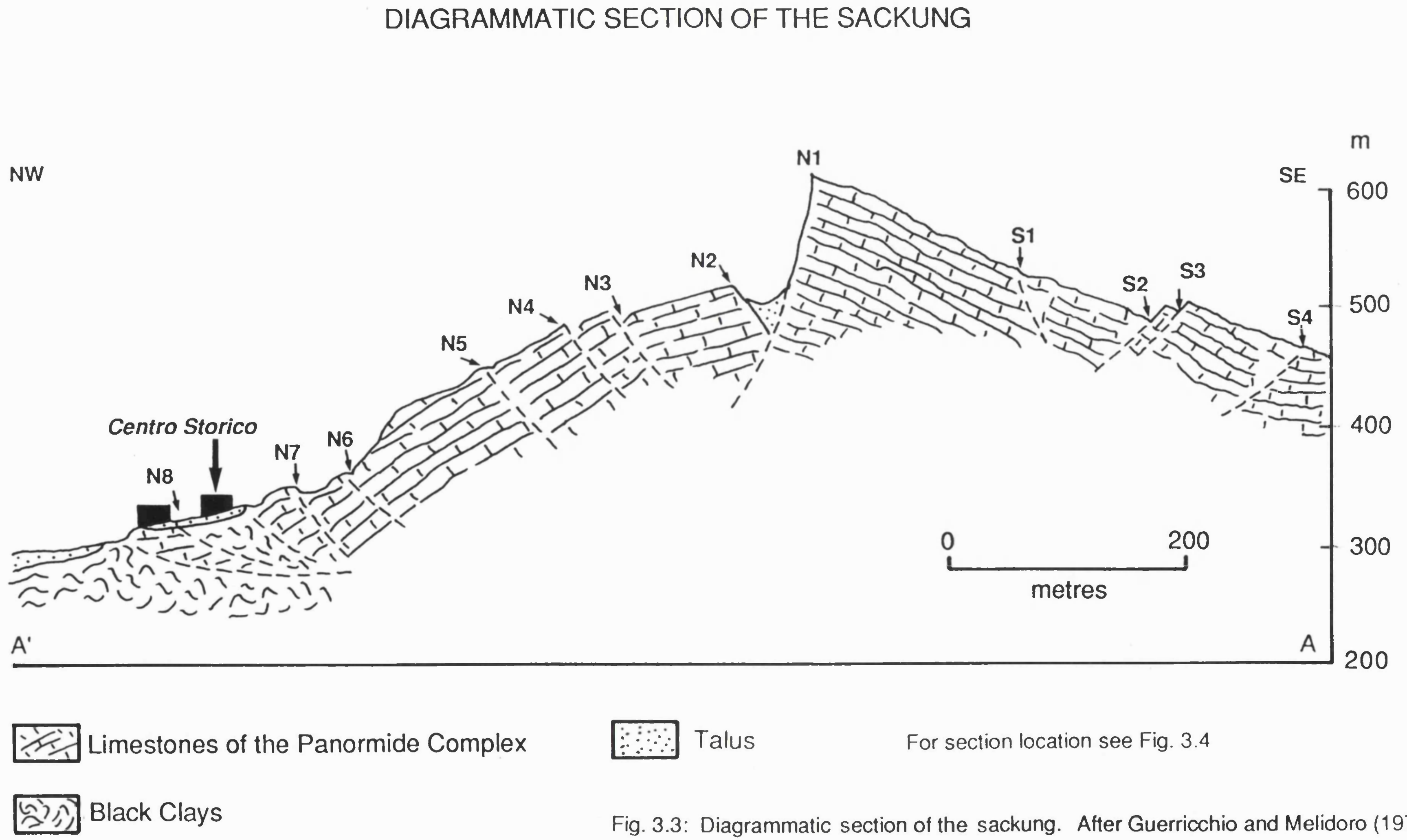
3.3 Structural Characteristics and Slope Instability

In Chapter One, section 1.5.2, each of the three major visible structural features in the Maratea valley was briefly introduced and discussed. In the next three sections each feature will be dealt with in detail with particular reference to the work that had been carried out on them prior to the beginning of this thesis.

3.3.1 The Sackung

Sackung deformations have been described by Forcella (1984) in the Italian Central Alps, Radbruch-Hall *et al*, (1976) in the U.S.A. and, most recently, from Ben Attow in Scotland (Holmes and Jarvis, 1985). They have been classified as 'long term deformations of mountain slopes (gravitational slides)' by Zaruba and Mencl (1982, p.128). Ampferer (1939, 1940) described rock-sag deformations - Bergzerreißung - in the Austrian Alps as did Zischinsky (1966, 1969a & b), who termed them *'sackungen'*. Zischinsky's sackungen occur on slopes composed of phyllites and mica schists lying unconformably over limestone sediments, with deformation having taken place along the contact zone. As such he seems to be describing a gravitational slide. Harrison and Falcon (1936) described a 'gravity collapse structure' in Iran. The collapse was in limestone massifs which had been deformed during Tertiary mountain building.

The Maratea sackung appears as a series of breaks or 'tears' in the limestone units of the Panormide Complex. Eight of the nine breaks are on the north - north-east facing slope of Monte San Biagio (these are numbered N1 - N8 on Fig. 3.3) and appear to be inclined towards the valley and away from the mountain (Plate 3.2). The uppermost and largest break (N1) is about 100m from crest to base (although its true size is obscured by talus accumulations in the graben of the break) and dips into the mountain ridge (see Fig. 3.3). Inland this break (N1) merges into a clear fault plane scarp and it may therefore be considered as the extension of the Maratea fault, which would account for



For section location see Fig. 3.4

Fig. 3.3: Diagrammatic section of the sackung. After Guerricchio and Melidoro (1979) Numbering system by author.

Plate 3.2: The sackung from the summit of Monte San Biagio, looking towards the Calabrian mountains. The break in the foreground is N2. The primary break (N1), leads from the fault plane scarp in the background.

its size and differing inclination. The other breaks have the following approximate maximum heights; N2, 20m; N3, 15m; N4, 10m; N5, 10m; N6, 5m; N7, 15m; N8, 5m; N9, 2m. It is possible that the break planes associated with these scarps join underground, although there is no evidence to confirm or refute this hypothesis.

On the south facing slope there are four further breaks; again the uppermost dips away from the mountain and the other three into the mountain. These four tears are not well pronounced, S1 is about 1m high and S2 and S3 are approximately 2m high. The break S2 is only about 1.5m high and has had a terrace wall built against it.

The structural processes which opened the sackung are not well understood and the available literature is often contradictory and confusing. For example, Guerricchio and Melidoro (1979) argue that 'evident neotectonic signs can be observed in it [the sackung]: renewal of the movement along one of the lateral faults, re-establishment of the violent erosion processes, multiple sliding of large rocky masses and gravitational phenomena of deep deformation' (Guerricchio and Melidoro, 1979, p.13). In contrast, these same authors in a later paper, argue with specific reference to Maratea that 'large gravitational movements in the Apennines of southern Italy are often interpreted erroneously as active tectonic processes' (Guerricchio and Melidoro, 1981, p.252). Regrettably, the authors do not present any evidence for either their 1979 or 1981 opinions or their change of interpretation and both papers are essentially descriptive.

Both an initial neotectonic origin and an historical gravitational rejuvenation of the sackung are envisaged by Guerricchio *et al* (1987) in a four-phase scenario:

• **Phase A**: Phase of tectonic rejuvenation and opening of the sackung. Collapse of carbonate blocks - "the limestone blocks" - near the fault line, especially along the line of what is now the main Maratea - Trecchina road (Fig. 3.4).

MAJOR STRUCTURAL FEATURES OF THE MARATEA VALLEY

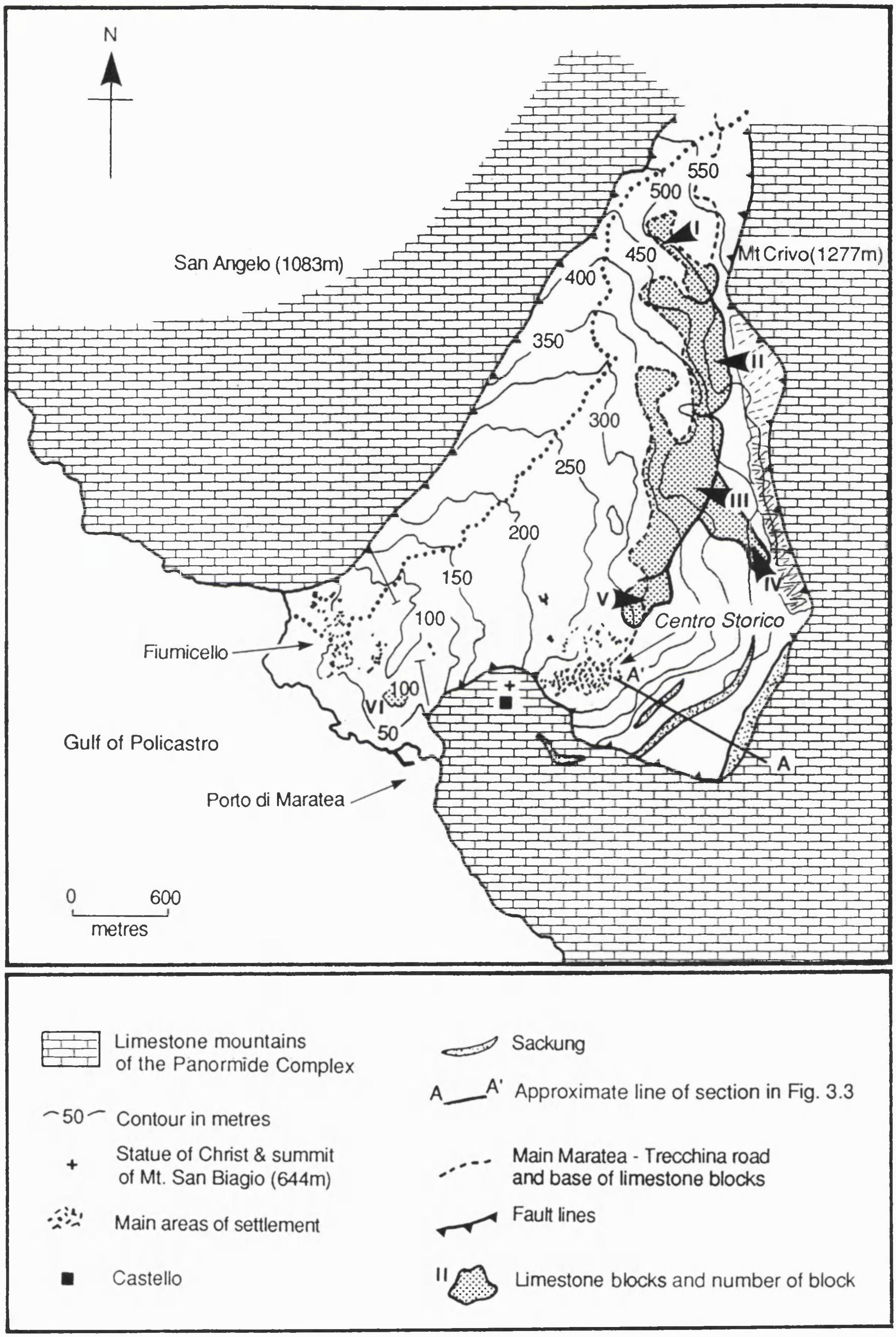


Fig. 3.4: Major structural features of the Maratea valley. For rest of key see Fig. 1.3

•Phase B: Deposition of large volumes of loose breccia on top of cemented breccia. This situation is well illustrated by the borehole study of Regione Basilicata (1978), Fig 3.2a - 1. Bands of loose and cemented breccia are observed in boreholes S1 - S4, S6 and S11. There are two interpretations of this phenomenon. Guerricchio *et al* (1987) argue that it is the result of active tectonic processes. Conversely, Vita-Finzi (1986) has cited an apparently similar case at Epirus in north-west Greece. Here large volumes of breccia have been deposited 'principally in response to increased weathering by frost and accelerated slope erosion', Vita-Finzi (1986, p.129). The situation at Maratea may, similarly, be the result of climatic change, although the hypothesis of Guerricchio *et al* cannot be discounted.

•Phase C: Phase of slipping. Depressions are filled with *terra rossa*.

•Phase D: Renewed historical slipping and rejuvenation of the sackung.

The evidence presented by the authors for these phases is not clear. Guerricchio *et al* (1987) recognise the presence of the fault plane scarp in the landscape and argue that the displacement of the limestone blocks must post-date, or be coincident with, this feature. Similarly, they note that the uppermost sackung tear (N1) trends into the fault plane scarp. From these general observations they infer that the opening of the sackung probably occurred shortly before, or at about the same time as, the movement of the limestone blocks. The authors Phase B and C is inferred from borehole evidence only; Phase C post-dating B as it is the depressions in the deposited breccia that are filled with *terra rossa*.

The timing of these phases is not well understood. Guerricchio *et al* (1987) have argued that their Phase A began at some point shortly after 30,000 years before present. They support their hypothesis by reference to a 3m - 4m raised beach along the coast at Maratea. Cotecchia *et al* (1969) dated 3m - 4m raised beaches along the Ionian coast (Gulf of Taranto) to 20,000 - 40,000 years BP. Guerricchio *et al* (1987) contend that the displacement of the carbonate blocks during Phase A, interrupted the line of the 3m - 4m beach so that it only appears on either side of the valley. The authors inference is that their Phase A, involving an opening of the sackung and collapse of the limestone blocks, must have occurred after the formation of the raised beach, that is after about 30,000 years BP. This line of argument is very dubious and must be treated with a great deal of caution. The major limestone blocks do not interrupt the line of the beach; only one small block, known locally as Capo la Timpa, can be identified in the vicinity of the coast. Indeed, the elevations of the bases of the other limestone blocks are well above 3m - 4m a.s.l. This can be seen very clearly on Fig. 3.4; in the southern portion of the valley the block base tends to follow the 350m contour, rising inland (northwards) to cross the 400m, 500m and 600m contours. In short, it is unlikely that raised beach deposits have been destroyed by the movement of limestone blocks. Similarly the raised beach on either side of the valley is formed on limestone. Limestone, however, does not outcrop at this elevation in the valley and thus any raised beach which may have been present in this area would have been formed in black clay. As black clay is more easily eroded than limestone the raised beach in the central portion of the valley could have been obscured or destroyed by other processes such as erosion by the sea or by changed climatic conditions which, for example, may have caused the Torrente Fiumicello to have a higher discharge. These alternatives must be treated as hypotheses and no data can be brought forward to either confirm or deny them. The important point to note is that it is unnecessary to call upon a tectonic process to explain the absence of the raised beach along the central portion of the coast.

It must also be regarded as an unsafe line of argument to transplant raised beach dates from the Ionian Sea (Cotecchia *et al*, 1969) to Maratea. Such a case requires the assumption to be made that the rate of neotectonic uplift affecting the Ionian Sea area is the same in the Gulf of Taranto. Such a link has not been proven and would appear highly unlikely, considering the geological complexity of the region and the variable rates of uplift that have been suggested (see Chapter Two, section 2.4 and

Cotecchia *et al*, 1969; Fairbridge, 1973; Brogan *et al*, 1975; Brückner, 1982, 1983).

Although no information is available to support this scheme of events, it would seem plausible to attribute at least an initial opening of the sackung to a phase of neotectonic activity, although the postulated age of "around 30,000 years BP" appears highly debatable). The sackung clearly trends into an area of normal faulting and its genesis is probably coincident with the fault plane scarp.

Renewed historical movements associated with the sackung (Guerricchio *et al's*, Phase D, 1987) are easier to date. The oldest building in the *centro storico* is a small chapel in the *Via Pendinata*, adjacent to the sackung, dated to the 11th century A.D. (Plate 3.3) From this time, until the present, the *centro storico* has experienced serious building damage, widely thought to be the consequence of a rejuvenation of the sackung (Guerricchio *et al*, 1987). For example, in the late 11th - early 12th centuries, the records of one of the main churches - the *Chiesa di San Vito* - detail repairs to the church thought to be the result of sackung movement. In 1500 the church records describe more damage and further repairs. The situation is repeated throughout the 15th century to the late 18th century, as more cracks appeared and further restoration was required, and persists to the present day. The *Chiesa di San Vito* now displays a distinct rotation of its altar relative to the main structure (Plate 3.4). A similar situation can be observed with the foremost church in Maratea - the *Chiesa di Santa Maria Maggiore* or *Chiesa Madre*, the 'Mother Church'. Here again a relative rotational movement of the altar stone is evident (Plate 3.5).

Historical evidence of this nature, while useful, nonetheless requires careful interpretation. The damage to the *Chiesa di San Vito*, for example, may have been the result of seismic activity or poor construction rather than a movement of the sackung. Fortunately, there is supporting evidence to reinforce the view that widespread movements are affecting the area of Maratea

Plate 3.3: Small chapel in the *Via Pendinata*, thought to be the oldest building in Maratea. Dated to the 11th Century.

Plate 3.4: Interior of the Chiesa di San Vito - the altar has rotated relative to the main structure. Photograph courtesy of Prof. V. Rizzo, CNR, Cosenza.

Plate 3.5: Interior of the Chiesa Santa Maria Maggiore - the altar is also thought to have rotated relative to the main structure. The church suffered severe damage during the 1982 earthquake. Photograph courtesy of Prof. V. Rizzo, CNR, Cosenza.

adjacent to the sackung. Guerricchio *et al* (1987), argue that four lines of evidence are relevant:

(i) The population of the *centro storico* argue for a subsidence of about 80cm in the last 60 years. Their assertion is based on the time of sunrise, during the summer months, above the mountains surrounding the *centro storico*. The sun rises in the east over Monte San Biagio and, as it clears the mountain summit, 'spotlights' the *centro storico*. The local people argue that the time the sun strikes the *centro storico* has become progressively later, as either Maratea moves downslope or the sackung ridge moves outwards. The subjectivity of such data is clear, but nonetheless provides useful supporting evidence.

(ii) Italian railway authorities report that every three years, on average, there is a need to correct the alignment of the railway below the *centro storico*, uphill by 2cm.

(iii) A hut below the *centro storico* is reported to have moved downhill 1m in 60 years (Guerricchio *et al* 1987, cf with (i) above). No plan was given by Guerricchio *et al* (1987) and the location of this hut remains uncertain despite a search by the present author.

(iv) The back wall of a building near the Porto di Maratea has moved by 1cm per year for the last 5 years. Again no location plan was given for this building by Guerricchio *et al* (1987).

While the available evidence suggests that widespread movements are affecting the area of the *centro storico* and the slopes below, it does not point to the processes involved nor to a proven connection with the sackung. Movements could be the result of either:

(i) an outward movement of the sackung ridge (although this would not explain the movements affecting the railway line) or;

(ii) shallower sliding movements affecting the *centro storico* and lower slopes, possibly localised; or

(iii) a combination of the two.

To investigate the cause of the observed movements Guerricchio *et al* (1986a & b), established a monitoring system in 1983 for the *centro storico*. Instrumental surveys included a surveyed monitoring network, extensometer measurements of the sackung and seismic vibration profiles.

- **Surveyed Monitoring Network**

Guerricchio *et al* (1986b), established six fixed theodolite points within the valley. Two points were of relevance to the sackung; point A was located on the crest of tear N1 (see Fig. 3.3) and point B on the crest of tear N3 (see Fig 3.3). The other four points (D, E, F and G) were located within the valley; points H and M are not given locations on their survey plan (Guerricchio *et al*, 1986b, p.36; see Fig 3.5). From point A readings were taken to fixed points on the ground between N2 and N3 (see Fig. 3.3) and from B to fixed points within the *centro storico*. The extent of the survey can be clearly seen in Fig. 3.5 and the results of three years readings are displayed in Table 3.4 and Figs. 3.5 and 3.6). Measurements A^1, A^8 and B^{10} - B^{15} all fall outside the range which can be attributed to instrument error (instruments used were an Aga Meter 12 geodometer pointing at a treble prism, mounted on an Autoriduttore Salmoiraghi theodolite; the Aga Meter has an error of ± 8mm at 100m and ±16mm at 1000m). Points A^1 and A^8 are nonetheless still close to these limits, whereas B^{10} - B^{15} show considerable movement. Each recorded measurement was the mean of six actual measurements, taken each day at 11:00 hours over a period of one week (Rizzo, *pers. comm.*) Measurements were recorded in the July of 1983, 1984 and 1985. There is a clear error in the authors work, in that their map of the surveyed network (Fig. 3.5) and table of results (Table 3.4) disagree; the map shows a measurement from Station A to Point 9, whereas the

SURVEY NETWORK OF GUERRICCHIO *et al* 1986b

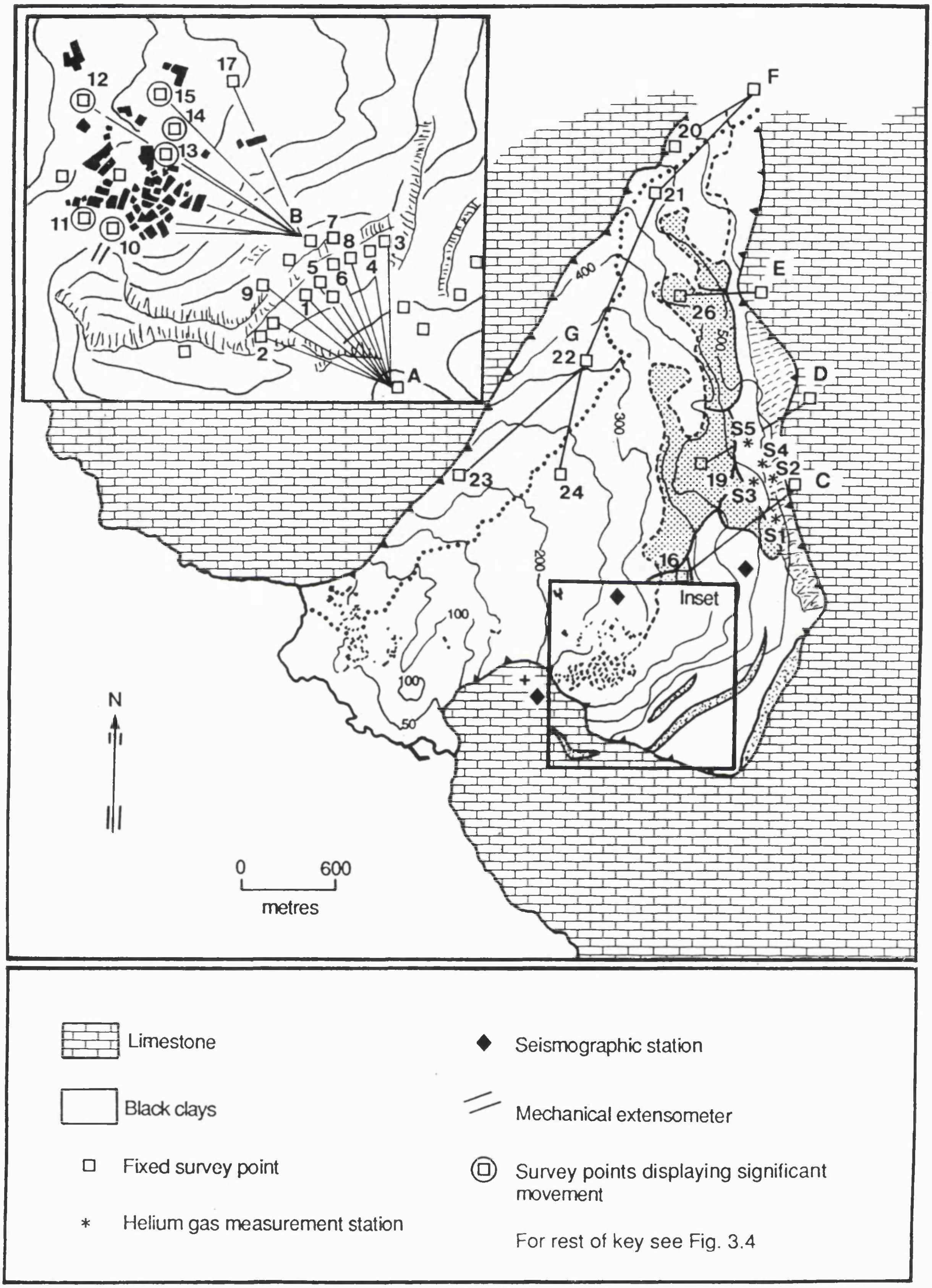


Fig. 3.5: Survey network of Guerricchio *et al* (1986b)

Station	Measurement to Point	Reference	Azimuth	Zenith	1983 Median (m)	1983 Error (mm)	1983 Max/Min (mm)	1984 Median (m)	1984 Error (mm)	1984 Max/Min (mm)	Difference 84 - 83	1985 Median (m)	1985 Error (mm)	1985 Max/Min (mm)	Difference 85 - 83	Instrument Precision
A -	1	Christ	19,25	3,3	583,607	3	8	583,594	2	6	−13	–	–	–	–	11
	3	»	24,45	7,3	607,100	6	18	607,115	4	10	+15	607,116	2	6	+16	11
»	4	»	26,95	7,3	605,615	3	8	·605,610	2	6	− 5	605,614	2	6	− 1	11
»	5	»	35,11	10,3	586,511	4	10	586,504	3	8	− 7	586,510	3	6	− 1	11
»	6	»	35,49	10,1	590,416	2	5	590,416	2	5	0	590,417	3	8	+ 1	11
»	7	»	35,40	10,0	590,652	2	4	590,648	4	8	− 4	590,650	2	6	− 2	11
»	8	»	35,08	11,5	591,273	2	16	591,288	7	16	+15	591,292	9	24	+19	11
A -	2	Christ	17,01	5,5	621,306	3	7	621,314	3	8	+ 8	621,308	3	8	+ 2	11
	30	»	7,89	7,6	658,121	3	6	–	–	–	–	658,131	3	8	+10	12
B -	9	Christ	44,89	−27,5	–	–	–	787,830	3	7	–	787,832	4	11	+ 2	13
»	10		64,82	−36,6	892,020	5	10	892,047	3	6	+27	892,074	7	20	+54	14
»	11	»	69,26	−35,2	933,712	17	44	933,751	7	14	+39	933,789	2	5	+77	14
»	12	»	87,29	−25,2	1.298,775	21	52	1.298,781	21	48	+ 6	1.298,824	29	48	+49	18
»	13	»	79,74	−41,5	732,562	9	26	732,570	4	12	+ 8	732,606	3	7	+44	12
»	14	»	83,49	−39,1	761,791	4	9	761,815	5	6	+24	761,844	4	12	+54	13
»	15	»	97,09	−34,2	854,502	16	48	854,515	3	8	+13	854,546	2	4	+44	14
B -	16	Christ	110,25	−17,9	1.106,390	6	19	1.106,934	16	40	− 5	1.106,939	4	9	0	16
	17	»	251,76	12,3	1.030,893	6	17	1.030,899	5	10	+ 6	1.030,902	3	8	+ 9	15
D -	19	Christ	279,16	27,7	392,932	2	6	392,946	3	6	+14	392,938	3	8	+ 6	9
E -	26	»	255,17	22,7	377,136	2	4	377,135	2	6	− 1	377,134	3	9	− 2	9
F -	20	Christ	25,74	−15,4	300,754	2	5	300,763	3	6	+ 9	300,772	2	8	+18	8
»	21	»	5,31	−14,8	643,015	3	9	643,014	2	5	− 1	643,016	2	6	+ 1	10
»	22	»	17,83	−14,4	1.055,154	11	32	1.056,125	5	16	−29	1.056,143	6	16	−11	16
G -	23	Christ	24,75	−16,2	831,635	3	8	831,624	3	8	−11	831,620	4	10	−15	13
»	24	»	387,40	−14,1	659,237	12	38	659,263	20	70	+26	659,255	31	86	+18	12
H	18	Christ	231,10	24,9	147,538	2	3	147,540	2	2	+ 2	147,542	3	4	+ 4	4
	25	»	316,66	0,4	143,309	1	2	143,312	1	1	+ 4	143,315	3	4	+ 6	4
A -	30		7,89	7,6	658,121	3	3	–	–	–	–	658,131	3	4	+10	11
	31		10,25	7,7	744,559	3	4	744,564	17	21	+ 5	744,558	2	3	− 1	12
»	32		10,41	7,8	752,831	4	6	–	–	–	–	752,835	3	5	+ 4	12
»	33		15,37	6,3	752,749	2	3	752,761	6	9	+12	752,767	4	5	+18	12
»	34		18,56	5,1	734,485	2	3	734,484	4	5	− 1	734,491	1	2	+ 7	12

Table 3.4: Survey measurements of Guerricchio *et al* (1986b)

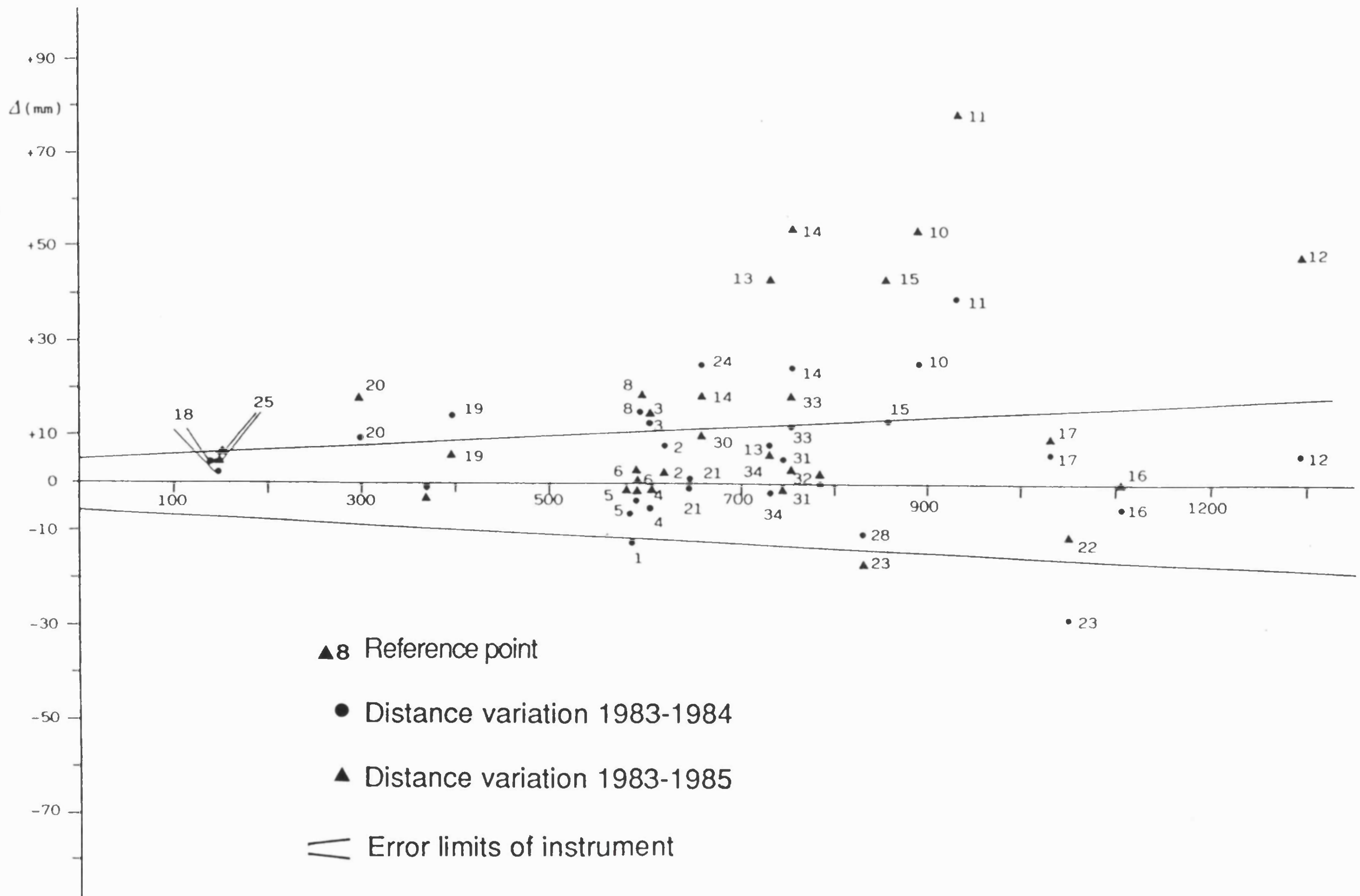


Fig. 3.6: Survey measurements of Guerricchio *et al* (1986b)

table gives a reading from Station B to Point 9. Similarly, the authors have not related A to B and do not account for this omission.

The authors argue from these results that the sackung is stable relative to the mountain but that the *centro storico* is moving downslope relative to the sackung. The added implication of this statement is that the authors regard the sackung as a particular feature. This interpretation can be related to Fig. 3.3; in this case surveyed measurements from N1 (Station A) to the ground between N2 and N3 are similar, suggesting that either there is no movement of these points or that they are both moving downslope at the same rate so that their actual separation remains the same. In the second case surveyed measurements taken from Station B on the hillslope (crest of N3) to the *centro storico* are increasing, suggesting that the *centro storico* is moving downslope relative to the sackung.

As with so much work in Maratea, it is regrettable that the field techniques of the authors were not more fully documented. Hopefully, their fixed points in the *centro storico* were not on buildings liable to settlement, or subsidence caused by poor foundations and/or defective construction. If they were, then the readings obtained would not necessarily reflect a movement of the *centro storico* downslope. Unfortunately, given the steep, heavily vegetated nature of the terrain and the density of housing in the *centro storico*, it is likely, in order to obtain a line of sight, that the authors would have been required to site at least some of their targets on buildings. If this were the case then their results must be treated with caution. In addition, greater accuracy would have been obtained by the authors if their theodolite points had been established outside the unstable area. If both their theodolite and target points were moving (which could be the case especially with the sackung measurements) then the results obtained will be meaningless. In short, the work of Guerricchio *et al* (1986b) has succeeded in establishing that differential movements are taking place in the sackung area but does not confirm absolute movements.

- **Extensometer Measurements**

Extensometer measurements carried out by Guerricchio *et al* (1986b) were designed to establish the existence of small movements of the sackung, beneath the limits of instrumental error associated with standard surveying equipment. Two instruments were used:

(i) A mechanical extensometer stretched between the crest and trough of tear N3 (see Fig. 3.3). This showed a gradual, but very small, widening of the sackung between July 1983 and March 1985 (Fig. 3.7a), presumably due to a movement on the downhill (crest) side of tear N3; at its greatest extent this movement was 1mm. Between March 1985 and August 1985 the sackung appeared to close again before beginning to widen between August 1985 and October 1985 when the band broke. A second extensometer band also stretched across the gap of N_3 showed a similar widening of the sackung until measurements were stopped in February 1985 when the band broke (see Fig 3.7b).

(ii) Two other extensometers were placed on the uphill side of the *centro storico*. The instrument used was a Shinko Electric $80B_z$-L with an invar band of 0.6mm and an estimated precision of ± 0.1mm. The authors argue that detected movements of 2.4mm - 12mm per year (see Fig. 3.8a & b) are in accordance with the survey figures noted above. It should be noted however that these annual figures have been extrapolated from the measured data; measurements, in fact, only took place over a two month period from 11 September - 20 November 1985.

The other problem with the second set of two readings (ii above) is that what is being measured is not clear. For example, Fig. 3.8a is a graph of extensometer measurements taken near the *Chiesa di San Vito*. Field inspection indicates that the extensometer may have been placed between two small (approximately 15m square) limestone boulders rather than across a sackung tear. If this is the case then all that is being measured is the relative movements between these two boulders.

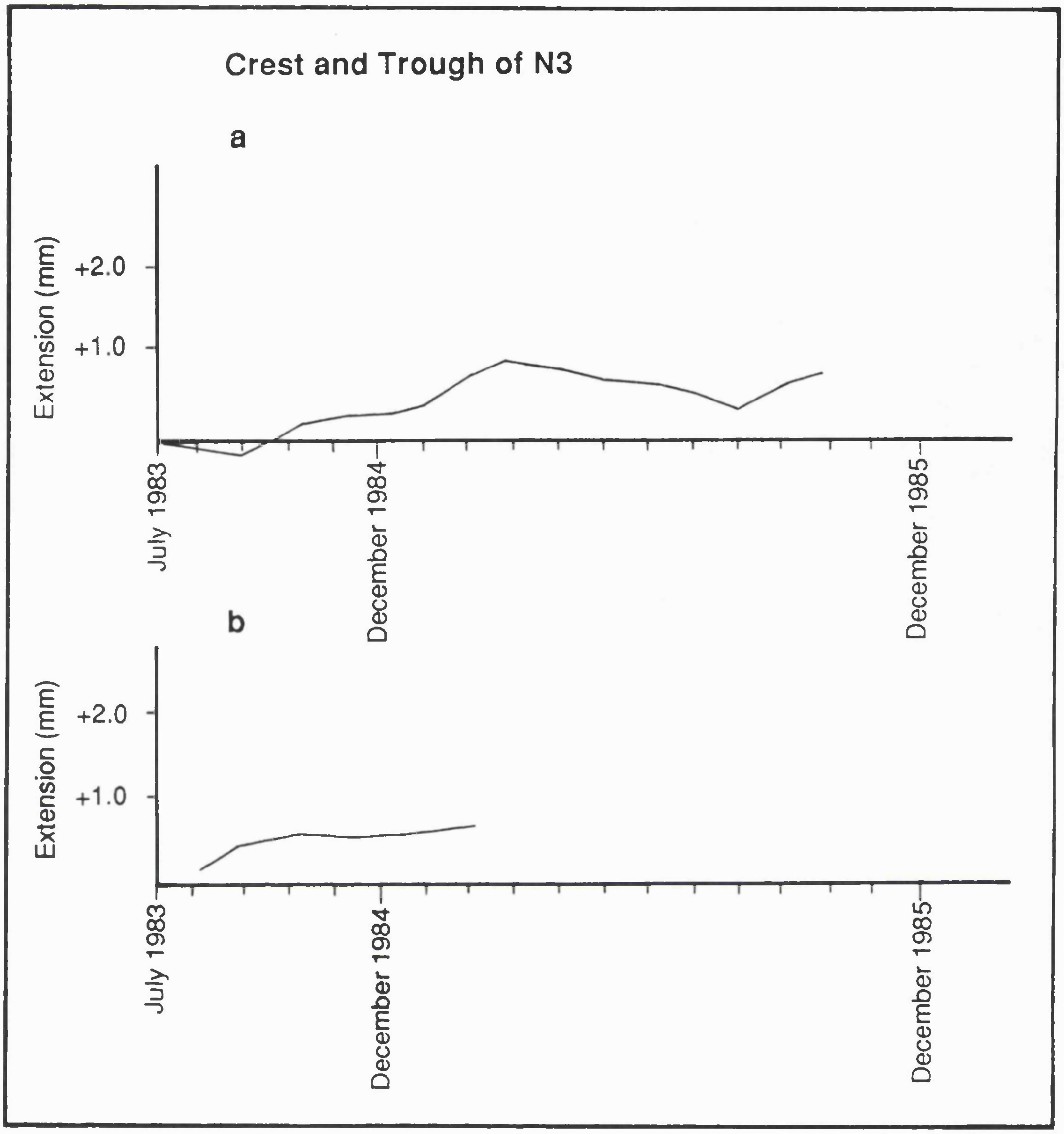


Fig. 3.7: Mechanical extensometer measurements. From Guerricchio *et al* (1986b).

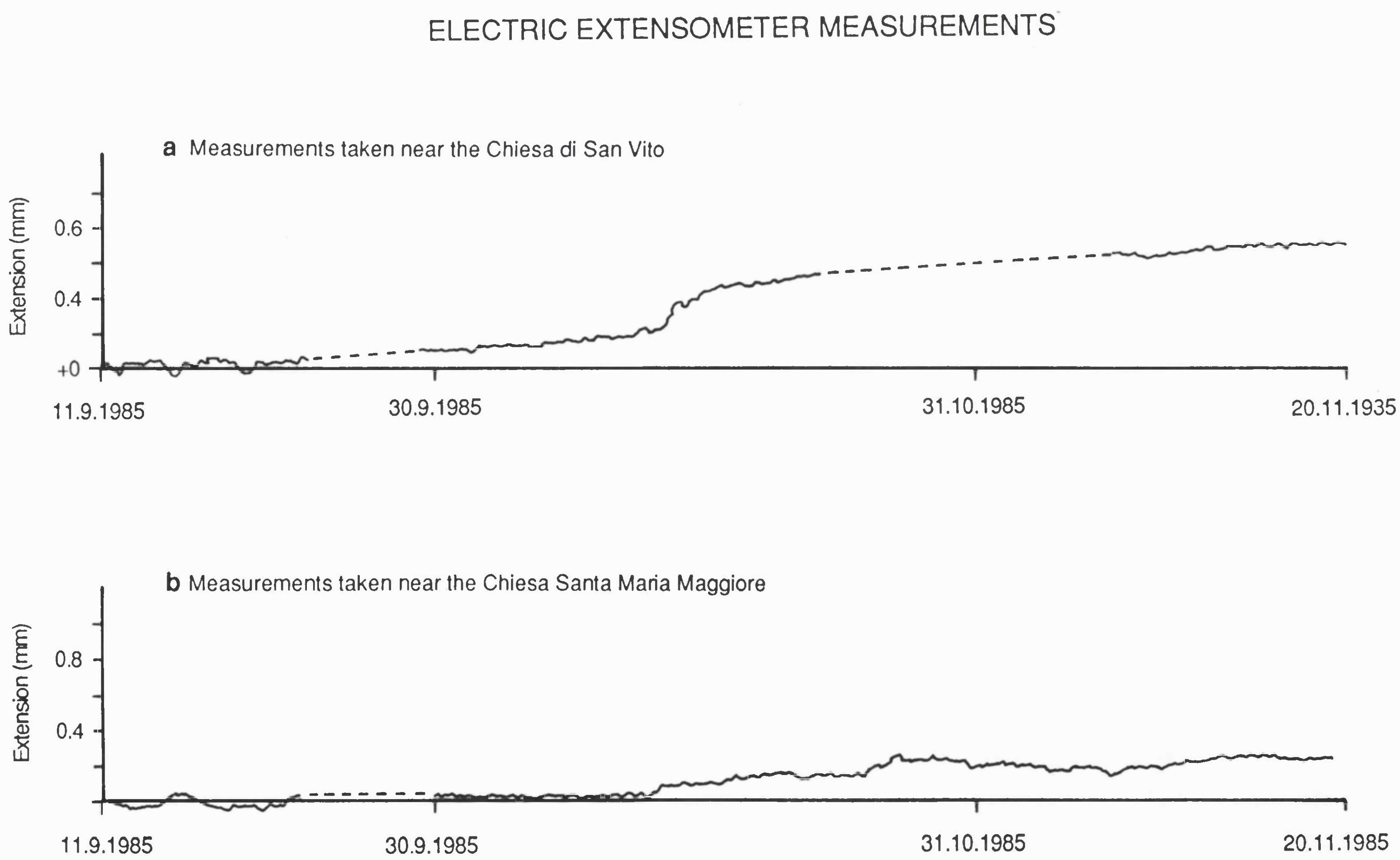


Fig. 3.8: Electric extensometer measurements of Guerricchio *et al* (1986b).

Similarly, the second extensometer (Fig. 3.8b) was placed between the side of the *Chiesa Santa Maria Maggiore* and a small limestone block into which part of the church had been built. The same question arises here as in the survey network, namely is the actual movement downslope being measured or merely relative settlement due to poor foundations and/or defective construction?

- **Seismic vibration Profiles**

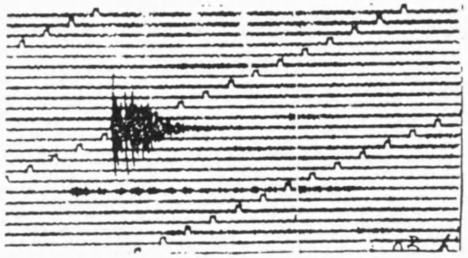
The surveyed monitoring network and extensometer study led Guerricchio *et al* (1986b) to argue that the sackung is relatively stable and that the observed movements in the *centro storico* are the result of slope movements affecting the old part of the town. The authors argue that their evidence for this is based upon the survey measurements indicating that readings taken from the summit of Monte San Biagio (their reference point A) into the sackung show little variation whereas measurements from reference point B into the old town suggest substantial movement. Guerricchio *et al*, reinforce this assertion by pointing to the extensometer survey; here they argue that extensometer measurements in the sackung reveal very little movement (approximately 1mm over 18 months) but that extensometer readings in the vicinity of the old town are of the order 2.4mm - 12mm per year. The authors put forward the hypothesis that the data suggest a creep mechanism, alternated by occasional phases of sliding. Similar movements have been identified by one of the authors in complex block-type landslides in Bulgaria (Rizzo and Tzvetkov, 1984).

To test the creep/slide hypothesis, Guerricchio *et al* (1986b) installed seismic vibration monitors in the *centro storico*, near the *Chiesa Santa Maria Maggiore*. Two instruments were employed - a Sprengether MEQ with an M800 geophone, Mk.L4c and next to this, for comparison, a Geotech Rv320 Portarecorder also with a Mk.L4c geophone. The observations in Maratea were compared with those obtained from Mormanno, a town 15km to the south. The authors argue that the Maratea readings (Fig. 3.9) have an atypical form if they are due to seismic activity, for they occur in distinct

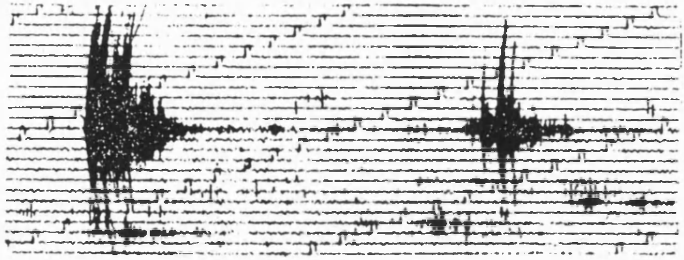
SEISMIC VIBRATION PROFILES

(a)

(b)



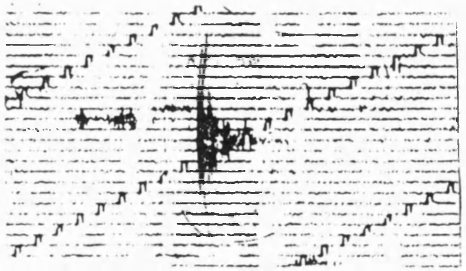
01.11.1983 / 00.36.54 hours



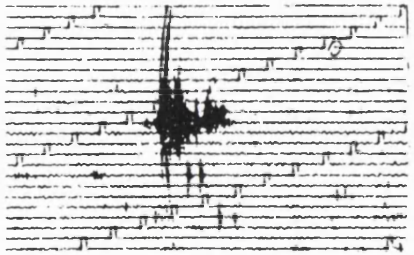
21.02.1984 / 06.01.06 hours

Fig. 3.9: Seismic vibration profiles of Guerricchio *et al* (1986b).

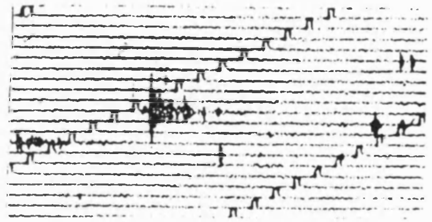
(c)



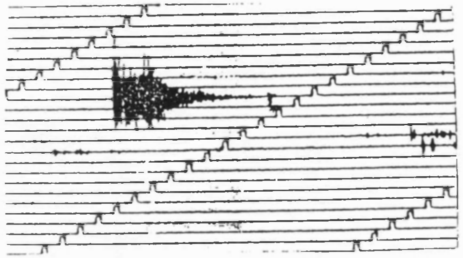
30.03.1984 / 10.52.48 hours



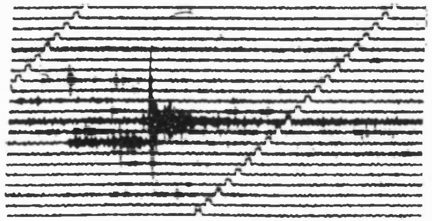
21.02.1984 / 16.10.04 hours



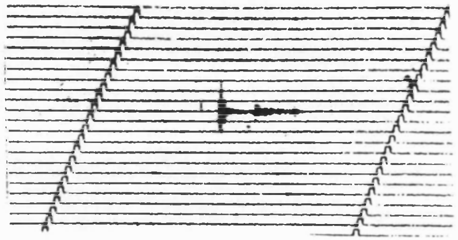
03.04.1984 / 22.14.50 hours



14.01.1984 / 6.26.21 hours



29.06.1983 / 02.33.32 hours



27.12.1983 / 06.38.23 hours

'bunches'. As such they attribute the vibrations to small scale failures of the landslide body. Within these seismic vibration profiles (Fig. 3.9) they have distinguished small scale creep ruptures (Fig. 3.9a & c) and larger slide movements (Fig. 3.9b). Both types can be distinguished by their wave forms, the slide ruptures being short- term, high amplitude events and the creep movements recognisable as low amplitude, long term phenomena.

Guerricchio *et al* (1986b) contend that the creep/slide hypothesis is confirmed by these measurements and by plastic extensometers placed over building cracks in the *centro storico* (Fig. 3.10). These extensometer investigations, full results of which are yet to be published, are claimed to show both horizontal and vertical movement of buildings downslope. The same criticism levelled at the other work of this group of authors must be repeated here; namely that the extensometer survey could be measuring building degradation due to poor construction or inadequate foundations rather than any actual slope movements.

The work of Guerricchio *et al* (1986a & b), sought to establish the nature and scale of movements affecting the *centro storico* area of Maratea, suggested by historical records, local folklore and remedial work required to the railway. This section has been highly critical of that work, largely because the field techniques of the author's have not been well thought out and carefully designed. A number of points emerge:

(i) The monitoring survey did not take account of the fact that movements may affect the whole of Monte San Biagio. Thus, the authors reference points may have been moving relative to each other. In short, their theodolite stations should have been located outside the envisaged unstable area.

(ii) Buildings should not have been used as survey points.

(iii) Electric extensometers were not well sited.

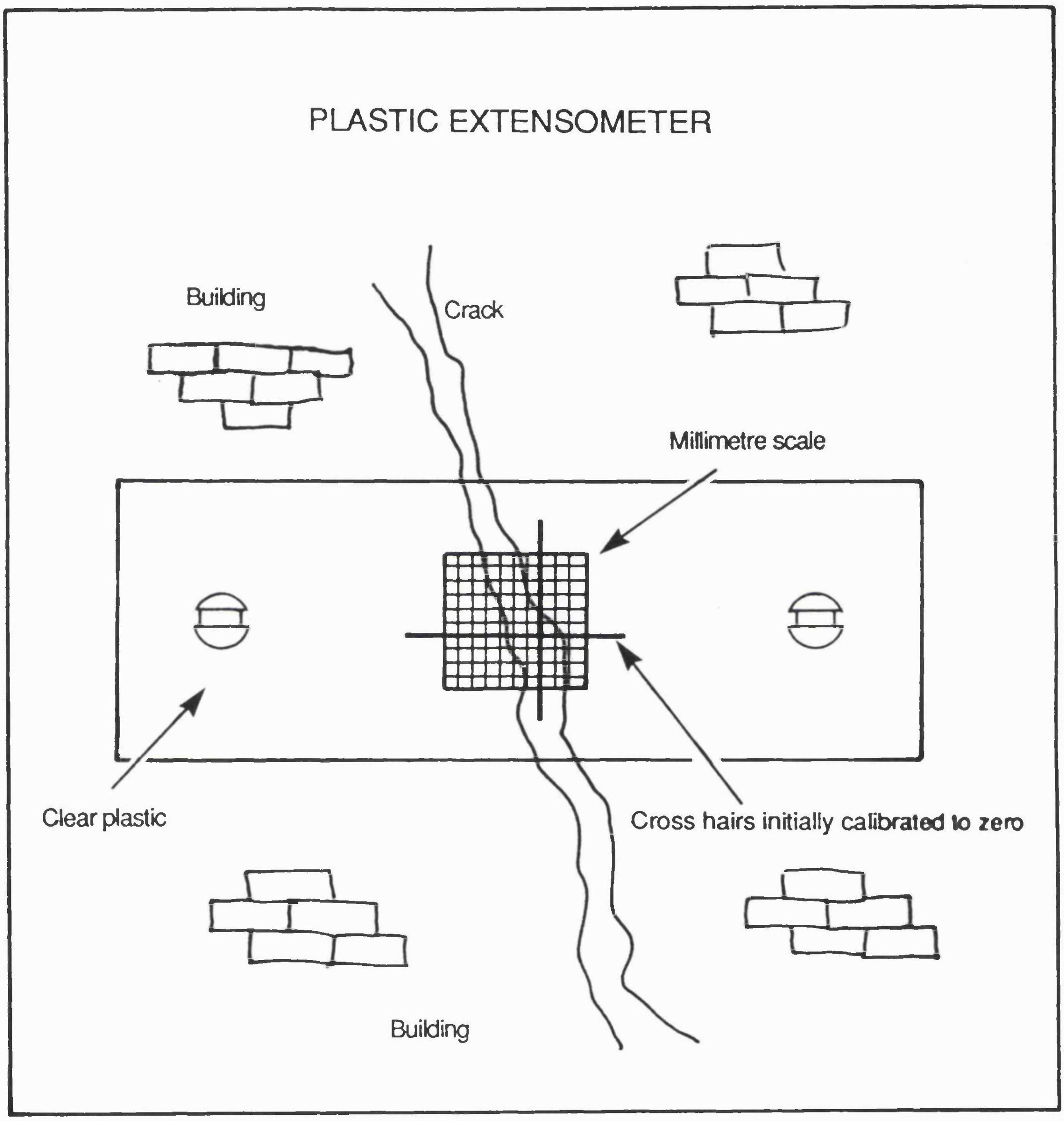


Fig. 3.10: Plastic extensometer.

(iv) The authors compare seismic vibration profiles for Maratea with Mormanno, but while the Maratea data is presented, the Mormanno data is not.

Points (i), (ii) and (iii) could, almost certainly, have been avoided had the authors carried out a thorough preliminary site survey involving air photograph interpretation and accurate geomorphological mapping. Not least, it may have identified sackung tears as opposed to fallen boulders and suggested more appropriate sites for the placing of monitoring instruments.

3.3.2 Faulting

One of the most impressive structural features in the Maratea valley is the fault plane scarp which extends inland from the sackung. The fault plane scarp is a smooth, pale grey, exposed shear plane, about 2.08km in length with a maximum height of 30m. It is distinguished as a fault plane scarp by:

(i) A smooth polished surface often with vertical grooves, known as a slickenside surface. Slickenside surfaces have been described by Whitten and Brooks (1972, p.419) 'when one surface of rock moves over another surface in close contact under pressure, the two surfaces develop a kind of polish, with linear grooves and ridges parallel to the direction of movement. This is termed slickensiding and is commonly seen on fault surfaces'.

(ii) Helium gas measurements have been taken along the fault plane scarp, up to a maximum distance of 50m from the scarp face, by Guerricchio *et al* (1986b). Surface concentrations of 525 - 718ppm are among the highest ever recorded in Italy and indicate the presence of a very deep fault.

The fault plane scarp is a normal dip slip fault with some strike slip component (see Fig. 3.11). The slickenside striations are evidence of the strike slip component (Plate 3.6). In a true dip slip fault the striations would be oriented vertically down the

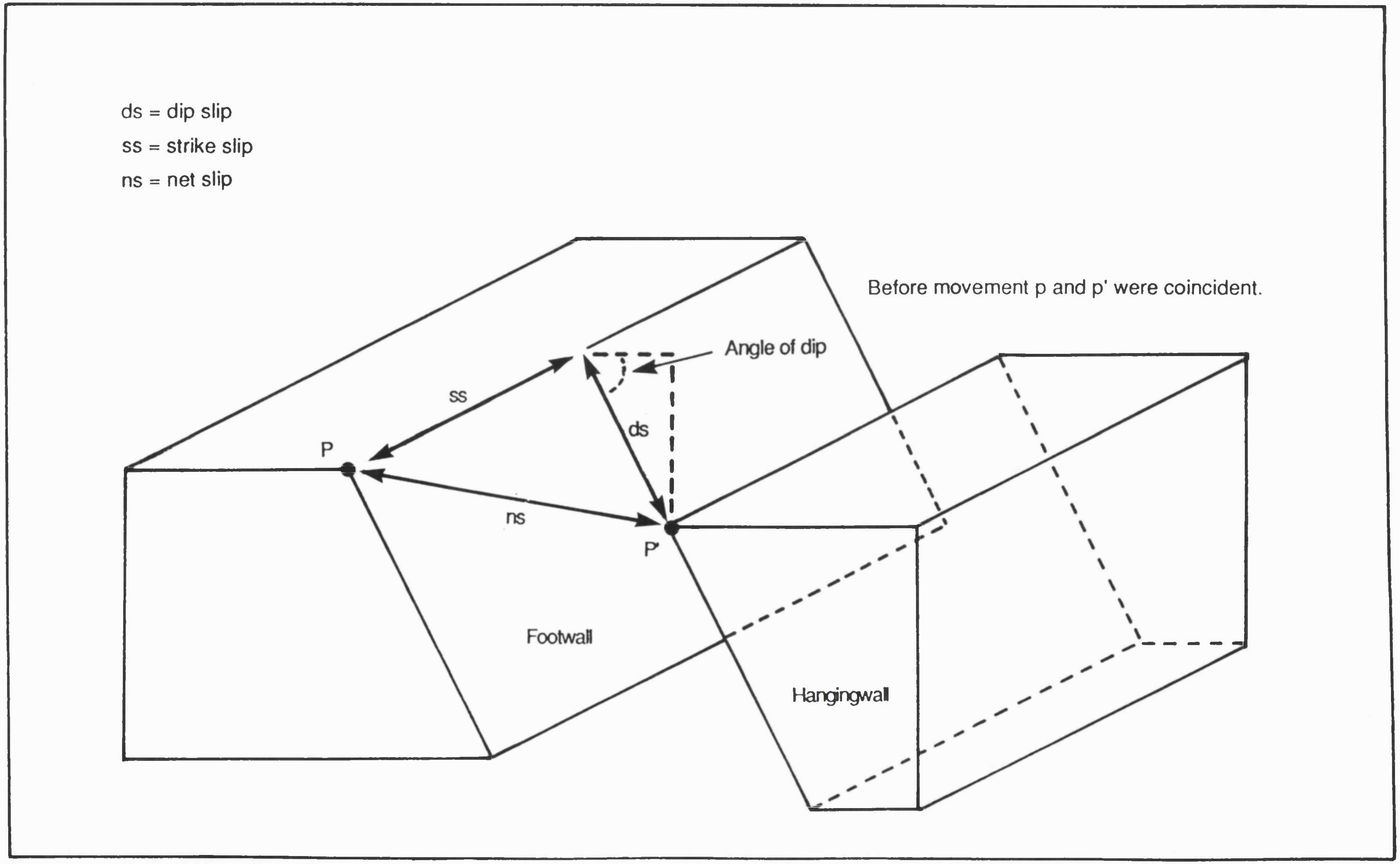


Fig. 3.11: Fault terminology. After Hobbs *et al* (1976).

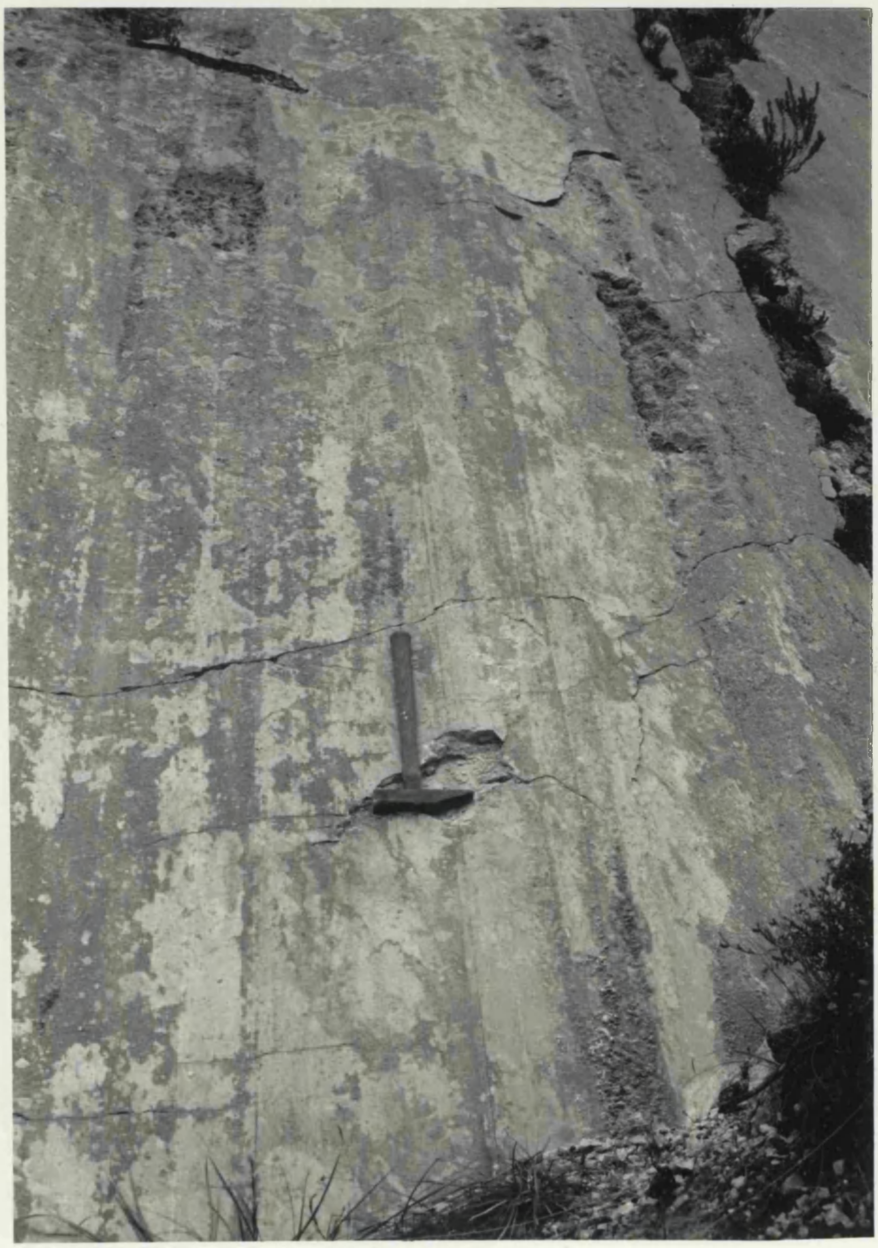


Plate 3.6: Section of the fault plane scarp showing vertical slickenside striations.

face of the fault scarp but horizontally in the case of a strike slip fault. In some areas of the fault plane scarp the striations are angled to the fault (see section 4.2.2 for a full description); hence it is described as a dip slip fault with a strike slip component.

Guerricchio and Melidoro (1979) argue that two faults can be observed within the Maratea valley. The last fault is marked by the present fault plane scarp and the earlier fault, the authors contend, by another fault scarp 150m - 200m above the fault plane scarp. Guerricchio and Melidoro (1979) present no data to support their assertion which is based on the general appearance of the hillslope when viewed from the valley. The steep terrain above the fault plane scarp is extremely difficult and dangerous but was searched by the present author for evidence of a second scarp. None was found, although scattered loose fragments of polished material similar in appearance to the fault plane scarp were observed. However, as none of the polished faces were found in situ or concentrated in a single belt, but scattered randomly over the hillslope, they could not be described as evidence for the existence of a second scarp.

In addition to this search, slope profiles were surveyed by the present author in order to investigate the morphology of the slope above the fault plane scarp; because of the nature of the ground conditions in this area only two profiles were possible (see Figs. 3.12 and 3.13; the reader is asked to refer to the fold-out map in the back pocket of this thesis for the location of the profiles, this map will be described in detail in the following chapter). A marked similarity between both profiles is a distinct break of slope about 60m above the present fault plane scarp (marked 'A' on both Figs 3.12 and 3.13). This marked break of slope could only occur for two reasons; the first possible reason is that the fault opened in a single movement (Fig. 3.13). After opening the hillslope began to weather back, but a band of harder and more resistant material in the area marked 'A' has resulted in the break of slope. No evidence could be found on the hillslope to support this view; the material forming the break of slope was the same as that of the hillslope with no

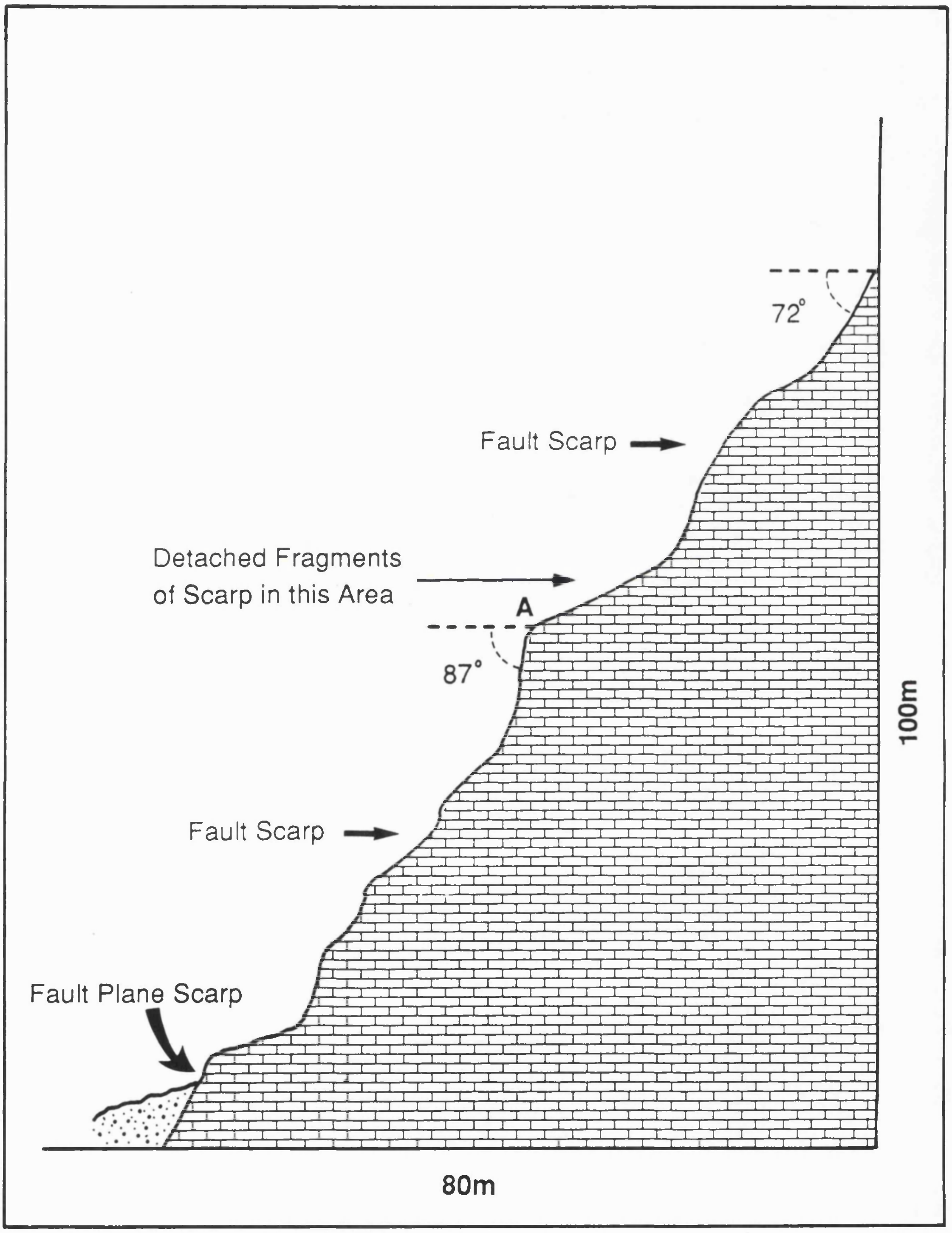


Fig. 3.12: Surveyed fault profile between pins 75 - 74. For location see fold-out map in back pocket.

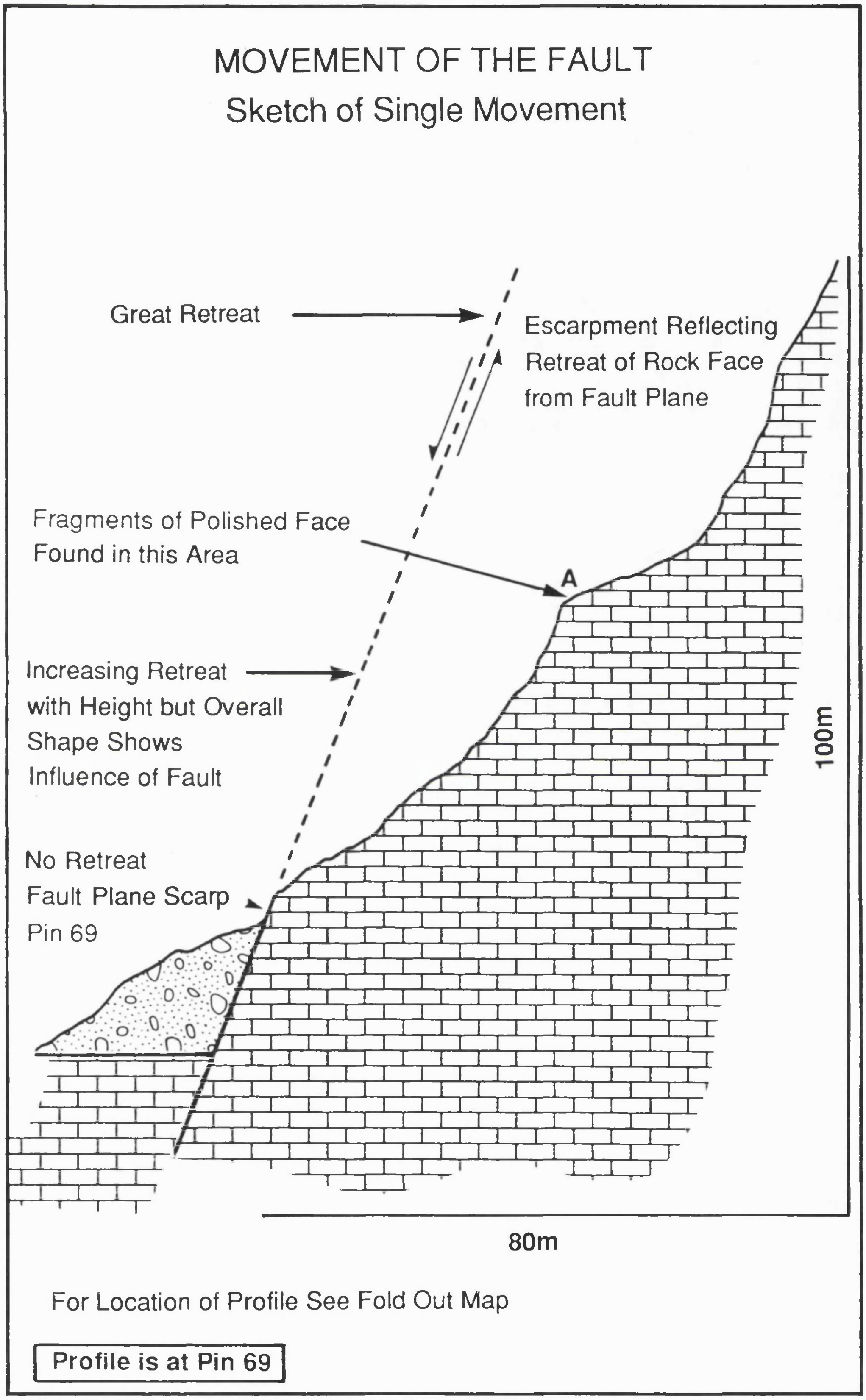


Fig. 3.13: Sketch of how the Maratea fault may have opened in a single movement. This model is difficult to accept because of the step marked 'A' above; this very marked break suggests at least two possible faulting episodes.

evidence of more compaction or resistance to erosion. The second explanation could be that the fault has moved twice; the first movement affecting the upper part of the hillslope so that it has weathered back further than the bottom (see Fig. 3.14). It is in the area of this break of slope on both profiles, that loose fragments of polished material were found scattered randomly over the slope. These could be interpreted in the case of a single fault, as being remnants of the fault deposited during scarp retreat. In short, a search of the hillslope and slope profiles undertaken by the present author, do not substantiate the assertion of Guerricchio and Melidoro (1979) that a separate phase of faulting preceded the present fault plane scarp. A single fault, affected by two phases of movement, is offered as an alternative hypothesis (Fig. 3.14).

In contrast to the sackung, which has been the subject of a number of studies (see section 3.3.1), little work has been carried out on the character and timing of movements along the fault plane scarp. In an attempt to answer these questions, a detailed survey of the fault plane scarp was carried out. From this survey which is described in detail in the following chapter (see section 4.2.2.) a number of general points emerge:

(i) Although the fault plane scarp appears, from a distance, to maintain an even height (but not elevation), in reality it is very broken-up . In many areas gullying has completely destroyed the scarp and in yet other areas hanging gullies are evident. Some sections of the fault plane scarp have been deeply weathered by water percolating in from behind the scarp face leaving the scarp face standing proud of the hillside with no material behind it.

(ii) The fault plane scarp tends to 'fade' away at the inland extremity of the valley. This point may mark the 'hinge' around which the fault has pivoted (see Fig. 3.15).

(iii) At the coastal end the fault plane scarp trends into the sackung. The relationship between the sackung and the fault plane scarp was recognised by Guerricchio *et al*,

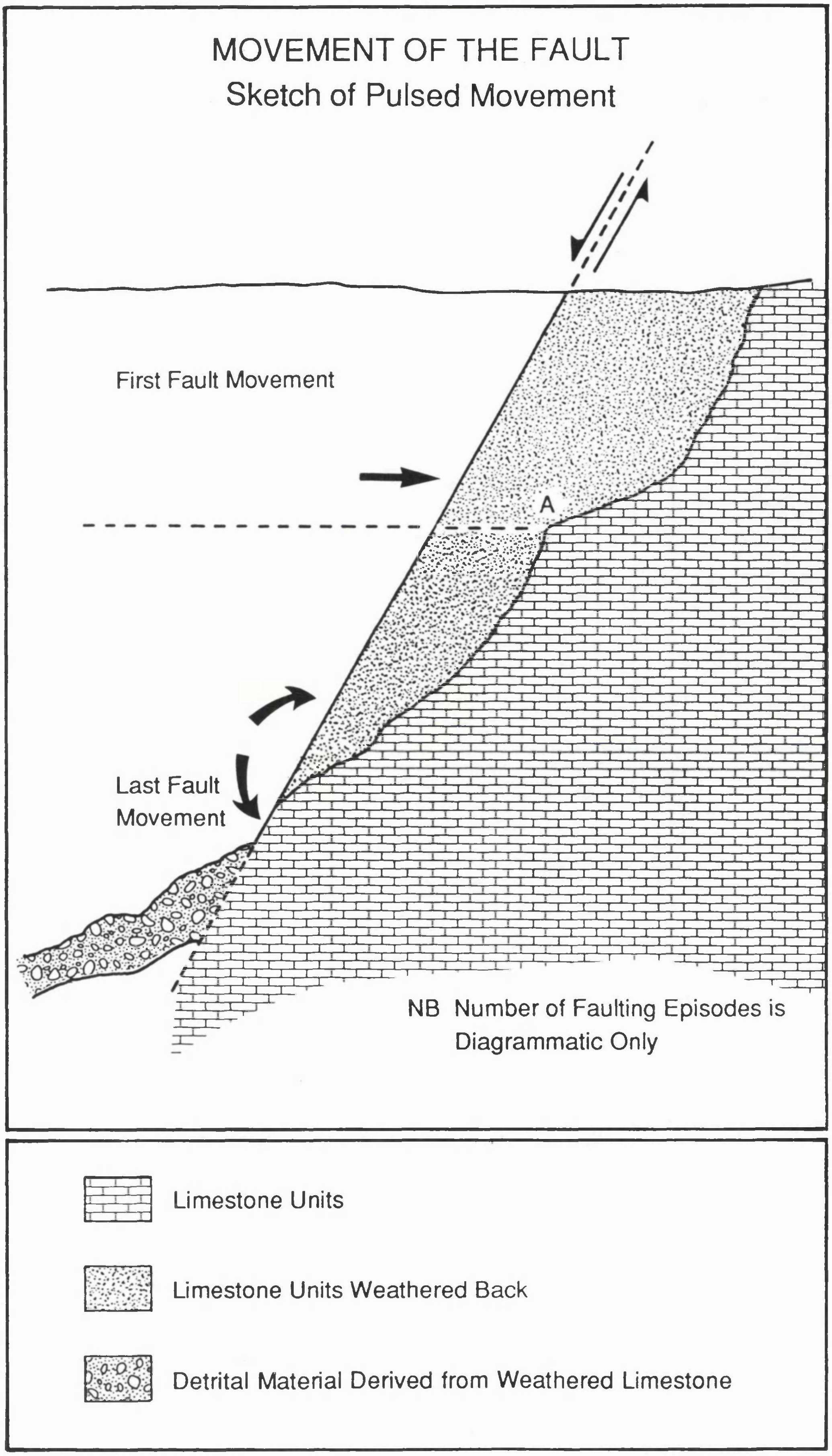
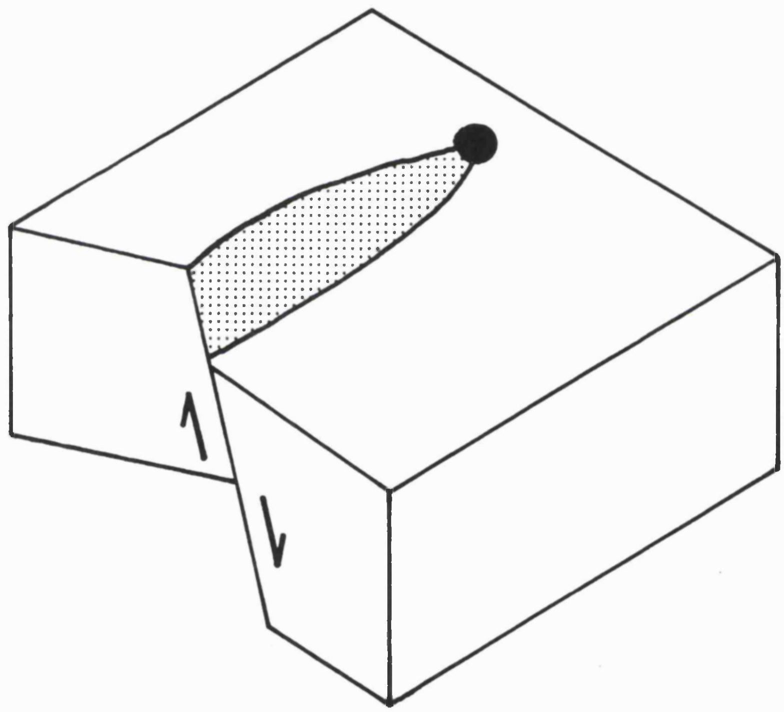


Fig. 3.14 Sketch of how the Maratea fault may have opened in two or more movements. This diagram more closely fits the hillslope profile and explains the step 'A'.

DIP SLIP HINGE FAULT



after Hobbs *et al* (1976)

Fig. 3.15

(1986a) and confirmed by the present author during the detailed survey of the scarp. Approaching the sackung when walking beside the scarp face it became increasingly difficult to discern a smooth slickenside fault surface. The end of the fault plane scarp was marked when the last trace of a smooth surface disappeared. The author was, however, still able to walk beside a clear break of slope (although this could not be described as a smooth fault plane scarp), which increased in height southwards and eventually became the major tear or break of the sackung (N1 on Fig. 3.3).

(iv) Slickenside ridges are apparent over much of the fault plane scarp. These ridges show the direction and movement of the fault.

The age of the fault plane scarp was unknown in 1984 at the commencement of this study. In section 3.3.1 it was noted that the sackung could date from neotectonic movements that occurred at some point after 30,000 years BP, although this section was very critical of the assumptions which Guerricchio *et al* (1987) made in arriving at this figure. As the fault plane scarp trends into the sackung it could be concluded that it too dates from about the same time.

There is clear evidence for more recent movements associated with the fault plane scarp. At its base there is a band of very pale grey colouration, termed here the 'white line', indicating minimal weathering. Along many parts of the fault plane scarp two, and sometimes three, distinct colour bands can be observed suggesting variable periods of exposure to weathering processes. The date of these colour bands was unknown at the commencement of this study. The 'white line' phenomena will be examined in greater detail in Chapter Four. The important point to note is that prior to this present study, the fault plane scarp was presumed to be a Pleistocene relic; there was no knowledge of its actual age nor of any movements associated with it (Lazzari, *pers. comm.*).

3.3.3 Limestone Blocks

As noted in section 1.5.2, air photograph interpretation and geomorphological mapping of the Maratea valley by the author, delimited the six major limestone blocks. Although the presence of these blocks had been recognised before (Guerricchio *et al*, 1986a) the work of the present author was the first to map them accurately. Chapters Six and Seven (sections 6.2.2 and 7.1), will expand on the techniques used to identify the blocks and discuss the characteristics and significance of them in greater detail.

Five of the blocks are immediately below the zone of talus deposition adjacent to the fault plane scarp; in all these cases a common feature is a marked concave break of slope at the base of the talus. Talus angles immediately above the break of slope are in the range 23° - 25°, reaching a maximum angle of around 35° in the area adjacent to the fault plane scarp. Westward of the concavity there is either level ground (zero slope angle) in the case of blocks IV, V and VI, or a reverse slope angle of 2° - 3° in the case of blocks I, II and III. The reverse slope angles indicate a back tilt of the blocks and signify possible downslope rotation.

There is a considerable variation in the sizes of the blocks. Fig. 3.4, shows the position of each block which has been given a number - I - VI. Number I is 700m wide with a breadth of 200m and a depth from scarp crest to base of 120m. Number II is 900m X 200m X 100m; Number III, 900m X 500m X 90m; Number IV, 300m X 100m (depth uncertain due to large amounts of talus deposited around its flanks); Number V, 450m X 500m X 80m; Number VI, 150m X 150m X 100m.

Guerricchio and Melidoro (1981, p.256) argue that the blocks 'float' on the black clays, although no sub-surface information is available to either confirm or reject this hypothesis. The size of the blocks, their position and the fact that they are of limestone, suggest that they have come from the Monte Crivo massif and subsequently transported downslope. The blocks may have broken away from either the hangingwall or the footwall of the fault. Figs. 3.16, 3.17, 3.18 and 3.19 are four possible

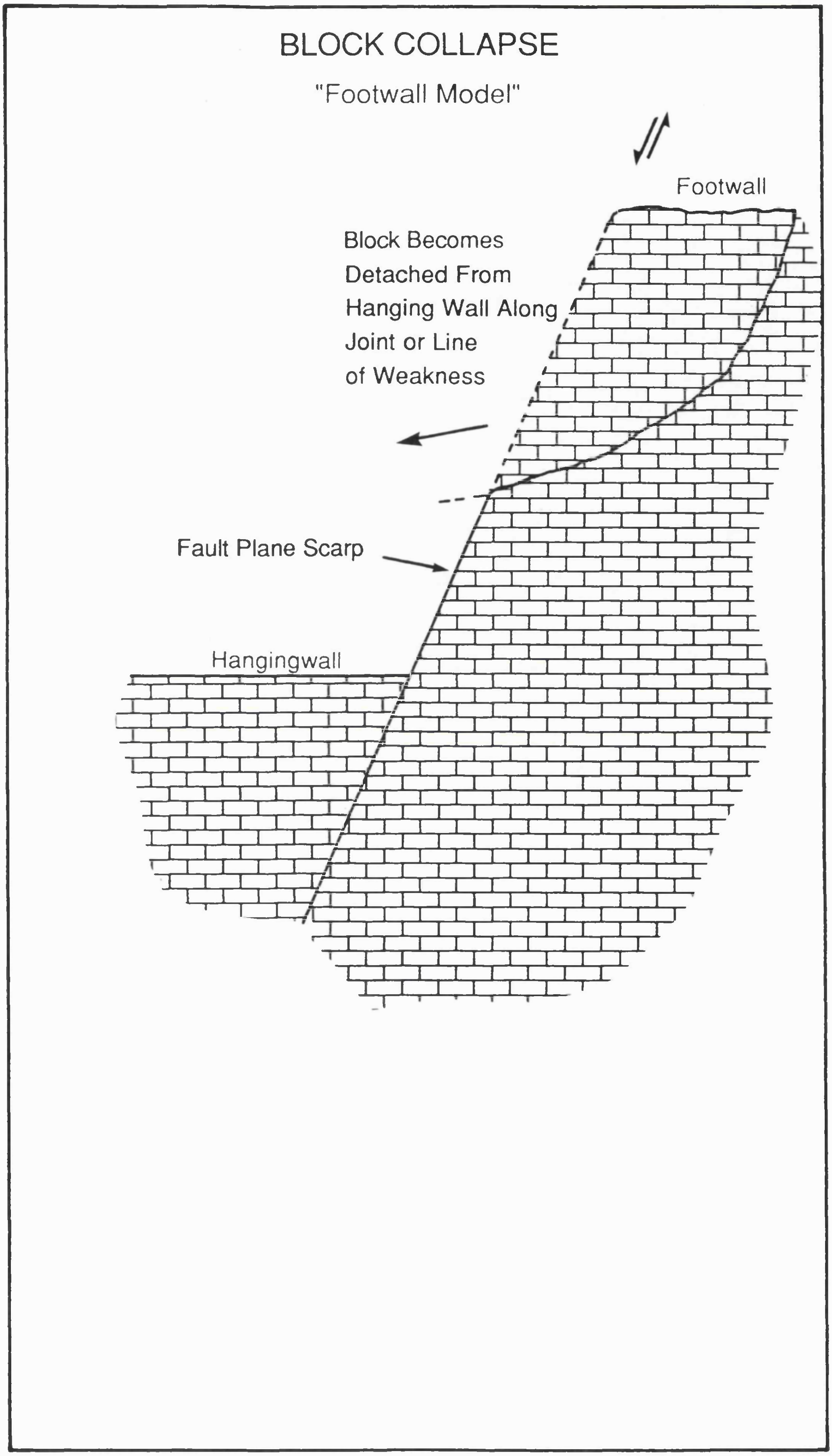


Fig. 3.16 Sketch of block collapse. 1 - The "Footwall Model"

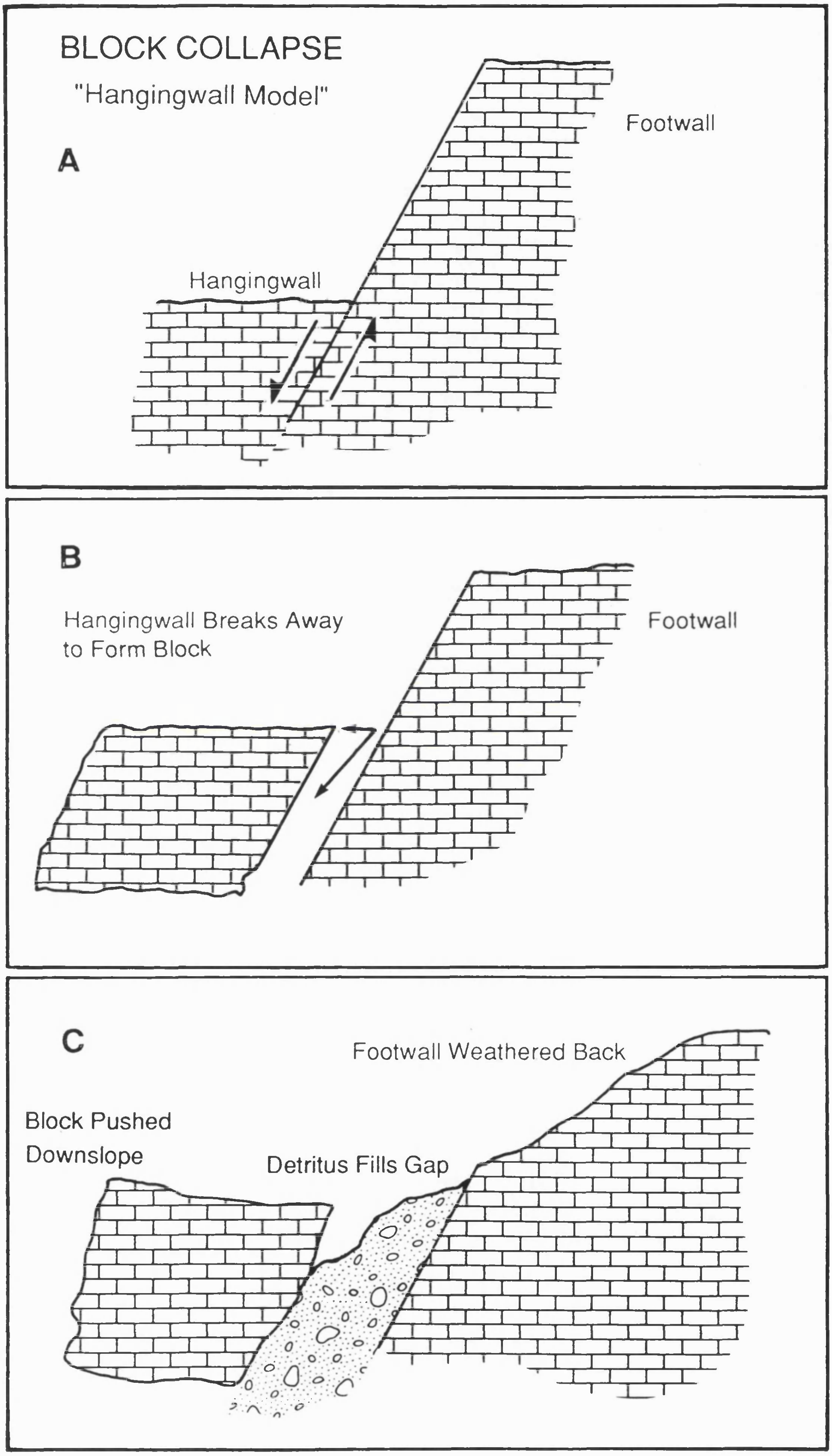


Fig. 3.17 Sketch of block collapse. 2 - The "Hangingwall Model"

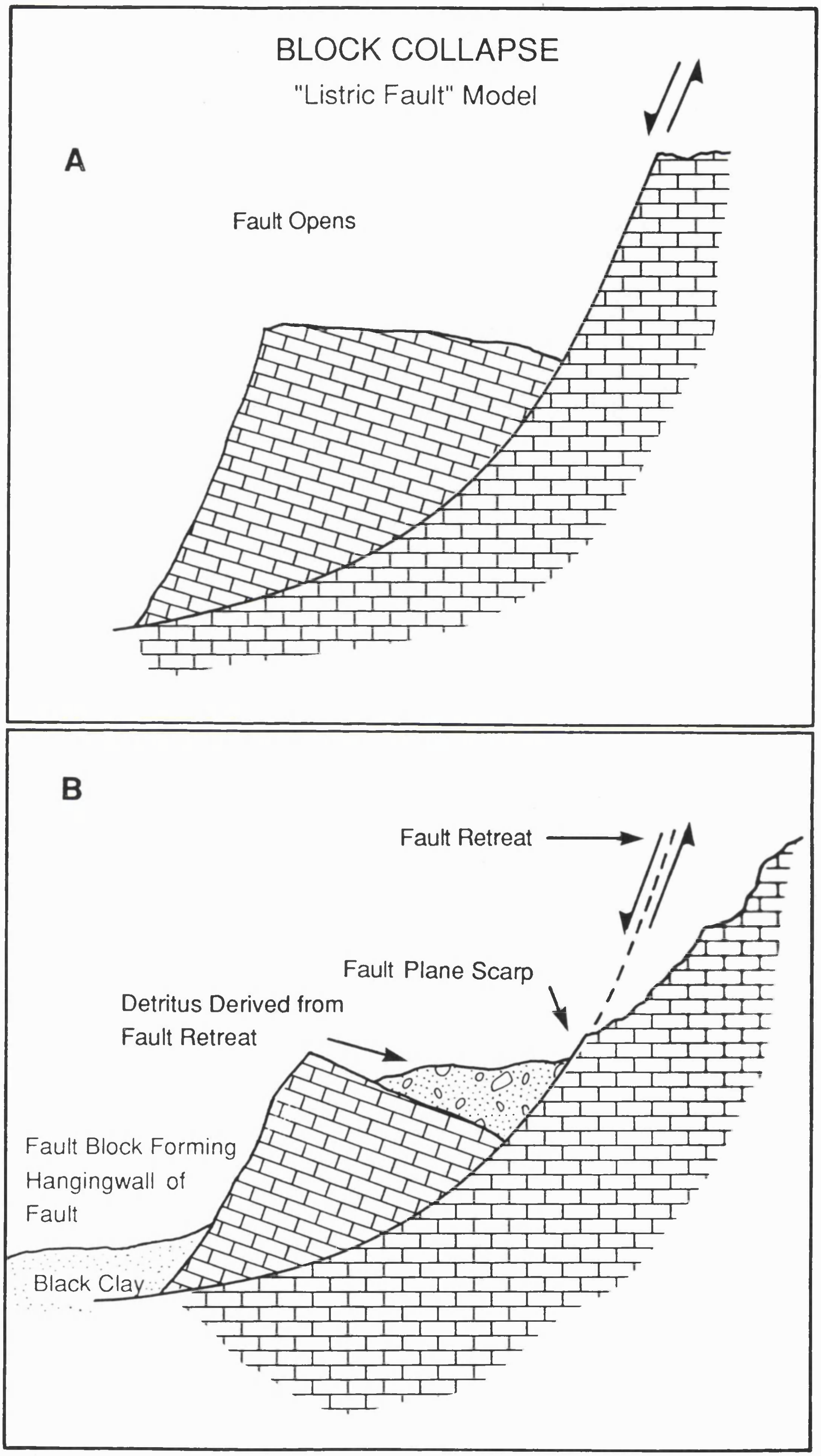


Fig. 3.18 Sketch of block collapse. 3 - The "Listric Fault" Model.

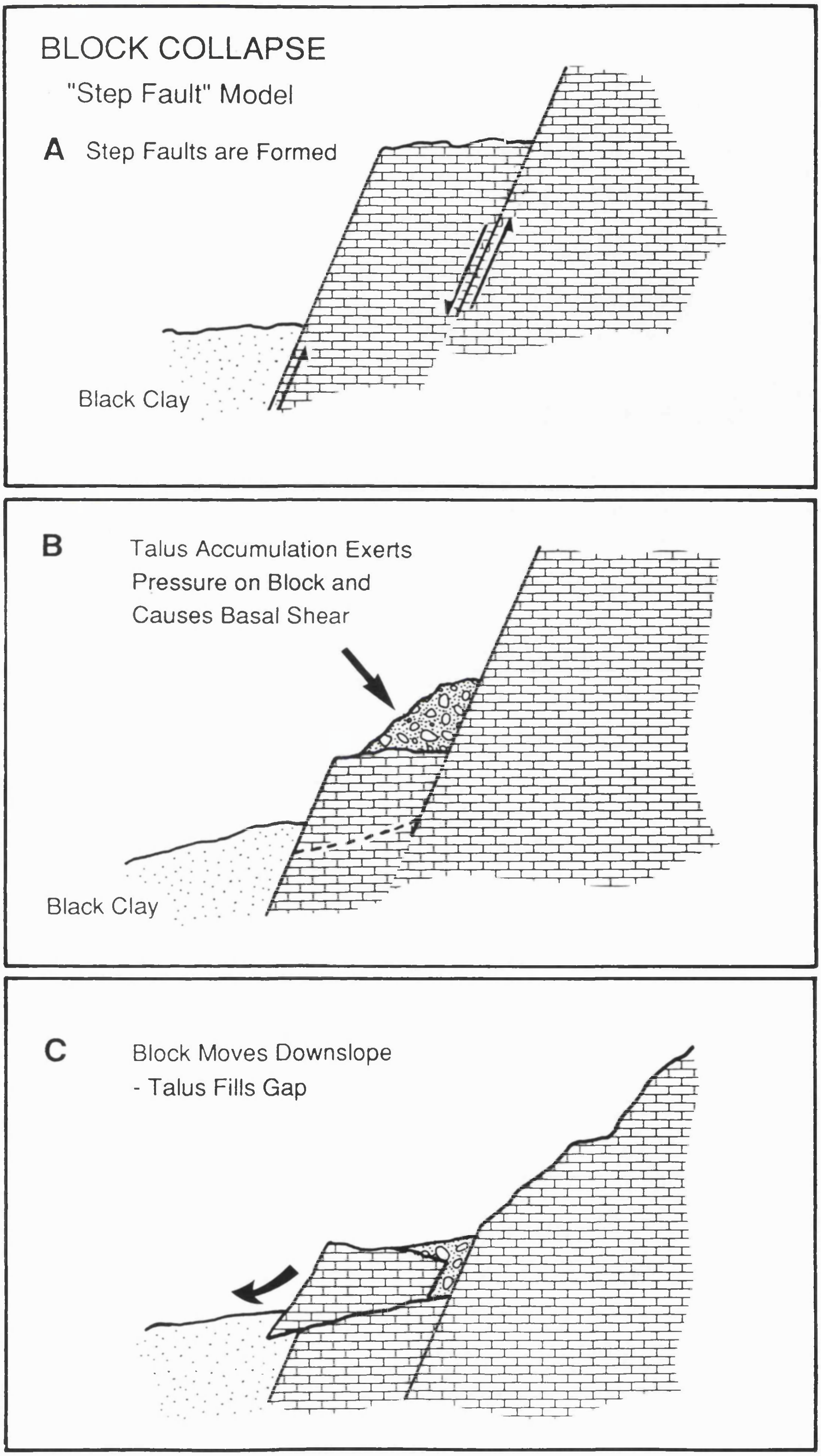


Fig. 3.19 Sketch of block collapse. 4 - The "Step Fault" Model

models of how the blocks may have become detached from the Monte Crivo ridge. The "Footwall Model" (Fig. 3.16) would probably require a sudden catastrophic event such as an earthquake to detach the block. In such a case the block may be expected to break under the shock of the event or to break as it fell downslope, although clearly it does not have to fall to its final position in one movement. In either event the block, or fragment of it, may be transported a considerable distance downslope. The problem with this model is that there is not enough room between the fault plane scarp (marking the line of the fault) and the fault scarp (marking the retreat of the slope from the fault plane; see Fig. 3.13) to create the size of block seen in the valley. Figs. 3.12 and 3.13 show that there is around 80m between the fault plane scarp and the fault scarp yet all of the blocks are much wider than this.

The "Hangingwall Model" (Fig. 3.17) would suggest a much slower break-up as the fault itself moved. Fault retreat producing debris from the higher slopes and talus produced along the fault itself, would fill the void behind the block. Block movement would be much slower and the block may remain intact. If all the blocks became detached at the same time they may be expected to have reached a similar position within the valley. The main problem with this model is that it requires the assumption that the block has not only become detached from the fault, but from its base as well. The mechanism required to achieve such dislocation is difficult to envisage.

The third model - the "Listric Fault Model" (Fig. 3.18) - is an extension of the Hangingwall Model. In this case, however, no assumption of basal detachment is necessary. The fault plane itself is curved and governs the direction of block movement; moreover the blocks are not separate features but are the hangingwall of the fault. The observed rotation of the blocks is a natural consequence of this type of fault. It should also be noted that this model could equally apply to a series of blocks rather than just one as illustrated in Fig. 3.18. In either case the blocks could not float on the black clay layer as Guerricchio and Melidoro (1981) suggest. However, such a fault line, because it would not be as deep as a straight fault, could not be expected to reveal the high levels of Helium gas as identified by Guerricchio *et al* (1986b), thus rendering this hypothesis highly unlikely.

The 'Step Fault Model' is proposed as the fourth model of block collapse (see Fig. 3.18). This model overcomes the problems of both the Listric Model, in that it describes a straight fault plane, and the problems of the Hangingwall Model, in that overcomes the question of basal detachment. The Step Fault Model assumes a 'staircase' of faults; talus accumulations on top of the fault blocks exert pressure on the blocks and therefore cause basal shear and block rotation.

Any one of these four models could provide a plausible solution to the problem of block detachment; they are examined here purely as hypotheses to be tested. However it is clear that the Step Fault Model provides a solution which fits the available evidence closely. It explains both the similar position reached by the blocks (see section 7.1) and their backtilt and does not contradict the Helium gas evidence of Guerricchio *et al*, (1986b) who argue for the presence of a very deep fault . Blocks which are isolated from the others could be explained as fragments which has become detached from one of the larger blocks Hence, the Step Fault Model is proposed as the most likely model of block detachment.

Prior to the beginning of this thesis in 1985, no work had been carried out on the limestone blocks. Guerricchio *et al* (1987), make a passing reference to the blocks in Phase A of their four phase model of the development of the valley. As has been explained earlier, they argue on the basis of secondary sources that the blocks interrupted the line of a raised beach and there collapse is coincident with the opening of the sackung which they date at about 30,000 years BP. If the Listric Fault Model is taken as a working hypothesis, then the opening of the fault and the movement of the blocks are part of the same event. A date for the fault would therefore provide a date for the movement of the blocks. These ideas will be developed and expanded in sections 4.3 and 4.5.5.

3.4 Seismicity

3.4.1 Introduction

Maratea is fortunate in that it lies outside the major seismic zones of southern Italy. It is situated between the seismic zone of the Potenza - Naples area and the belt of seismic activity associated with the Calabrian arc. This has been clearly illustrated in the previous chapter where Fig. 2.6 shows the foci of all known earthquakes that have occurred in Basilicata, southern Campania and northern Calabria between 1550 and 1982. This reveals a line of earthquake activity, to the south of the main Apennine ridge, extending from Melfi through Potenza, Marsico Vetere and Tramutola, in a north-west - south-east direction. A great deal of seismic activity is seen to the north-west of this belt stretching towards Naples, while there is another pocket in the Tricarico-Pisticci-Craco area, well to the east of the Apennine ridge. Maratea lies to the extreme south and east of this belt of earthquake activity.

Chapter Two also discussed the reasons behind the observed distribution of earthquake foci in the region. With this in mind, this section will concentrate solely on the effect of earthquakes in the Maratea area.

3.4.2 Earthquake Impacts in the Maratea Area

In addition to plotting the distribution of earthquake foci in southern Italy, Fig. 2.6 also indicates all those foci which have occurred within an arbitrary 80km radius of Maratea since 1550. Fourteen earthquakes have occurred in the defined area during this period, all of these have measured VI or above on the

Medvedev-Sponheuer-Karnik (MSK) scale of earthquake intensity (this scale is the one used by Calcagnile *et al* (1977) who list the earthquakes in Basilicata since 1550; it is similar to the Modified Mercalli scale, see comparison in Appendix B). The earthquakes of 1934, 1953 and 1982 are the last three recorded earthquakes to have occurred within the 80km zone.

While these fourteen earthquakes have the nearest foci to Maratea, other seismic shocks may have had epicentres beyond 80km but nevertheless significantly affected the area. Among these are the earthquakes of 1857 and 1980 which, because of their severity and the widespread destruction which they caused, have been described in detail in both the historical and academic literature. Indeed, during the period 1550 to the present, historical records only describe the impact of the 1857, 1980 and 1982 earthquakes on Maratea. The *Comune di Maratea* do not have records of the affects that any of the other earthquakes had on the town.

3.4.2.1 Impact of the 1857 Earthquake

The so-called 'Great Neopolitan Earthquake' of 16 December 1857 has been described in detail by Mallet (1862) and affected an extensive area to the west of the main Apennine ridge between Molise and northern Calabria. The earthquake had an estimated Richter Scale magnitude of 6.84 and an estimated Modified Mercalli intensity in the Maratea region of VI. Branno *et al* (1985) have established the affect of the earthquake on the towns of Basilicata, based on documents found at the *Fondo Intendenza* of the State Record Office in Potenza. There is also correspondence in the Potenza archives between the local administrative authorities and the central authority; in this case the Minister of the Interior in the then Kingdom of the Two Sicilies. A magistrate of Maratea speaks, in a document found at the *Fondo Intendenza*, of a strong tremor, although the town had only one death to mourn, that of a 38 year old farmer killed when the first floor of a building collapsed *'uns sola vittima a deplorasi...un contadino di anni 38...crollata la stanza al primo* *piano'*. Other documents describe Maratea as escaping the worst affects of the earthquake because of *Divina Provvidenza;* the first shock struck the town in the evening of the 16 December 1857 before the townspeople were in bed and the aftershocks lasted until the afternoon of the fourth day causing damage of various kinds. The tremors shook the town from "east to west" (the records do not make clear whether this refers to the whole town or the direction of shaking) and lasted only a few seconds each *'s'intese in quest Comune una scossa di tremuoto dalla direzione Est ad Ovest tutta ondulatoria e della durata di piu secondo'*.

3.4.2.2 Impact of the 1980 Earthquake

The 23 November 1980 southern Italian earthquake is the largest and most recent earthquake to have struck the Italian peninsula. The earthquake had its epicentre near the village of Laviano in Campania about 50km north-west of Potenza (95km north of Maratea) and caused widespread damage in Basilicata and southern Campania as well as nearly 3,000 deaths. The impact of the 1980 earthquake on Basilicata and southern Campania has been described in detail in Chapter One. The earthquake had a magnitude of 6.8 on the Richter scale. The limit of Mercalli intensity I for the 1980 earthquake is described by Alexander (1984a). Alexander argues that this limit lies about 15km due north of Lagonegro and about 30km due north of Maratea (see Fig. 2.6). A tremor of Modified Mercalli intensity I is described as 'not felt except by a very few under especially favourable circumstances'; intensity II is experienced when 'delicately suspended objects swing' (see Appendix B). The Italian Government classification of damage lists 686 *comuni*, in Basilicata and southern Campania, either destroyed, severely damaged or damaged; Maratea is one of only five *comuni* which do not appear in this classification (see Alexander, 1984a).

De Fiore and Brando (1985) describe the impact of the 1980 earthquake on the *centro storico* in a supplement to their original 1978 Structure Plan (see section 1.7). The authors argue that virtually all the buildings in the *centro storico* suffered at least some damage. The most severe damage occurred in the area immediately adjacent to the slopes of Monte San Biagio and the least severe on the downhill side of the old town. Three buildings were described as partially collapsed and two were ordered to be demolished.

In view of Maratea's supposed position outside the main area of seismic damage associated with the 1980 earthquake this reported situation is surprising. The work of De Fiore and Brando was based on the number of claims for earthquake compensation submitted to the regional government. Furthermore, because of the very large number of *comuni* affected by the 1980 earthquake, regional claims inspectors never visited Maratea. Given this, it seems reasonable to assume that a great many compensation claims were for damage that had existed prior to the earthquake, although this is only the opinion of the author and is difficult to establish. From interviews with local people carried out by the author, it is also apparent that compensation claims were actively encouraged by the administrators of the *comune* in an effort to provide funds for the Structure Plan. In short, the true effect of the 1980 earthquake on Maratea will probably never be known, but it is unlikely that the assessments of earthquake damage arrived at by De Fiore and Brando (1985) are accurate or that Maratea suffered greatly, if at all, from the event.

3.4.2.3 Impact of the 1982 Earthquake

The earthquake of Sunday 21 March 1982, was the last major earthquake to affect Maratea. It had a Richter magnitude of 4.85 and struck Maratea with an intensity of VI - VII on the Modified Mercalli Scale (Alexander, 1986). Its epicentre (39° 59'N, 15°38'E) in the Gulf of Policastro was 9.5km offshore of Maratea (see Fig. 3.20). The focal depth of the earthquake was 19km and during the three days after the main tremor there were thirty aftershocks per day.

THE 1982 (Gulf of Policastro) EARTHQUAKE

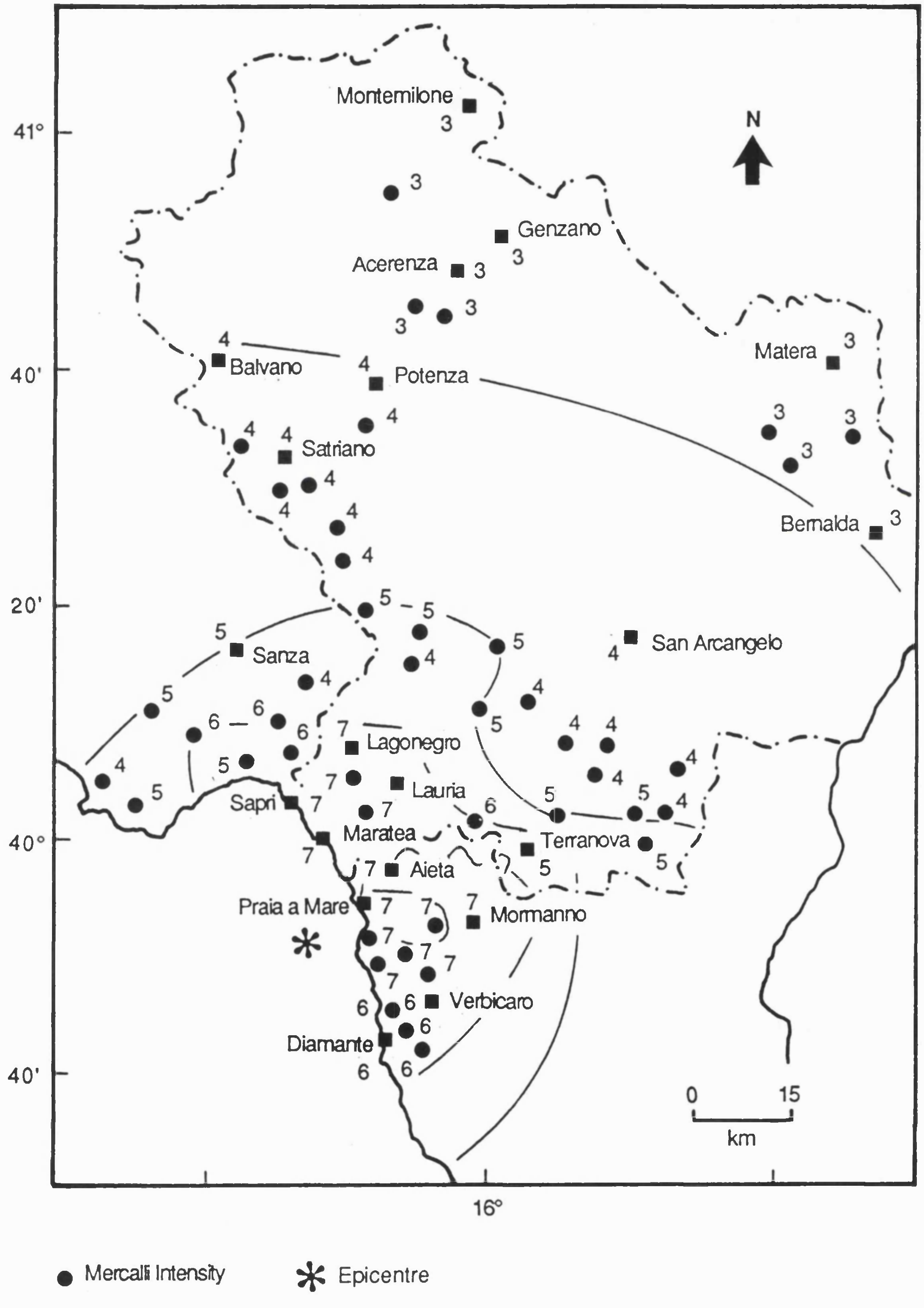


Fig. 3.20: Isoseismals for the 1982 (Gulf of Policastro) Earthquake

The earthquake excited little international concern; bulletins appeared in two Italian newspapers *Il Mattino* of Naples, and the Bari paper *La Gazzetta del Mezzogiorno*. Apart from the research of Alexander (1986) there was no outside interest and yet, for Basilicata and Calabria in general and Maratea in particular, the earthquake had important consequences.

There were no reported deaths but 1,357 people were made homeless in Basilicata and Calabria. In Maratea, 138 houses in the *centro storico* were damaged, 79 seriously and 70 evacuation orders were issued during the first three days after the earthquake. One hundred and thirty evacuees were accommodated, first in the Santa Venere Hotel in Fiumicello, and then in 100 trailer homes (originally used for housing victims of the 1980 earthquake), which arrived during the first week after the earthquake. In Fiumicello, the Intessa textile factory was forced to close and lay-off several hundred workers due to extensive damage of the building. The coastal roads (south to Praia a Mare and north to Sapri) and the main road to Trecchina were blocked for about two days.

A similar situation prevailed in many of the towns surrounding Maratea and in five of them evacuation orders had also to be issued. These included Lagonegro (37 houses evacuated), Rivello (20 houses) and Trecchina (17 houses). The earthquake renewed landsliding in Bisaccia, thirty miles north-east of Avellino (about 60km due east of Naples), which had suffered landsliding since the earthquake of 1930 and which was badly damaged by the 1980 earthquake (see Crescenti *et al*, 1984).

Alexander (1984a) argues that the 1982 earthquake highlighted the new awareness of the Italian authorities to rapid disaster relief, an awareness gained through their experience of the 1980 earthquake. 'The 1982 earthquake generated a very rapid response from the Italian authorities. Manpower, equipment and the first 33 trailers for the homeless arrived from Naples and Salerno a few hours after the tremors [in fact 48 hours later after the Trecchina road had been made passable]; and Signor Zamberletti, the Special Commissioner for Disaster Relief, visited the area on the same day', Alexander (1984a, p.510). This new awareness is now even more apparent in Maratea where, at the head of the valley, a large new Ministry of Civil Protection building has been constructed. In addition to housing the normal public services (for example the *Vigili del Fuoco* - Fire Brigade) the complex contains a large stock of earth moving machinery, trailer homes, emergency food rations and other provisions required in the event of a major disaster. The depot is one of several throughout southern Italy and serves as a relief centre for a number of widely dispersed villages in the area. The rationale behind the siting of the depot at Maratea, which is not the most central location, is that it is by far the largest tourist resort in the area and relief on a massive scale would be required if a major earthquake struck during the summer months when the population is eight to nine times higher than normal.

3.4.3 Significance of Earthquake Activity in the Maratea Valley

None of the reports on earthquake activity in the Maratea valley has mentioned the effects of seismic shaking on the physical landscape. The two most recent earthquakes in the area, namely 1980 and 1982, are not reported to have had any effect on the sackung, the fault scarp or the limestone blocks. Whether or not this is a true reflection of the situation is uncertain; this thesis will return to this debate in Chapter Four, section 4.3, and examine it in greater detail.

The main conclusion to emerge from the historical records and recent literature is that seismic shaking in the area is viewed as a hazard. The new Ministry of Civil Protection building is witness to the very high importance that the Regione Basilicata now place on earthquake preparedness in the area. While Maratea is fortunate to lie between the main zones of seismic activity in southern Italy, earthquakes are nonetheless viewed as a very real problem.

3.5 Case Study Methodology

This chapter has examined the physical and historical setting of Maratea and discussed its future development strategy.

The area has clearly been tectonically active, and clear signs of recent movement can be seen along the fault plane scarp and in the *centro storico*. Periodic seismic activity has caused severe damage. Against this background, the *Comune di Maratea* would like to see the tourist industry expand, in a structured manner which takes account of the traditions and unique cultural heritage of Maratea as well as its immense natural beauty. To this end they formulated the 1978 Structure Plan, which planned for future expansion, rather than allow it to happen, and sought to counter some of the problems caused by hitherto unplanned development. The principal error of the Plan was that it contained no specific allocation for a geomorphological/ geotechnical input at the planning stage.

Given the nature of the area, this type of input is essential if future developments are not to require expensive post-project remedial work. This thesis seeks to provide that input by identifying a number of key problems that need to be assessed. These issues can be summarised as follows:

- **Neotectonics**

(i) **The Fault Plane Scarp**: Is it an active or relic tectonic feature, or is the exposure of the fault plane scarp the result of its exhumation by the processes of mass movement? What is the date of the last movement of the fault? Are there any clues as to the date of sackung initiation?

- **Landslides**

(ii) **The Limestone Blocks**: A knowledge of their stability is required. For example, when did they come to rest in their present position and is there any evidence of continuing movement?

(iii) **The "White Line"**: What is the cause of the recent movement that has resulted in the creation of the "white line" at the base of the fault plane scarp? What is the age of the "white line" feature?

- **Planning**

(iv) **Existing Development**: If slope movements are occuring have they had any effect on building structure? What is the influence of seismic shaking on building structure? Can any patterns of building damage be identified and, if so, why? Is building damage the result of poor building design and construction?; can this be improved?

(v) **Structure Plan**: What are the implications of the answers to the above questions for the works detailed in the Structure Plan? Should the Structure Plan be revised in the light of these investigations?

The thrust of this thesis is centred around the stability of the area adjacent to the fault plane scarp. The sackung is considered, though not in as much detail, as are the factors causing building damage in the *centro storico*. The rationale behind this is quite straightforward; as noted in this chapter, a great deal of work has been done on the problems of the *centro storico*. In contrast, very little work has been carried out on the area adjacent to the fault plane scarp. This is surprising, bearing in mind the comments in Chapter One, that given the scarcity of available land any new development will have to be in this area.

CHAPTER FOUR

CHRONOLOGICAL FRAMEWORK

I

DATING THE FAULT PLANE SCARP

4.1 Introduction

Chapter Three examined the physical setting of the Maratea valley and concluded that it is a graben-like trench, bounded on either side by two converging normal faults. The chapter identified the three principal structural features of the valley, namely the fault plane scarp, the sackung and the limestone blocks. It was argued furthermore, that the fault plane scarp had clear signs of recent movement associated with it (termed in section 3.3.2, a 'white line').

The next three chapters will examine the fault plane scarp in detail. In this chapter the nature and date of formation of the fault plane scarp is considered. Chapters Five and Six will concentrate on the date of more recent movements. Both the date of formation of the limestone blocks and their recent history is examined in Chapter Seven.

4.2 Nature of the Fault Plane Scarp

4.2.1 Introduction

The existence of a fault plane scarp in the landscape may indicate contemporary tectonic processes, or a mass movement of overlying material merely exhuming an ancient fault from beneath covering deposits, or possibly a combination of the two. For example, Vita-Finzi (1986) cites an example of a misleadingly fresh looking fault scarp in Turkey, which has been exposed by the erosion of overlying material (Vita-Finzi, 1986, p.160, Fig. 91). The purpose of this chapter is to examine the nature of the fault, determine whether it is an active or fossil feature and to date its time of formation.

4.2.2 Survey of the Fault Plane Scarp

In order to understand in more detail the precise nature of the Maratea fault plane scarp, a survey of it was undertaken by the author during the summer of 1986.

The survey was carried out in two parts; first 87 metal marker pins were inserted into the polished face of the fault plane scarp at regular intervals. The 'pins' were 6" galvanised masonry nails and acted as fixed reference points for the survey (see Plate 4.1). The interval between pins was placed at about 20m although there was necessarily a degree of variation as some areas of the fault plane scarp were too hard to drive a marker pin into. Marker pins were not located in areas of the fault plane scarp that had been weathered back or dissected by gullying. Second, a detailed map of the fault plane scarp was produced by the author using tapes, poles, a compass and an inclinometer.

The map of the fault plane scarp has been produced as a fold out sheet and is contained in the back pocket of this thesis. It shows a 2083.71m scarp which, although when viewed from the valley floor, gives the appearance of being a light coloured band of regular height, is in reality very broken-up with only sections of recognisable scarp face. The portions of the scarp face that remain, have a hard polished slickenside surface which has been produced by intense friction along the scarp face during movement of the fault.

The nature of the polished surface can be clearly seen in Plate 4.2a and b. Plate 4.2a is a portion of the fault plane scarp, approximately 150mm thick, removed from the section of face adjacent to pin 82. Small pieces of material on the surface of

Plate 4.1: Survey marker pin 45. For location see fold-out map in back pocket.

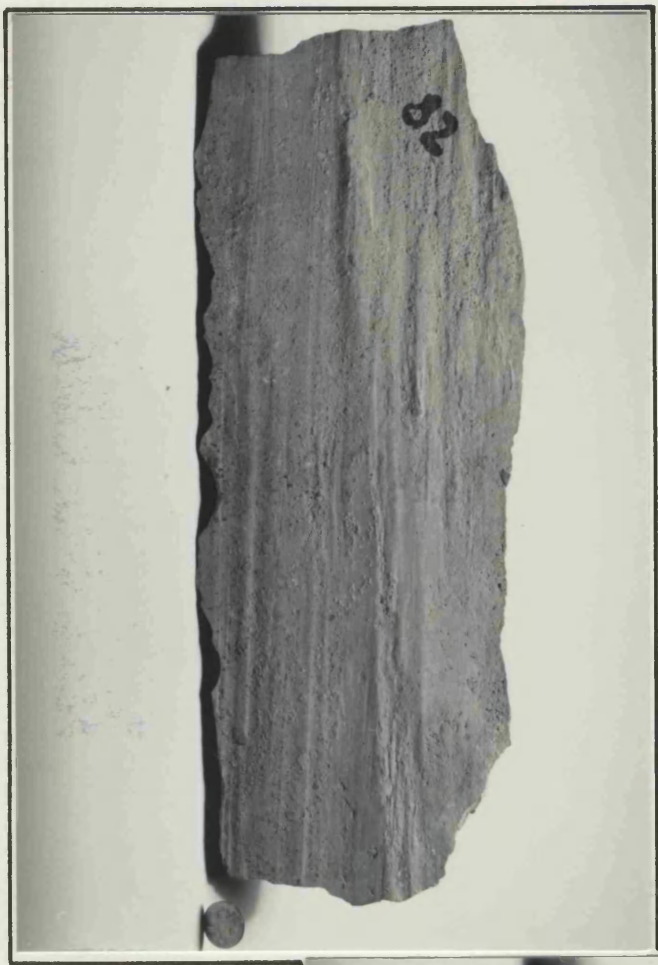


Plate 4.2a: Fragment of the fault plane scarp taken from the scarp face adjacent to Pin 82. Note its smooth surface , vertical slickenside striations and pieces of dolomite and limestone planed flat during the formation of the fault.

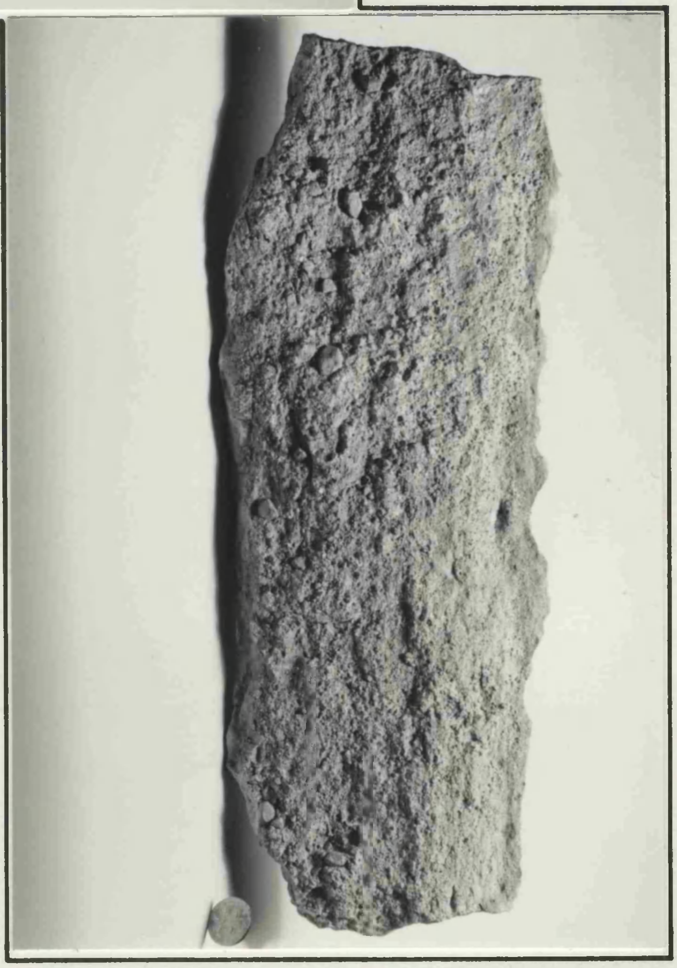


Plate 4.2b: Reverse of Plate 4.2a. Note roughness of sample and angular fragments.

the fault plane scarp, are particles of limestone and dolomite which have had one face 'planed' smooth by the action of fault movement and have thus lost their normal angular shape. Vertical slickenside striations are also readily apparent. Plate 4.2b, is the reverse of the same sample of fault plane scarp and displays a quite different appearance. Angular pieces of well cemented dolomite and limestone can be clearly seen, which have been unaffected by the planing action of fault movement. The lack of a polished surface is very evident as is the absence of slickenside striations. The polished surface is, therefore, made of the same dolomitic limestone as the rest of the Monte Crivo massif (see Plate 3.1); it differs from the normal bedrock in that friction along the scarp face has produced a smooth surface, planed flat and hardened, during the parting of the fault.

In many places the polished slickenside surface is continuously exposed for tens of metres, in other areas gullying has dissected the fault scarp and only fragments of the polished surface remain. For example, in its southern portion, particularly between marker pins 65 - 81, the dolomitic limestone, in which the fault plane scarp is formed, is very poorly cemented. In this section, where erosion has removed the polished surface, (or the polished surface has collapsed due to material being eroded from behind it, Fig. 4.1), it is possible to fracture the underlying material with a few light blows from a geological hammer. In other areas, particularly between pins 1 - 18 and 28 - 41, the scarp face is unbroken although very variable in height. In contrast to section 65 - 81, the polished surface has not been removed and will not fracture even after repeated hammer blows.

A more quantitative measure of the hardness of the fault plane scarp was obtained by the author with a concrete test hammer more popularly known as a 'Schmidt Hammer' after its inventor. This instrument was, as its name suggests, originally developed for the non-destructive in-situ testing of concrete but has found applications in geomorphology particularly where rapid field assessments are required of rock hardness (Yaalon and Singer, 1974; Day and Goudie, 1977; Day, 1980; Gardiner and Dackombe,

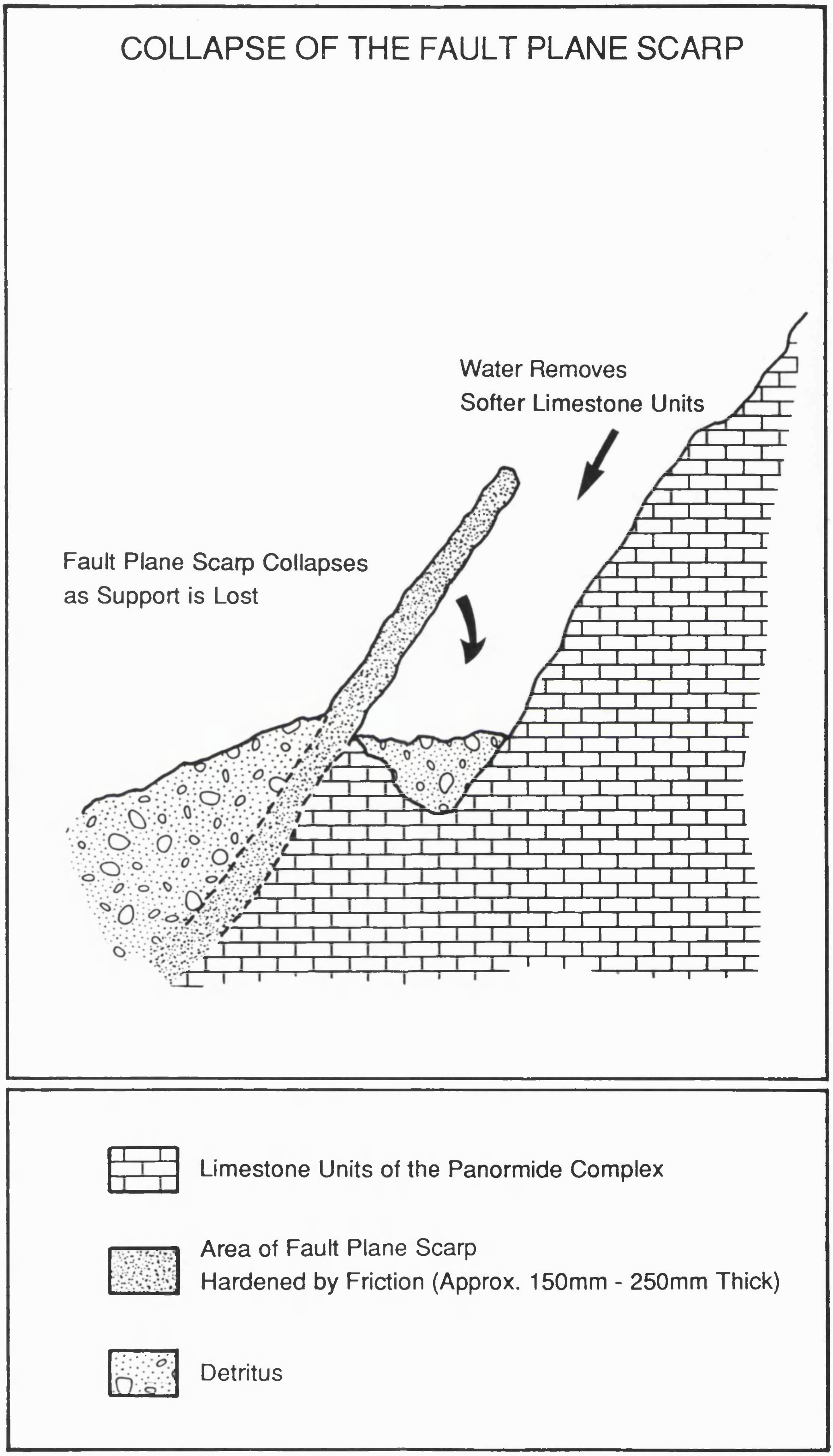


Fig. 4.1: Sketch of the collapse of the fault plane scarp.

1983). The Schmidt Hammer consists of a steel case enclosing the hammer, essentially a steel bar, which is held in place by a spring. In operation the hammer tip is pushed against the rock surface and rebounds onto the spring. The rebound distance (R) provides a measure of the rock surface hardness which is related to strength. Matthews and Shakesby (1984), have successfully used the instrument to provide a relative dating sequence for the moraines of southern Norway, based on the differential weathering (and thus hardness) of boulders forming moraines of varying ages.

In the present study, Schmidt Hammer readings, using a Type N hammer, were taken by the author at each of the 87 metal marker pins placed in the fault plane scarp. All readings were taken by the author to exclude operator variance, and as the angle of the hammer against the rock face has an affect on the reading, all readings were made with the instrument at right-angles to the face. Each R value for a given marker pin was the mean of 50 readings taken over a 2m x 5m grid adjacent to each pin (each reading was therefore at 0.5m distance from the previous reading). This grid size was chosen as it is both a convenient area over which the operator can work, and allows readings to be taken at some distance from each other. This second point is important as the hammer necessarily involves a local crushing of the rock, making it vital that readings are spaced in order to avoid error. In addition 10 intermediate stations, on areas of bedrock exposed by the erosion of the scarp, were sampled on the same basis. The results are displayed in Fig. 4.2 and clearly demonstrate the difference between the sections of the smooth polished fault plane scarp and the areas of bedrock exposed by the removal of the scarp face. Mean R values for the fault plane scarp all fall within the range R = 40 to R = 55 whereas the less well cemented bedrock has values of R = 20 to R = 30. Additionally the Schmidt Hammer results indicate that there is no variation in rock hardness over the length of the fault plane scarp. If it is assumed that rock hardness is partly a function of the degree of weathering, then clearly a low R value will indicate a higher degree of weathering and thus a longer exposure of that section of scarp. It is therefore reasonable to assume that, as similar R values are obtained for all areas of the fault

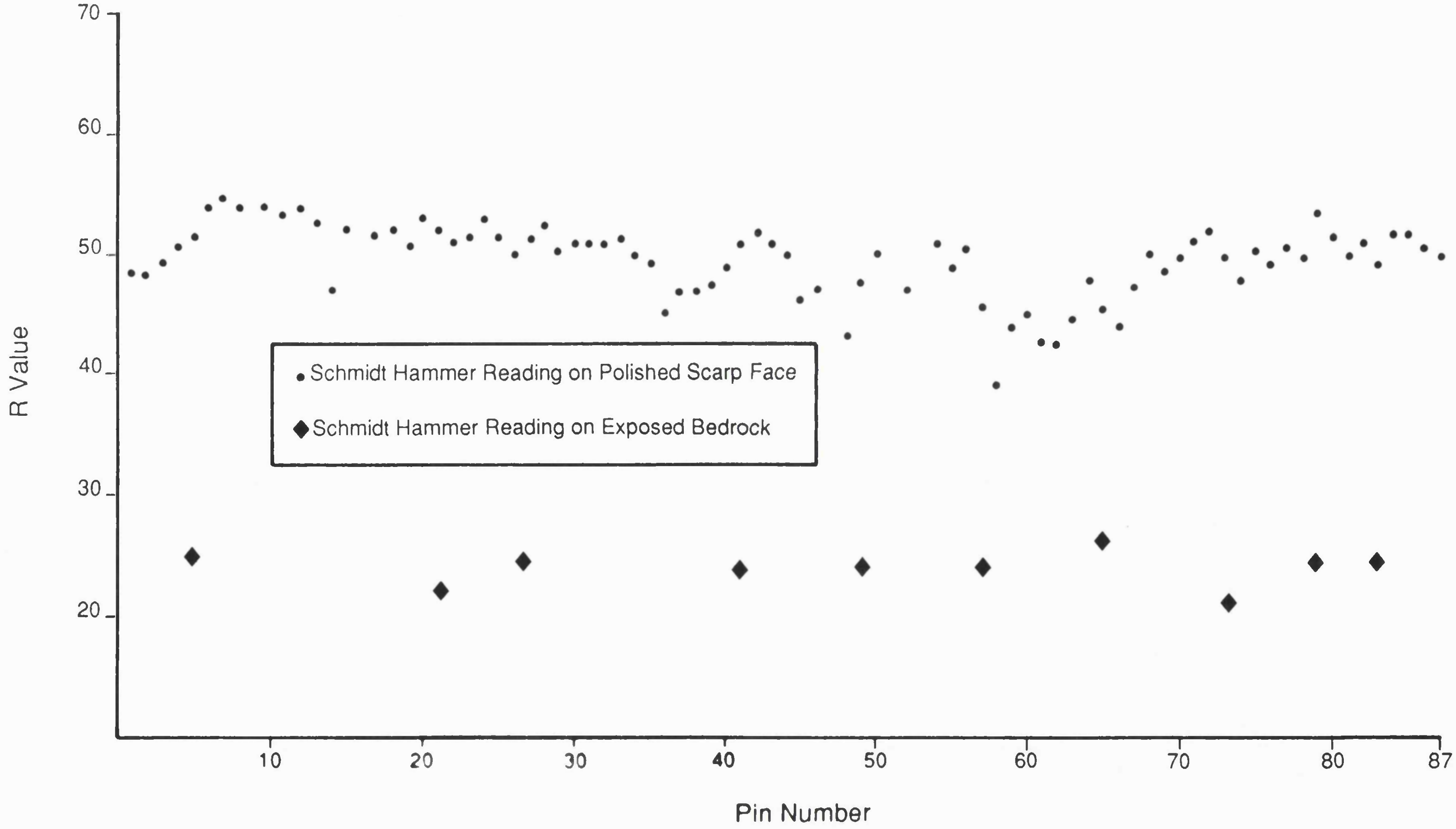


Fig. 4.2: 'Schmidt Hammer' readings for the fault plane scarp. The smooth polished fragments all have R Values in the range R = 40 - R = 55, whereas the bedrock is in the range R = 20 - R = 30.

plane scarp, the entire length of the scarp has remained exposed for a similar period of time.

The survey of the fault plane scarp also revealed that the angle of dip of the scarp changes at regular intervals. For example, from the first visible occurrence of the fault plane scarp (at marker pin 1) to pin 42 the angle of dip rarely varies outside the range 60° - 70°. From pins 43 - 52, however, the angle is 70° - 80°, while it falls to its former level (60° - 70°) between pins 53 - 65. Between pins 65 - 81 the inclination of the fault plane scarp declines to 50° - 60°, but from there on rises to 60° - 70° between pins 81 - 84 and 70° - 80° from pin 84 to the end (pin 87).

The polished slickenside surface is covered by extensive calcite deposits. These deposits are found in three forms. First, between marker pins 57 - 65 the calcite deposits occur as thick (approximately 10mm) layers of material, bonded to the underlying limestone and inseparable from it (see Plates 4.3a and 4.3b). The outer layer of the calcite has a smooth slickenside surface. In thin section veins of calcium carbonate can be seen within the limestone underlying the calcite layer (Plate 4.4).

Second, and principally where the polished surface is very fragmented (for example, between marker pins 43 - 56), calcite deposits appear in thin layers (1mm - 2mm thick) deposited on the scarp face. Where this occurs, the calcite layer can be peeled away very easily to reveal a polished surface beneath. Furthermore, slickenside striations and scratches on the scarp face have been imprinted onto the reverse side of the calcite layer, clearly identifying it as a secondary deposit which has been formed after the formation of the fault plane scarp (Plate 4.5). Thus, the calcite layer has probably been formed by rainwater mobilising calcium carbonate in the weathered area above the fault plane scarp and washing it over the scarp face.

In the third case, calcite deposits occur in fault breccia which has been 'plastered' onto the scarp face. Fault breccia has been defined by Whitten and Brooks (1985); 'during the process of faulting, the rocks are commonly broken-up to a greater or lesser

Plate 4.3a: Thick calcite layer embeded onto the fault plane scarp near Pin 65.

Plate 4.3b: Looking down onto the thick calcite layer near Pin 65. The material at the top of the photograph is the talus at the bottom of the fault plane scarp.

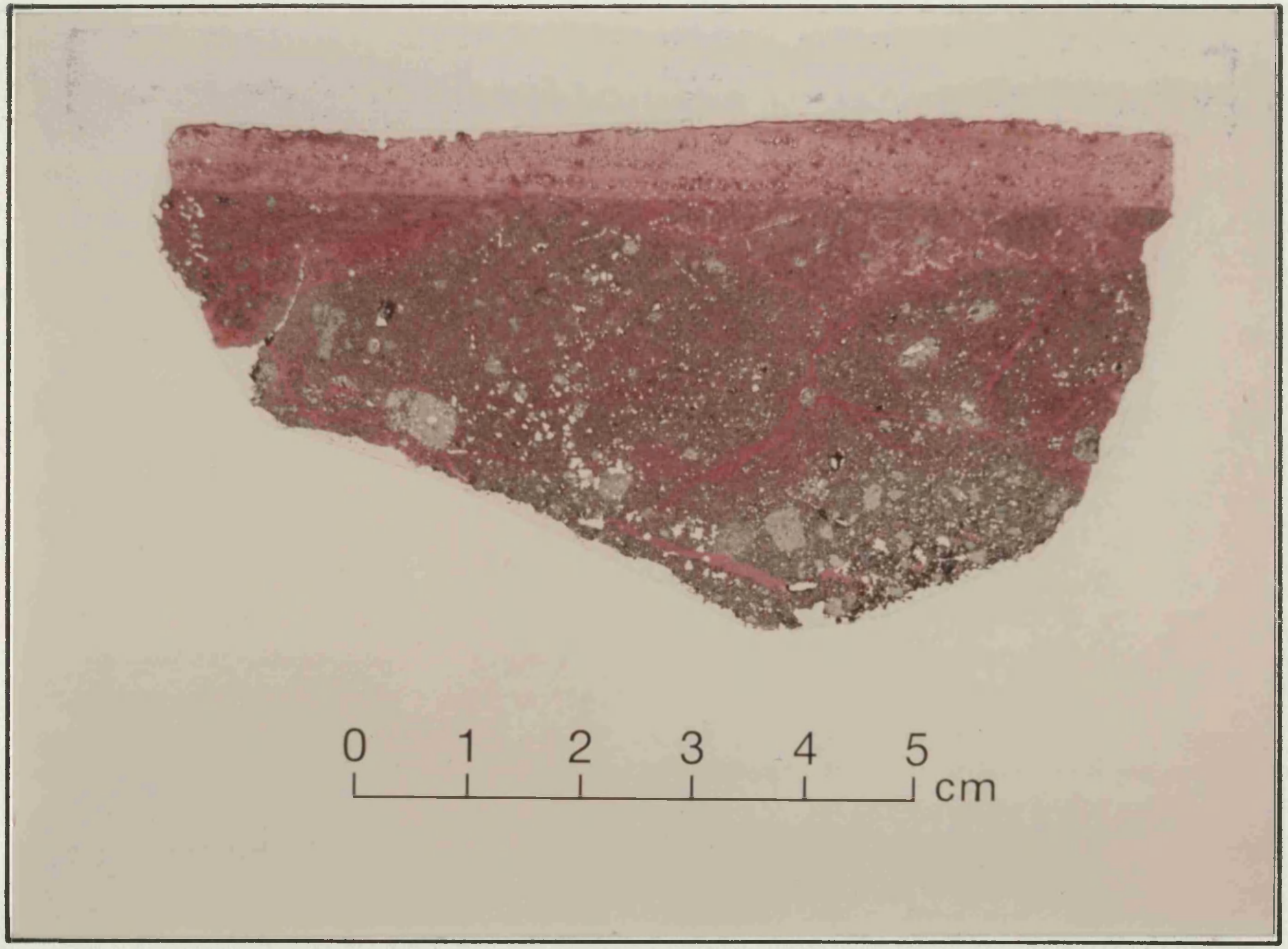


Plate 4.4: Thin section of the thick calcite layer near Pin 65. Sample has been stained with Alizarin Red-S and Potassium Ferycyanide. The white unstained particles are dolomite. Veins within the sample are the source material for the calcite layer.

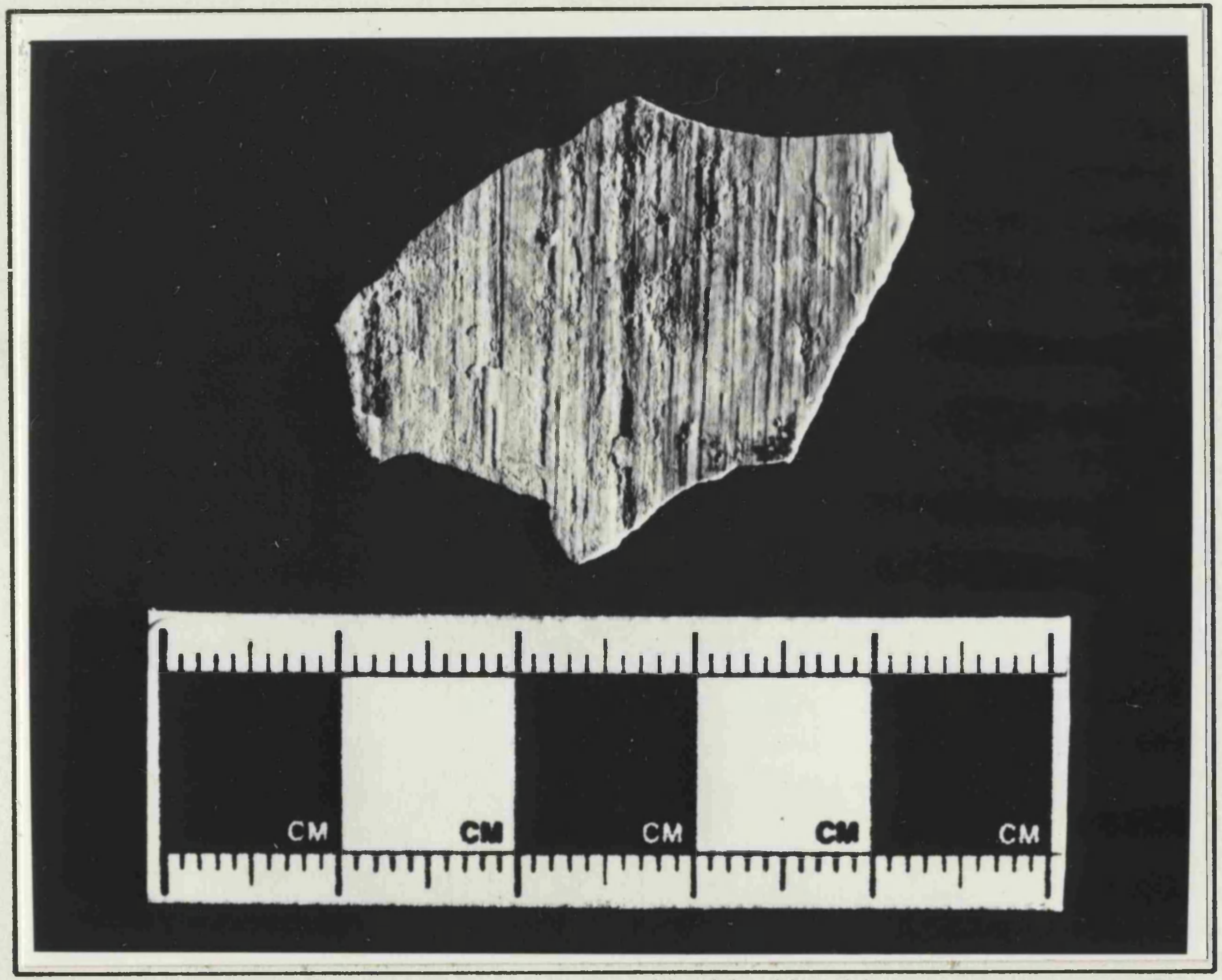


Plate 4.5: Magnified photograph showing the reverse side of the thin calcite layer taken near Pin 47. The fossilised slickenside scratches imprinted on the reverse are clear evidence that the calcite is a secondary deposit, which has covered the fault plane scarp after the movement of the fault.

extent. If the rocks on either side of the fault plane are hard, the fragments produced will be large and angular and are termed fault breccia. These fragments are often subsequently cemented by secondary calcite', (Whitten and Brooks, 1985, p.171). The fault breccia found on the Maratea fault, conforms to this description. It cannot be regarded as mylonite because crystal fragmentation and foliation which would be expected in mylonite is not apparent in thin section. Fault breccia was noted on the fault plane scarp between pins 38 - 41 and in patches from pin 48 to pin 61 and again between pins 16 - 5. These are all areas of hard polished scarp face. The breccia is very easily removed from the scarp face in layers 15mm - 25mm thick; beneath it is found a smooth surface with no slickenside striations or scratches. Slickenside striations are however, very well pronounced on the surface of the breccia.

As noted above, slickenside striations are evident over much of the polished surface. The striations take two forms; they either appear as quite deep (1mm - 3mm) gouges on the scarp face or as tiny scratches beneath the thin calcite surface layer described above. It is arguable that the larger gouges also displayed surface scratches but that these have been obliterated by the processes of weathering. The larger gouges or striations have also been affected by erosion. The striations are most prominent at the base of the fault scarp and barely recognisable at the top. Measurements of the striations were taken using a profile curve of the type obtainable through DIY retailers. More commonly used as a means of obtaining the exact shape of pipes or architrave when tiling or carpeting, the gauge consists of a number of narrow steel pins set through a central bar. The pins are pressed against the object and a profile taken which can then be traced around. Along the fault plane scarp groups of parallel striations whose form could be traced from the base of the scarp to the top, were selected for measurement. Measurements were taken of the 'amplitude' of the striation, defined here as the distance from the base of the groove trough to the crest of the groove ridge. Observations were at 0.5m intervals and taken at right angles to the dip of the scarp; ten sets of slickenside striations were measured. In all cases results indicate that the amplitude decreases up-slope. This can be clearly seen in Fig. 4.3a - e which displays the profiles taken with the pin gauge; the location of the profiles can be found with reference to the fold-out map.

The conclusion to emerge from the survey of the striations is that the fault plane scarp has either been subject to pulsed movement or has been progressively exposed or possibly a combination of the two. The low amplitude striations at the top of the fault plane scarp have suffered a higher degree of weathering than those at the base indicating that they have been exposed for a greater length of time.

Slickenside striations are believed to be parallel to the direction of fault movement. Thus, from the trend of the slickenside striations the direction of fault movement can be inferred. The trend of the slickenside striations was noted by the author during the fault scarp survey. When looking directly at the scarp face (as in the fold-out map) if the striation trend ran from top-left to bottom-right it was described as "normal". "Reverse" striations were those which trended top-right to bottom-left. No vertical striations were found. Normal slickenside striations were observed over the entire length of the fault plane except in the areas between marker pins 1 - 30 and 80 - 87 where they were reversed. It is clear therefore, that the fault has not moved as a single entity but in sections; two sections moving in a 'reverse' (north-westerly) direction and the other in a 'normal' (south-westerly) direction. This observation lends weight to the discussion on the limestone blocks in section 3.3.3, where a Step Fault Model of block formation was hypothesised suggesting that the limestone blocks are part of the hangingwall of the fault. If the hangingwall was segmented into fault blocks, each block could be expected to move as an independent unit thereby producing slickenside striations that had a trend unique to that block. In this way slickenside striation trend, of the type noted on the Maratea fault, would be expected. It may be envisaged, therefore, that the Maratea fault displays different directions of movement because it is segmented, that is composed of a number of fault blocks, rather

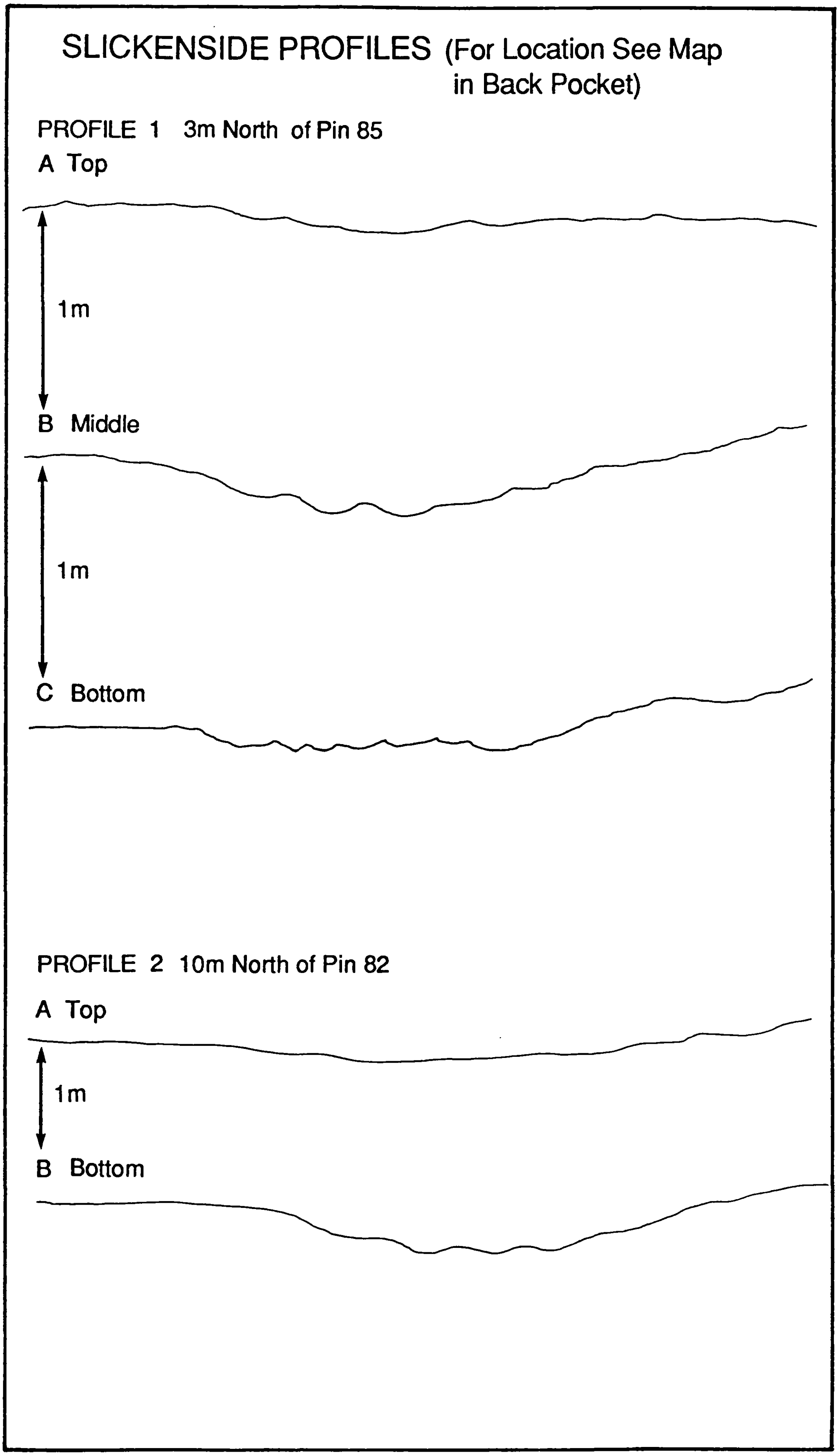


Fig. 4.3a: Slickenside profiles 1 and 2.

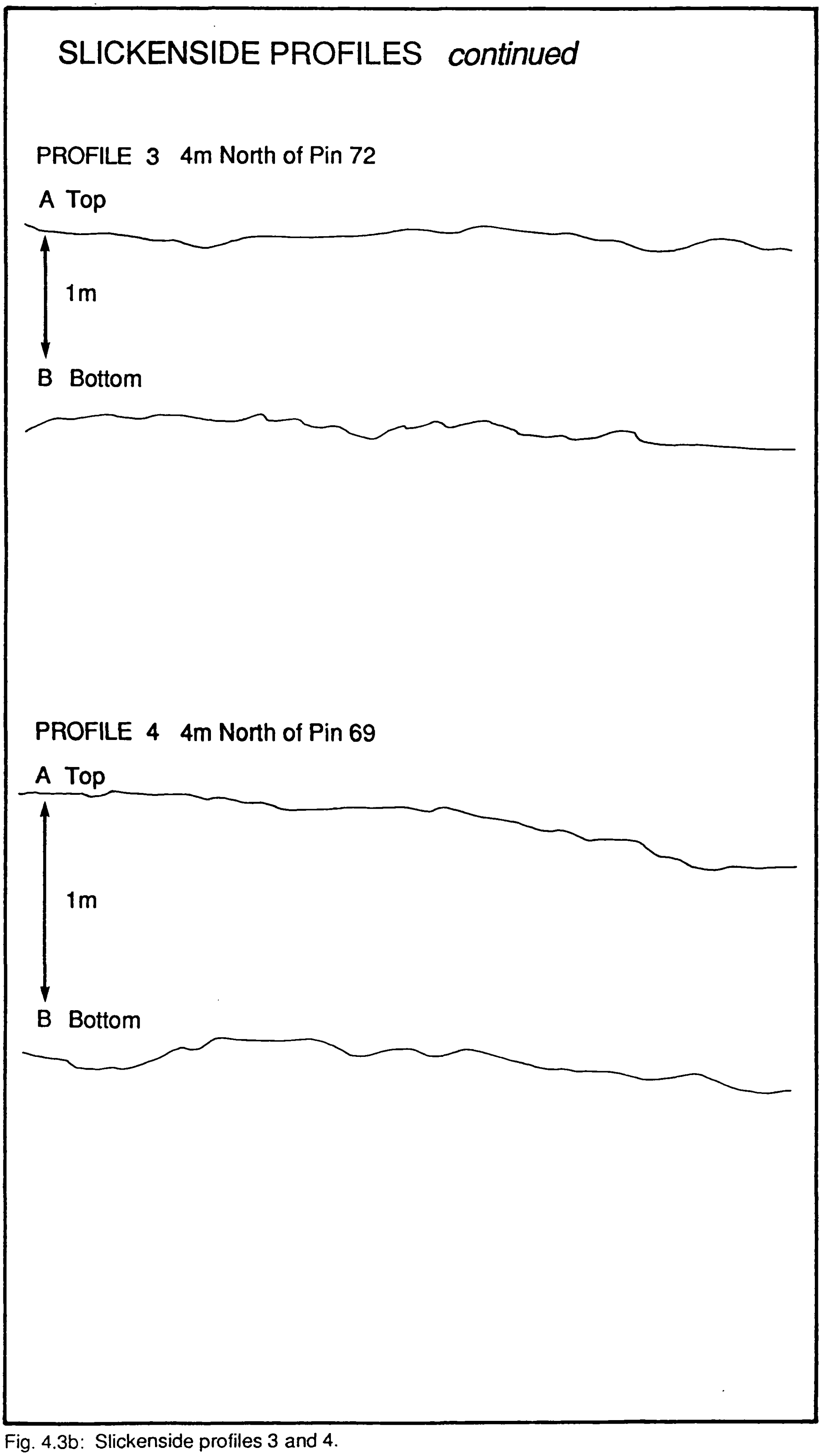


Fig. 4.3b: Slickenside profiles 3 and 4.

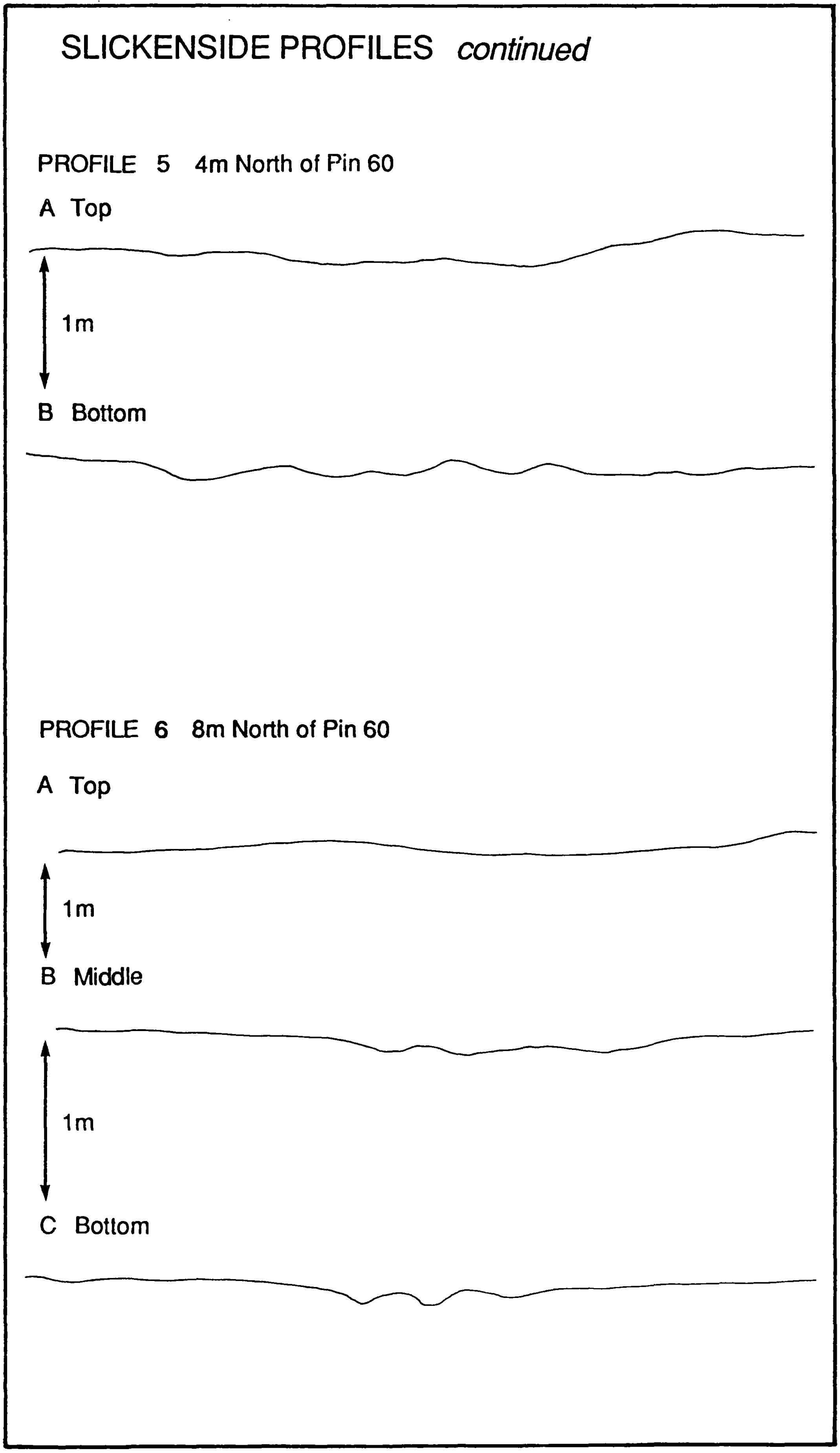


Fig. 4.3c: Slickenside profiles 5 and 6.

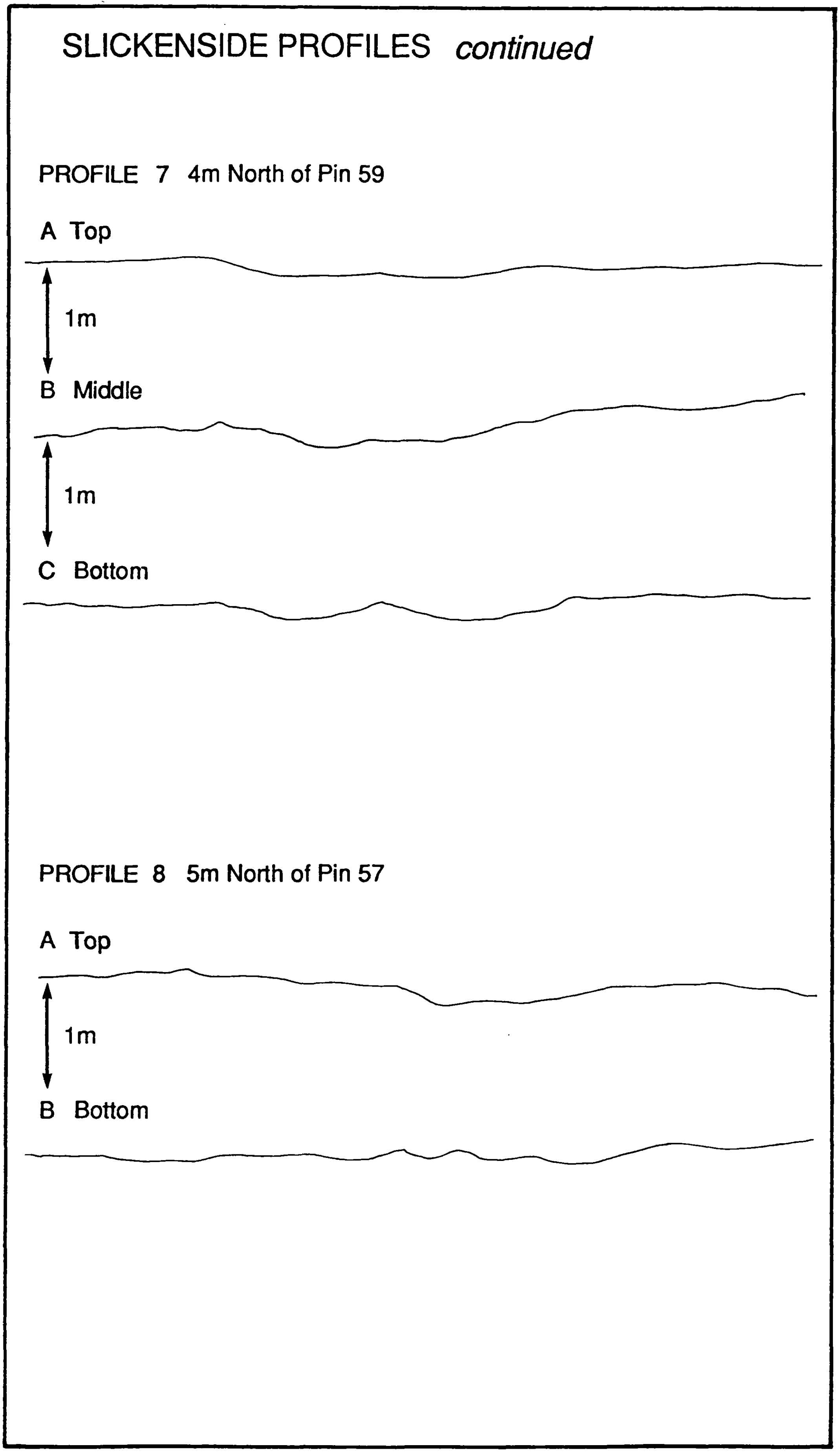


Fig. 4.3d: Slickenside profiles 7 and 8.

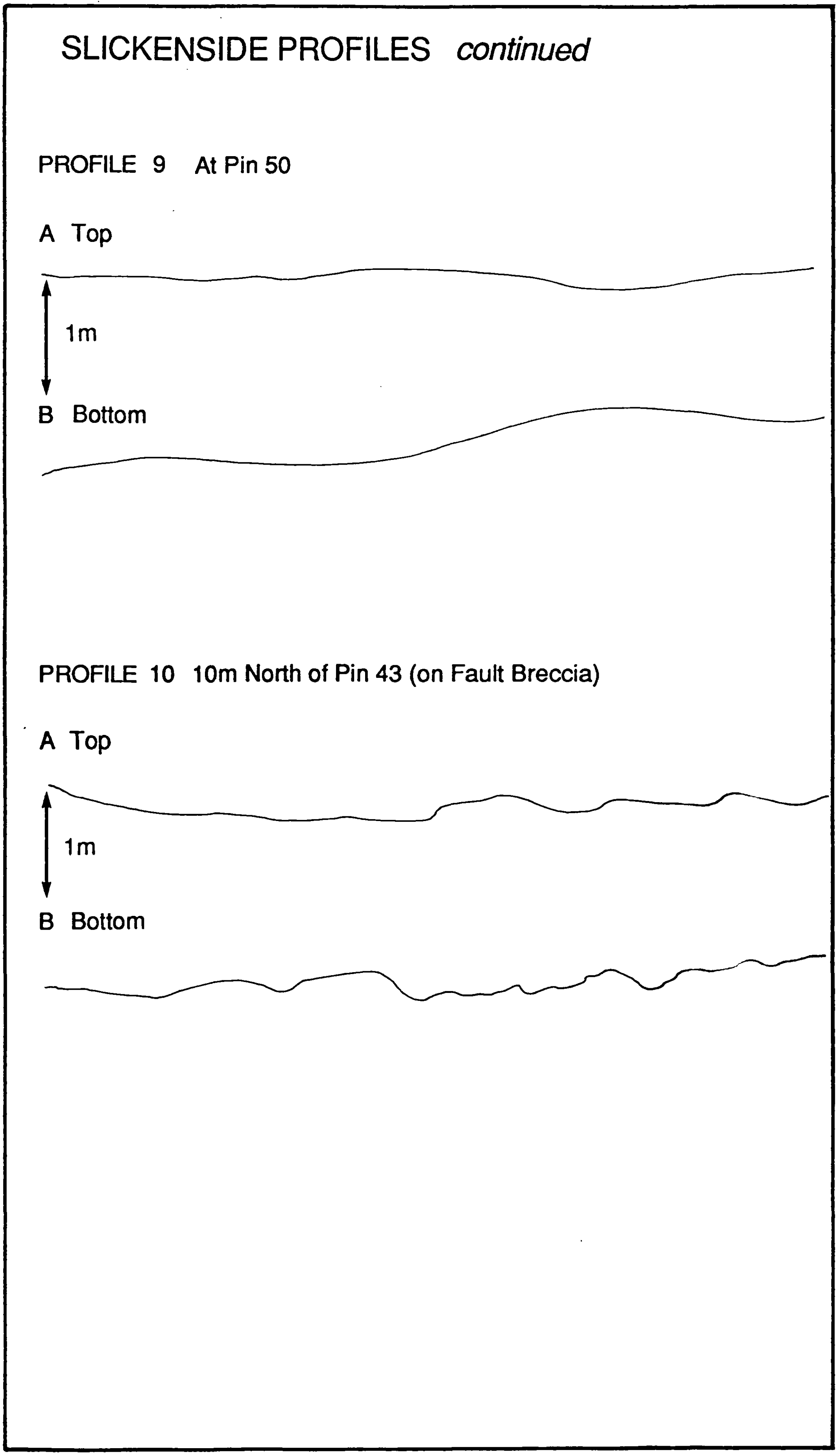


Fig. 4.3e: Slickenside profiles 9 and 10.

than being a single shear plane. This line of argument will be discussed further in Chapter Seven.

4.3 Evidence for the Formation of the Fault Scarp

In the last one thousand years, the Basilicata region has experienced a number of large seismic shocks. The largest of these are detailed in the attached table which also includes details and locations of earthquakes in Campania and northern Calabria (Table 4.1). The last earthquake suffered by Maratea occurred on Sunday 21 March 1982 and reached a surface wave magnitude (Ms) of 4.85 with an intensity of VI - VII on the Modified Mercalli Scale (Alexander, 1986). Its epicentre in the Gulf of Policastro was 9.5km offshore of Maratea (see section 3.4.2.3 and Fig 3.20).

When plotted on a map of Basilicata (see Fig. 2.6) it is clear that many of the earthquakes listed in Table 4.1 are at some distance from Maratea. Indeed, in the last fifty years the only earthquake foci within a 80km (50 mile) radius of Maratea were those of 1982, 1955 and 1934 (this again includes earthquakes in northern Campania). There are no reported earthquake epicentres at Maratea; if the Maratea fault were an active feature then seismic vibrations caused by the movement of the fault would have been expected . This suggests that either the Maratea fault is not an active feature or has very long intervals between movements.

During 1983, local people were reported to have heard a number of minor explosions and felt a series of tremors. Macroseismic surveys (Guerricchio *et al*, 1986b) suggest that this was an extremely localised and superficial event. Seismic vibrations measured in the Maratea *centro storico* were compared by the authors with data from nearby seismographic stations, principally Mormanno 15km to the south (see section 3.3.1 and Fig 3.9). They report that the vibrations have an atypical morphology to those caused by earthquake shaking; the vibrations are distributed in 'bunches' and accordingly the authors attribute the phenomena to

N	YEAR	D M	LAT.N	LONG.E	I
1	1550	25- 8	40.7	15.1	IX-X
2	1556	17-11	39.6	16.7	IX
3	1560	11- 5	41.3	16.4	IX
4	1561	31- 7	40.5	15.5	IX
5		1- 8	40.5	15.5	VIII
6		2- 8	40.5	15.5	VI
7		19- 8	40.5	15.5	X
8	1627	30- 7	41.7	15.3	X
9	1634	10-11	40.7	16.6	VI
10	1654	8- 9	41.0	15.7	IX
11	1683	31-12	40.5	16.5	VI
12	1688	- 1	40.4	16.6	X
13		5- 6	41.2	14.8	X
14	1689	21- 9	41.2	16.3	VIII
15	1694	8- 9	40.8	15.6	X
16	1702	14- 3	41.2	14.9	VII
17		14- 3	41.2	14.9	X
18		2- 4	41.2	14.9	DEST
19		6- 4	41.2	14.9	DAMA
20	1731	20- 3	41.5	15.6	X
21	1732	29-11	41.1	15.2	X
22	1733	16- 1	41.1	15.2	DAMA
23		29- 1	40.8	15.2	DEST
24		23- 3	41.1	15.2	DAMA
25	1794	12- 6	41.1	15.0	VI
26	1805	26- 7	41.5	14.6	XI
27	1807	11-11	40.3	15.9	VII-VIII
28		20-11	40.3	15.9	VII
29	1826	1- 2	40.6	15.7	IX
30	1831	2- 1	40.1	15.9	VIII-IX
31		2- 1	39.9	15.8	VII
32		13- 1	40.1	15.9	VII
33	1836	24- 4	39.6	16.6	XI-X
34		8- 7	40.4	16.5	VII
35		20-11	40.1	15.8	IX
36	1845	10- 7	40.7	16.6	VI
37	1846	9- 8	40.5	16.1	F
38		9- 8	40.5	16.1	VII
39	1851	14- 8	41.0	15.7	XI-X
40		6- 9	41.2	16.1	VII
41	1853	9- 4	40.8	15.2	IX
42		9- 4	40.8	15.2	VII
43		10- 4	40.8	15.2	VII
44		10- 4	40.8	15.2	VI
45		11- 4	40.8	15.2	VII
46		12- 4	40.8	15.2	VII
47		8- 5	40.8	15.2	VI
48+	1857	16-12	40.4	15.9	X .
49		28-12	40.4	15.9	VI
50	1858	2- 1	40.4	15.9	DAMAGE
51		6- 1	40.4	15.9	VII
52		7- 3	40.4	15.9	DAMAGE
53		7- 3	40.4	15.9	DAMAGE
54		8- 3	40.4	15.9	VI
55		30- 4	40.4	15.9	DEST
56		6- 8	40.4	15.9	DEST
57	1859	4- 2	40.4	15.9	DAMAGE
58	1861	19-11	40.6	15.8	VI
59		28-11	40.6	15.8	VI
60	1885	24-12	40.6	16.7	VI
61	1886	2- 1	40.5	16.5	VI

Table 4.1: Table of seismic shocks in Basilicata, southern Campania and northern Calabria. DM = day and month. I = intensity measured on the MSK Scale - see Appendix B for a comparison between this and the more widely used Modified Mercalli Scale.

N	YEAR	D M	LAT.N	LONG.E	I
62	1887	3-12	39.5	16.3	IX
63	1893	25- 1	40.5	15.4	VII
64		10- 8	41.7	16.1	X-IX
65	1894	28- 5	40.0	16.1	VIII
66	1895	19- 7	40.4	15.8	VI
67	1899	16- 8	41.1	15.3	VII-VI
68		2-10	40.5	15.5	VII-VI
69	1902	22- 6	39.8	16.6	VII
70	1905	29- 7	40.5	15.6	VII
71		26-11	41.1	15.0	VII
72		26-11	41.1	15.0	VI
73	1906	2- 7	40.3	16.0	VI
74	1909	3-12	40.9	15.4	VI
75	1910	28- 5	40.2	16.6	VI
76		7- 6	40.9	15.5	X
77		7- 6	40.9	15.5	F
78		16- 6	40.9	15.5	VI
79		31- 7	40.9	15.5	VI
80		3-10	40.3	16.0	VII
81	1910	3-10	40.3	16.0	F
82	1917	13-10	40.2	16.0	VII-VI
83		4-11	40.2	16.0	VII-VI
84		21-11	40.2	16.0	F
85	1920	7- 3	40.8	15.7	VI
86	1923	8-11	40.8	15.4	VI
87	1925	28- 7	41.2	15.9	VII-VI
88	1927	27-12	41.2	15.4	VII
89	1930	22- 7	41.1	15.4	F
90		22- 7	41.1	15.4	F
91		23- 7	41.1	15.4	X
92		5- 8	41.1	15.4	VI
93		6-11	41.0	15.4	VII-VI
94	1931	10- 5	41.1	15.4	VI
95		3-12	41.3	15.8	VII
96	1932	30- 3	40.6	16.9	VI
97	1933	7- 3	41.0	15.4	VI
98	1934	3- 7	40.2	16.0	VI
99	1935	3-12	40.5	15.9	VI
100	1941	13-12	40.2	16.9	VI
101	1946	18- 8	41.5	16.1	VIII
102	1950	6- 4	41.1	15.0	F
103	1954	6- 8	40.7	15.9	VI
104	1955	3- 7	40.1	15.8	VI
105	1956	9- 1	40.6	16.3	VII
106	1957	18-10	40.6	15.7	F
107		19-10	40.5	15.7	VI
108	1962	21- 8	41.1	15.1	IX-VIII
109		21- 8	41.1	15.1	IX
110		21- 8	41.1	15.1	VII-VI
111	1963	13- 2	40.6	15.7	VII
112		13- 2	40.5	15.7	VII
113	1964	18- 2	41.1	15.2	VI
114	1966	4-10	40.6	15.7	VI
115	1969	14-11	40.7	15.7	VII
116	1970	22-10	40.7	15.4	F
117		22-10	40.7	15.4	F
118	1971	29-11	40.4	15.8	VII
119	1973	8- 8	40.8	15.4	VII

+42 shocks reported as Felt (F) in the same area for the period 16 December 1857 - 10 February 1859, are exluded from the catalogue as they were assumed by Calcagnile *et al* (1977), to be lower than Intensity V.

Table 4.1 *continued*

a 'creep-type' landsliding affecting the historic centre of Maratea. Their views agree with those of Rizzo (1986a & b), who has identified a similar mechanism in deep landslides in Bulgaria. However, it is regrettable that the Guerricchio *et al* (1986b) did not extend their seismographic net into the area of the fault plane scarp and no data exists for seismic activity in this area.

The available data seems to suggest that active faulting is not a feature of the Maratea region, at least in historic times, thereby indicating that any fresh looking fault plane is probably an exhumed feature. The presence of a 'white line' at the base of the fault plane scarp, which indicates a zone of minimal weathering and thereby recent exposure, could be indicative of recent fault movements due to seismic activity. However, this phenomenon is extremely localised and does not occur along the entire length of the fault scarp; its formation by processes other than seismic activity is, therefore, more likely. This argument will be developed in Chapter Six. To summarise, seismic data indicates that, for this millennium at least, there has been no fault movement. Nonetheless there is clear evidence of a fault plane scarp in the landscape, so at some point in time active faulting must have ceased. If this point could be dated it would enable the chronology of events in the area to be more fully understood. In particular, if the assumption is made that the sackung and fault plane scarp are contemporaneous features, then dating the movement of the fault plane scarp would also date the initiation of the sackung. This would then enable estimates to be made of the rate of movement of the sackung. In addition, a date for the formation of the fault plane scarp would establish a possible date for the calving of the limestone blocks. It follows that this would be a minimum age only, as the blocks may have been calved at some time before the last movement of the fault.

4.4 Methods of Dating Fault Lines

Ikeya (1985) has argued that the 'age of fault formation or movement is vitally important for tracing the history of large earthquakes and assessing future movements of the fault' (Ikeya, 1985, p.81). Wallace (1977) attempted to date the age of fault scarps in Nevada by their geomorphological characteristics. His technique relied on the ability to recognise 'young' fault scarps in the landscape whose age was known. From this he constructed a chronological sequence of scarp degradation based on the morphological changes that occur to a scarp face through time. To this were fitted the profiles of scarps of unknown age. Unfortunately there are two major drawbacks with the work of Wallace (1977). The first is that his information is applicable to Nevada only. As Costa and Baker (1981) point out 'the processes operating on the hillslope are extremely complex functions of climate, vegetation, lithology and structure. Different regions tend to exhibit different types and/or intensities of processes. These will produce different time scales of modification' (Costa and Baker, 1981 p.92). The second major drawback of the technique, which was recognised by Bucknam and Andersen (1979), is that in any given area, there are often very few fault scarps of known age.

A more quantitative approach to fault dating was adopted by Vita-Finzi and Ghorashi (1978) in the Iranian Makran. Radiocarbon and archaeological dating (Vita-Finzi, 1969, 1975) enabled the age of two Quaternary alluvial units to be established. By tracing the depositional history of the area the authors were able to establish that faulting took place during an erosional phase, to which limiting ages based on the radiometric dates, could be ascribed.

In Japan much work has been carried out on the dating of fault movement by direct methods. Ikeya (1983) has applied the technique of Electron Spin Resonance (ESR) to fault lines at Rokko and Atotsugawa. ESR is similar to thermoluminescence (TL dating) in that it utilises the trapped electron population of a sample. The ESR signal intensity is used together with a calibration curve to assess the total dose (TD) of natural radiation received by a sample. The ESR age (T) is determined by dividing the TD of a sample by an estimate of the average annual dose rate of radiation (D); simply, T = TD/D. Despite extensive use in Japan (for example, Ikeya, 1983; Ikeya *et al*, 1982, 1983; Ikeya and Miki, 1980; Miki and Ikeya, 1982), the method has not been widely accepted in Europe although it has some advantages over TL dating (see, Hennig *et al*, 1981; also Faure, 1986, for a good review of isotope dating techniques).

The problem at Maratea is to find a suitable medium to date. The fault scarp is extensively covered in calcite deposits which would lend themselves to TL, ESR, Uranium-series or radiocarbon dating. Unfortunately, the significance of any dates obtained is more problematic. In many areas the calcite layer is thin and often flakes away to reveal slickenside ridges beneath. In these sections it is clear that the calcite and fault are not contemporaneous features and that the calcite layer has been formed by rainwater mobilising calcium carbonate in the weathered area above the fault and washing it over the fault plane scarp. The fault then antedates the calcite but it is not possible to say by how much. The calcite could relate to the last movement of the fault, but equally, may relate to any point between then and the present.

In other areas, the calcite layer is much thicker, often up to 15mm thick. This type of calcite is very different from the skeletal layer noted above. In addition to being thicker the calcite is firmly cemented to the fault plane scarp and will not flake away as does the thinner layer. Sections through it reveal the calcite source to be veins within the rock body. Vita Finzi (*pers. comm.*) has suggested that a process known as seismic pumping could be responsible for the calcite layer. Seismic pumping is a little known process that is not well understood but which is thought to be able to mobilise calcium carbonate within a carbonate rock during fault movement. The process cannot be confirmed although it can be said that the fault antedates the calcite. If caused by seismic pumping, the fault plane scarp and calcite will be contemporaneous and the age of one will reveal the age of the other.

Mineralogical differences also exist between the two calcite layers. X-ray diffraction (XRD) experiments revealed that the thinner calcite layer contained a high percentage of dolomite. Fig. 4.4 shows the XRD trace of the thin calcite layer. The three principal calcite peaks (I, II and III) have been noted; the other unmarked peaks can be determined by calculating their position along the trace and when this is done it is clear that these peaks are dolomite. In a similar manner, the percentage of dolomite can be determined by calculating the magnitude of the peaks. Results indicate a level of 93% calcite and 7% dolomite for the thinner layer.

An initial XRD trace of the thicker calcite sample revealed a dominant principal calcite peak that obscured the dolomite peaks. As a result a second trace (shown in Fig. 4.5) was run with the vertical scale increased. This takes the principal calcite peak off the trace but highlights the dolomite peaks. Calculations of dolomite and calcite concentrations indicate levels of >98% calcite and <2% dolomite.

These results indicate that the thicker of the two calcite layers is pure enough to provide an absolute radiometric date. As noted above TL, ESR and radiocarbon dating are all suitable for calcite, although again the choice can be narrowed. If it is assumed that the calcite and the fault and the fault and sackung are contemporaneous, then it could be that a date of the order of 30,000 years BP may be obtained for the calcite. Such a date would be at the very limit of standard laboratory ^{14}C dating. ESR dating is a technique that could be applicable but one which has been used sparingly in the UK. Some ESR work has been carried out on burnt flint deposits at the Department of Chemistry, University of Leicester but they are unwilling to carry out ESR work on a commercial basis. Outside Europe, apart from Japan, ESR dating has been undertaken at McMaster University in Ontario and at the University of Hanover. In the UK thermoluminescence is a dating technique that has been more

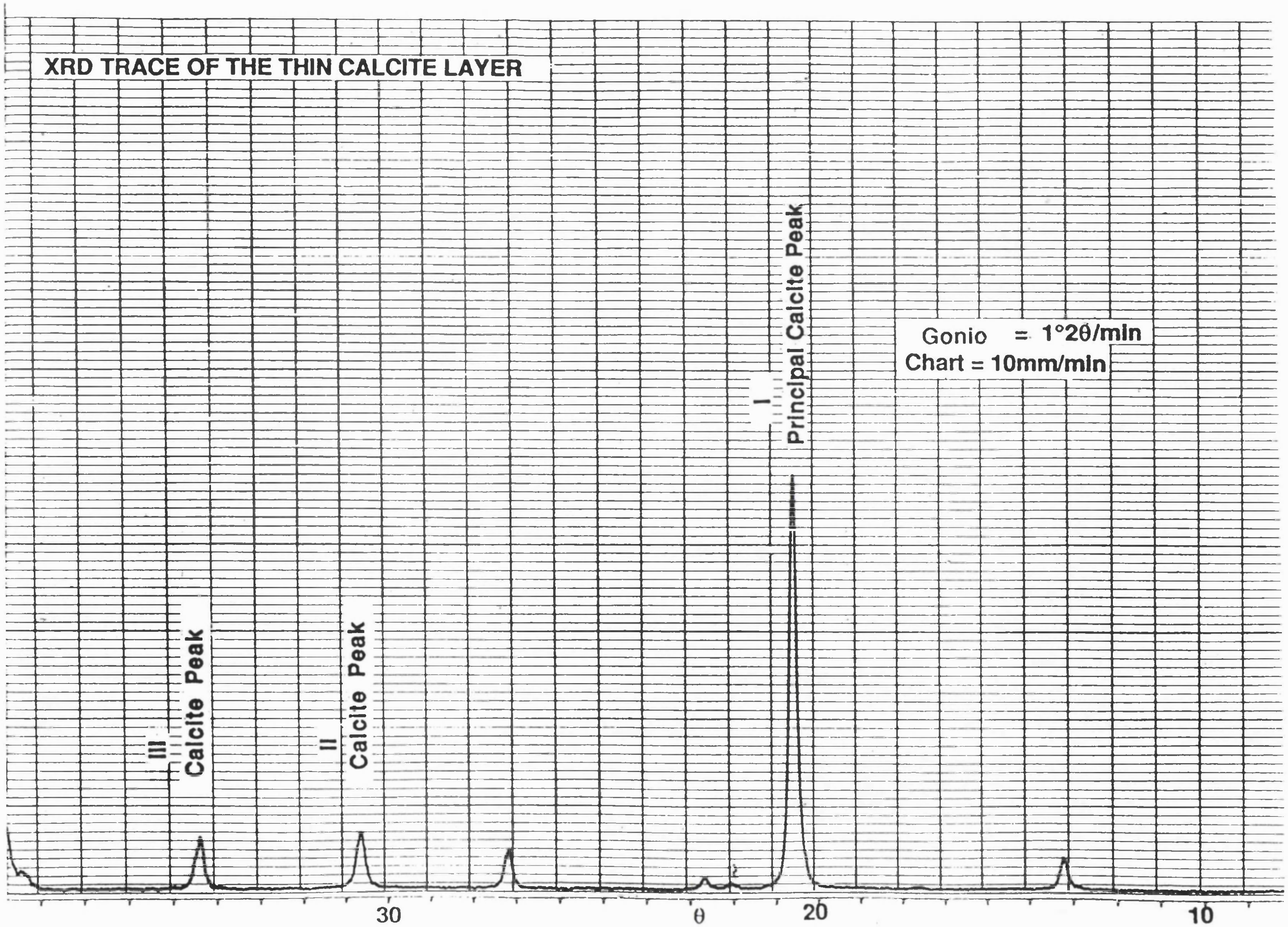


Fig. 4.4 : XRD trace of the thin calcite layer.

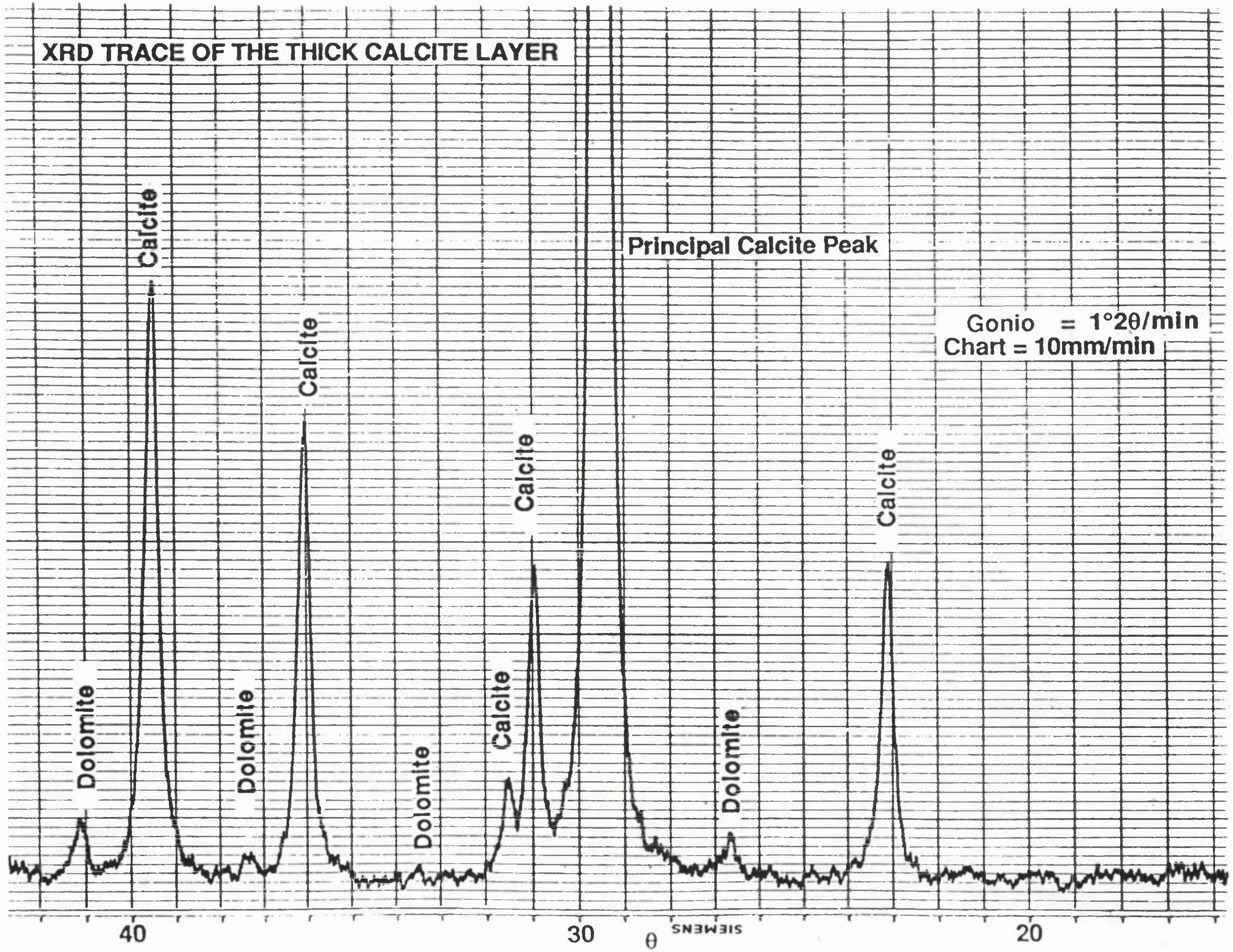


Fig. 4.5: XRD trace of the thick calcite layer.

widely applied, although there are no laboratories willing to undertake work on geological samples. In short, the uranium series disequilibrium method of dating calcite is the most readily applicable technique and is available commercially from the UK Atomic Energy Research Establishment at Harwell. The technique has been successfully applied on calcite (for example, Debenham and Aitken, 1984; Hennig, *et al*, 1980; Schwarcz, 1980). As detailed in Chapter Two, Carobene, *et al* (1986) have used U-series dating to date neotectonic movements along the shorelines of Calabria. The cost of U-series dating is high (about £450/sample at 1988 prices).

4.5 Uranium Series Dating of the Maratea Fault

4.5.1 Uranium Series Dating

Broadly speaking, radiometric dating techniques fall into two major categories:

(i) Dating techniques which measure the decay of a given radionuclide. Among dating methods in this category are ^{14}C, K/Ar (Potassium/Argon) and Rb/Si (Rubidium/Strontium).

(ii) Techniques which require a measurement of the degree of equilibrium between a parent and daughter radionuclide. Uranium Series (or U-series) dating is in this category.

Uranium Series dating is based upon the assumption that in any naturally occurring and undisturbed rock, which contains Uranium, a state of equilibrium exists between Uranium and its daughter nuclides. Resedimentation of the rock to form a sedimentary deposit (for example calcite), causes a set of geochemical reactions to take place in the Uranium chain bringing about a disequilibrium between Uranium and its daughter products. U-series dating measures the degree to which the parent and daughter radionuclides have returned to a state of secular equilibrium.

U-series dating can itself be sub-divided into two categories:

(i) Dating methods based on the measurement of the accumulation of U daughter products;

(ii) Dating methods based on the measurement of excess daughter products.

Table 4.2 (from Ivanovich and Harmon, 1982) provides a useful summary of the various U-series disequilibria dating methods that are available. Of these the $^{230}Th/^{234}U$ method is the most widely used for the dating of carbonate material and has a range of about 350,000 years.

4.5.2 The $^{230}Th/^{234}U$ Method

The $^{230}Th/^{234}U$ dating method relies on the assumption that at the time of its formation a sedimentary deposit contains no ^{230}Th, so that at a given time t, the ratio between $^{230}Th/^{234}U$ is given by the expression:

$$^{230}Th/^{234}U = \frac{1 - e^{-\lambda_{230}t}}{^{234}U/^{238}U} + \left(1 - \frac{1}{^{234}U/^{238}U}\right)\frac{\lambda_{230}}{\lambda_{230} - \lambda_{234}}\left(1 - e^{-(\lambda_{230}-\lambda_{234})t}\right) \quad \text{(Eq.4.1)}$$

Where: e = Naperian constant equal to 2.718281828

λ = A decay constant representing the fraction of radioactive atoms that decay per second

t = Time

The technique is based on a measurement of the activity ratios of $^{230}Th/^{234}U$ and $^{234}U/^{238}U$, obtained using alpha spectrometry. The ratios are then substituted into Equation 4.1. A comprehensive account of the chemical analysis that is required to produce these ratios and a description of the analysis of the alpha spectra is contained in Ivanovich and Harmon (1982, Ch.5).

In addition to the $^{230}Th/^{234}U$ and $^{234}U/^{238}U$ ratios, a measure is also taken of the $^{230}Th/^{232}Th$ activity ratio. This is to allow an estimate of the degree of contamination by detrital Th. ^{232}Th in a carbonate sample implies a detrital component which indicates a

Dating Method	Nuclide	$t_{\frac{1}{2}}$	Dating range	Application
$^{230}Th/^{234}U$ (accumulation of ^{230}Th)	^{230}Th	7.52×10^4 y	$\lesssim$ 350 ky	marine and terrestrial carbonates (fossil corals, shells, speleothems, bones, travertines), volcanic rocks
$^{231}Pa/^{235}U$ (accumulation of ^{231}Pa)	^{231}Pa	3.43×10^4 y	$\lesssim$ 150 ky	as above
$^{231}Pa/^{230}Th$ (accumulation of ^{231}Pa and ^{230}Th)	^{231}Pa, ^{230}Th		$\lesssim$ 200 ky	
$^{226}Ra/^{238}U$ (accumulation of ^{226}Ra)	^{226}Ra	1.602×10^3 y	$\lesssim$ 10 ky	limited application as above, mostly as a check for closed-system
$^{234}U/^{238}U$ (^{234}U-excess decay)	^{234}U	2.48×10^5 y	$\lesssim$ 1250 ky	limited, some fossil corals and some waters
^{230}Th-excess decay	^{230}Th	7.52×10^4 y	$\lesssim$ 300 ky	deep sea sedimentation rates, Mn nodule formation rate
^{231}Pa-excess decay	^{231}Pa	3.43×10^4 y	$\lesssim$ 150 ky	as above
$^{230}Th/^{232}Th$ (^{230}Th-excess decay)	^{230}Th	7.52×10^4 y	$\lesssim$ 300 ky	deep sea sedimentation rates.
$^{231}Pa/^{230}Th$ (excess decay)	^{231}Pa ^{230}Th average $t_{\frac{1}{2}}$	3.43×10^4 y 7.52×10^4 y 6.2×10^4 y	$\lesssim$ 150 ky	deep sea sedimentation rates
^{234}Th-excess decay	^{234}Th	24.1 d	100 d	rapid sedimentation rates in shallow waters, particle reworking and diagenesis study
$^{228}Th/^{232}Th$ (^{228}Th-excess decay)	^{228}Th	1.913 y	0.01 ky	shallow water sedimentation rate (as below)
^{210}Pb-excess decay	^{210}Pb	22.3 y	0.1 ky	sedimentation rates in lakes, estuaries, and coastal marine environment, geochemical tracer, settling rates
He/U (He accumulation)	all alpha emitting nuclides of U-series		1000 ky	fossil corals, groundwaters.

Table 4.2: Table of U- series methods. From Ivanovich and Harmon (1982).

concentration of non-radiogenic ^{230}Th. As the dating method relies on the assumption that no ^{230}Th is present in the deposit at its time of formation, a concentration of non-radiogenic Th in the sample to be dated would yield an unreliable $^{230}Th/^{234}U$ activity ratio and an inaccurate date. For a fully reliable dating estimate the $^{230}Th/^{232}Th$ ratio should be in excess of 20.

Equation 4.1 may be solved by two methods. The first involves plotting the activity ratios of $^{234}U/^{238}U$ against $^{230}Th/^{234}U$. The resulting isochron plot, is shown in Fig. 4.6 The age of the sample is determined by reading off the $^{234}U/^{238}U$ and $^{230}Th/^{234}U$ values. A more precise method is to substitute values of t into Equation 4.1 until the equation approaches unity. This is the method employed by the AERE Harwell who use a computer program - UTAGE-3 - to solve the equation. The $^{230}Th/^{234}U$ age is calculated according to the Newton - Raphson iterative method described in detail in Appendix C of Ivanovich and Harmon (1982).

4.5.3 Dating the Maratea Fault - Sample Pre-Treatment

Four samples of the thick calcite layer were removed from the fault plane scarp to the laboratory. Financial constraints, however, restricted the number of samples that could be sent for U-series dating to one, although clearly this is an unsatisfactory number. It was, therefore decided by the author to use the sample taken from the area of fault plane scarp next to pin 65 (see fold-out map in back pocket); the reason behind this decision was that this sample appeared to have a thicker calcite layer than the others and so would yield a sufficiently large amount of material for dating. Although the technique employed by the AERE, Harwell, requires only a 50g sample, it is clearly wise to collect more than this so that the dating experiment is safeguarded against loss or damage to the sample.

The calcite layer (see Plate 4.4) was removed by means of a rock saw taking care not to contaminate it with the underlying material. The sample was rinsed under tap water and dried. Next it was broken down and powdered for 10 minutes in a Teema mill.

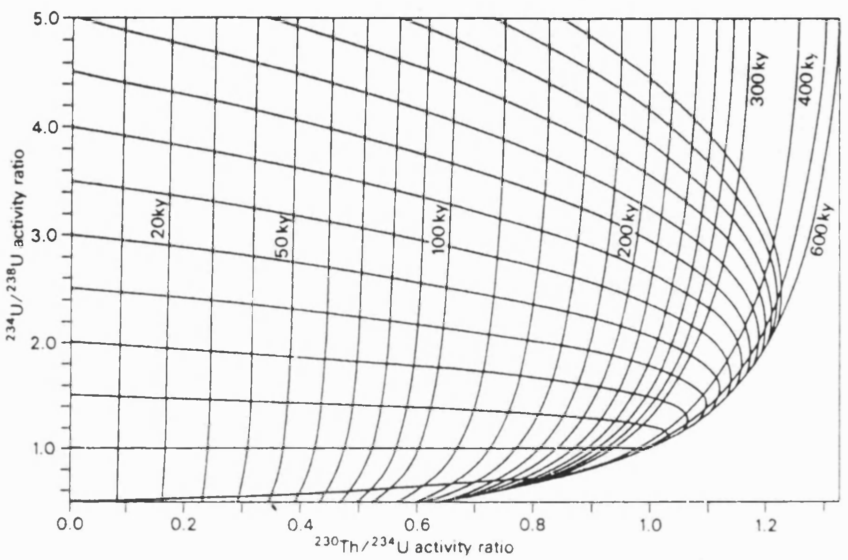


Fig. 4.6: Variation of $^{234}U/^{238}U$ and $^{230}Th/^{234}Th$ activity ratios with time in a closed system with no initial ^{230}Th. The near vertical lines are isochrons (lines of constant age obtained from Equation 4 1 but different $^{234}U/^{238}U$ activity ratio). The near horizontal lines show change in the nuclide activity ratios as age increases for different initial $^{234}U/^{238}U$ activity ratios as indicated. From Ivanovich and Harmon (1982).

The sample was weighed out and in all yielded 105g of calcite. Of this, a 50g sample was soaked in Hydrogen Peroxide (H_2O_2) for 36 hours to remove any organic material. It was then flooded with water and the sediment allowed to settle out for one and a half hours; this was done twice. Finally the sample was dried in the oven at 35°C for 16 hours. After pre-treatment the XRD traces described above were run and the sample sent to the AERE, Harwell, for dating.

4.5.4 Results of the AERE Harwell Dating

The results of the AERE Harwell dating are displayed in Table 4.3. It can be seen that the result of 46.4×10^3 years BP represents a maximum age for the calcite only as the $^{230}Th/^{232}Th$ ratio is low indicating, as described above, the possible presence of detrital Th. The age of the calcite layer is therefore less than the quoted date, that is it is younger than 46,400 years BP.

4.5.5 Discussion: Significance of the Results

The evaluation of the U-series date is difficult and problematic for two reasons; first, the origin of the calcite is not known with absolute certainty and some doubt must exist as to whether seismic pumping is the cause. Second, it is clearly very unwise to draw firm conclusions on the basis of one date alone.

Ciaranfi *et al* (1983) place the Maratea fault scarp in their Phase IIIb (2.0 - 0.7MY BP). As was discussed in section 3.3.2, however, it is likely that the Maratea fault opened in two phases, a situation witnessed by the distinctive break of slope evident on profiles of the fault. The U-series date therefore relates to the last movement of the fault with the first movement being clearly older than 46,400 years BP. Thus it could be argued that Ciaranfi *et al's* date more probably relates to the first round of neotectonic movements that formed the initial fault. The new date may suggest a further round of neotectonic

URANIUM SERIES RESULTS AERE Harwell Code 5213

U content (ppm)	Activity ratios $^{234}U/^{238}U$	$^{230}Th/^{234}U$	$^{230}Th/^{232}Th$	Age ± error $\times 10^3$ years	Initial $(^{234}U/^{238}U)_0$
0.19 ± 0.01*	1.14 ± 0.04	0.35 ± 0.02	8.91 ± 1.19	46.4 $^{+3.5}_{-3.4}$	1.16 ± 0.05

* All quoted errors are 1σ uncertainties due to nuclear counting statistics only.

Table 4.3: Results of the U-series age determination for the Maratea fault plane scarp calcite. The date of 46.4 x 10^3 years is a maximum age only as the $^{230}Th/^{232}Th$ ratio is low indicating the possible presence of detrital thorium. The ratio should be >20 for a fully reliable age estimate.

movements in this area, not recognised by Ciaranfi, occuring about 40,000 years ago and falling into Phase IV - V (0.7 MY BP - to date) of the neotectonic evolution of Italy. This is true whether the 46,400 year BP date holds, or whether a younger date is correct. Indeed a younger date clearly takes the last movement of the Maratea fault even further into Phase IV - V. As such the Maratea result, if it is correct, provides an argument to apply absolute dating techniques to a larger number of fault scarps in southern Italy in order that the neotectonic evolution of the area may be more fully understood.

As regards the estimate of 30,000 years BP, envisaged by Guerricchio and Melidoro for the formation of the fault and the sackung, this too is problematic. The U-series date neither proves, nor disproves the date. Indeed, if a date younger than 46,400 years BP is correct, then the U-series date moves closer to the 30,000 year figure. All that can be safely said is that the discrepancy between the authors U-series date and that of Guerricchio *et al* (1986a), lends further weight to the argu ment that the problem requires more absolute dates and more research into the seismic pumping phenomenon.

CHAPTER FIVE

CHRONOLOGICAL FRAMEWORK

II

DATING THE EXPOSURE OF THE FAULT SCARP BY LICHENOMETRY

5.1 Introduction

It is clear from the foregoing discussion that active faulting in the Maratea valley is a fossil, or at least dormant, process. No seismic shocks that could be associated with fault movement have been reported in historical time. The work of Guerricchio *et al* (1986b), which recounted the evidence of local people who felt minor tremors during 1983, is the only evidence for any seismicity associated with either the sackung or fault. As noted previously these authors do not attribute these tremors to earthquake activity but to minor slope failures in the area of the *centro storico*. Evidence from the U-series data suggest, albeit with a number of caveats that were discussed in the previous chapter, that the last movement of the fault may have occured around 40,000 years BP. The presently visible fault plane scarp has probably, therefore, been exposed by mass movement rather that tectonic processes. If the rate of operation of these processes could be established, then a clearer understanding of the chronology of mass movement in the area would be established.

During field visits to the Maratea area the author noted a number of lichen species growing on the fault plane scarp. A technique of dating known as lichenometry, which has been used in many geomorphological applications, was therefore applicable to the fault plane in order to date its time of exposure. This chapter will describe the technique used by the author and detail the results of the work. This work represents the first use of lichenometry in the Mediterranean and its first application to fault scarp dating.

5.1.1 Lichenometry

Lichenometry is a dating technique, widely used in geomorphological studies since it was conceived by the late Roland E. Beschel in the 1950s (Beschel, 1950, 1957, 1961, 1965). It involves the assumption that when a surface (known as a substrate) is exposed to sub-aerial conditions it will immediately be colonised by lichens; the largest lichen on any surface will be the oldest growing under optimum environmental conditions and its size will be in proportion to the age of exposure of the substrate.

Lichenometry can be used as a relative dating technique if the spatial variation in lichen sizes can be determined over a given area (for example, Andrews and Webber, 1964; Birkeland, 1973; Matthews and Shakesby, 1984). On the other hand, if an age can be calculated for a lichen of a given size, lichenometry may be extended to predict an absolute chronology (for example; Andersen and Sollid, 1971; Benedict, 1968; Gordon and Sharp, 1983; Lindsay, 1973; Matthews, 1975; Worsley, 1970). Lichenometry is a very simple technique to apply, requires no particular biological training and produces quick results in the field at no cost. Given this, it is not surprising that the technique has been extensively applied in many areas of geomorphological study. It is used exclusively in short term (Holocene) studies where radiocarbon dating, dendrochronolgy or other allied techniques are difficult or impossible. Within the Holocene the range of the technique has varied; many workers in southern Norway, for example, have used lichenometry to date glacier retreat since the 'Little Ice Age' of 1750, a period of only 250 years (see Andersen and Sollid, 1971; Mottershead and White, 1972, 1973). In more Arctic situations, on the other hand, it has been argued that some lichen species may be as old as 2000 years and that the technique may justifiably encompass this range (for example see Benedict, 1967). By far the largest group of lichenometric workers have been glacial geomorphologists wishing to study patterns and rates of glacier retreat and the literature cited below tends to reflect their dominance. Nonetheless, it must be remembered that lichenometry is applicable to many other branches of geomorphology as well as to other disciplines, although no record exists of it ever having been applied in a Mediterranean context.

The discussion below will be organised in two sections. The first section will focus on the conceptual framework and methodology of lichenometry, its assumptions, methods, species employed and principal applications. It is hoped that this brief resume will allow the reader unfamiliar with the technique to gain a working knowledge of lichenometry and its terminology. The second section will be a detailed account of the application of the technique in the Maratea area.

5.1.2 Assumptions

Lichenometry utilises the lichen species that colonise a substrate when it is exposed to sub-aerial conditions. A substrate may be defined as any surface that is available for lichen colonisation. Most commonly the substrates employed have been the end-moraines of glaciers in both arctic and alpine situations. Other types of surface may also form substrates which are suitable for lichen colonisation. For example, Trudgill *et al* (1979) dated the age of exposure of limestone pavements revealed by the processes of soil erosion.

Whatever substrate is employed, Beschel (1957, 1961) has argued that four main assumptions must hold good. These have been summarised by Worsley (1981):

(i) The substrate must be lichen free on exposure to sub-aerial conditions;

(ii) Rates of colonisation must be known;

(iii) Growth is linear with time; and

(iv) Selection of the single largest thallus will simultaneously select the oldest individual growing under optimum environmental conditions.

In glacial situations much time has been given to the first assumption as commonly, lichens do survive redeposition, and if sufficient care is not taken, anomalously large thalli become incorporated into lichenometric measurements and so make a substrate appear older than it is.

The most fundamental criticisms of lichenometry have centred on assumptions (iii) and (iv). Jochimsen (1966) has questioned the ecological foundations of the technique and the assumption that lichen growth is linear with time. Beschel (1961) argued that lichens initially experience a phase of very rapid growth; a so called 'great period' which lasts from 14 - 20 years after colonisation. Growth then becomes essentially linear with time. Both Jochimsen (1966) and Worsley (1981) have argued that the assumption fails to take account of lichen growth patterns. After the 'great period' growth may be linear with time until a point is reached where the thallus begins to meet other thalli growing on the same substrate. Growth may then be retarded and the shape of the growth curve will change. Worsley (1981) applies a similar arguement to his rejection of assumption (iv) stating that the selection of the single largest thallus in lichenometric dating is 'tantamount to claiming that in any generation the tallest or fattest person in a country is the oldest', (Worsley, 1981, p.303).

Clearly, while time is an important factor in lichenometric dating, probably the most important, it is not the only control on thallus size. Assessments of lichen diameter must take account of other parameters as well as time; competition between lichen specimens for space on a substrate may well prevent a lichen from reaching its maximum achievable size as will, for example, the stability of the substrate (see section 5.3.3.2 for a fuller discussion of these factors). Regrettably, in lichenometry it has not always been the case that the lichen has been viewed as part of a plant community and that the growth of an individual lichen is partly dependent on the community. For the reasons mentioned above, lichenometry has achieved a tremendous popularity as a dating technique, but unfortunately this has led on many occasions to a serious abuse of the technique. The assertion that the assumptions of lichenometry must be rigorously adhered to, not merely restated, is therefore of particular importance.

5.1.3 Methods

Lichen curves may be established in either of two ways:

(i) *The Direct Approach*

The direct approach involves the systematic recording of the increase in thallus diameter over time. This is the technique favoured by lichenologists (Innes, 1985) as distinct from geomorphologists. The direct approach has two major disadvantages. First, lichens grow extremely slowly and thallus measurements must be taken over many years before an empirically derived growth curve can be described with any certainty. Clearly, this removes one of the major attractions of the technique to geomorphologists, namely the ability to produce quick results in the field. The second problem with direct measurements is that, because of slow growth, they cannot be taken at every stage in a lichens life cycle. Necessarily, direct measurements are only confined to the middle years and then extrapolated to define the complete curve. This involves the assumption of climatic uniformity during the entire lichen life cycle, a time span which depends on the species in question but may, as with *Rhizocarpon geographicum*, be as much as 2000 years (see Benedict, 1967). This is an assertion which is particularly untenable in glacial situations where geomorphologists are dating glacier retreat which itself assumes climatic change. Nonetheless, despite these problems Proctor (1983) and Innes (1985) contend that direct measurements, particularly those involving repeated photography, are the most accurate method of describing the lichen growth curve.

(ii) *The Indirect Approach*

It is because direct thallus measurements are so time dependent that most studies have favoured the use of indirect methods. The technique involves the identification of substrates of 'known age', determined from historical records or by a number of ancillary scientific methods such as radiocarbon dating or dendrochronology. Measurements of the largest lichens on each of these substrates are taken and an age-size graph drawn, either through the diameter of the single largest lichen or an average of the largest lichens. Surfaces of unknown age can then be dated by applying lichen measurements from them to the graph. The main advantage of the technique is that a chronological framework for the area of interest can be obtained quickly. In addition, indirect measurements partly overcome the problem of climatic fluctuations. It should be noted, however, that an indirect lichen curve is not the same as an empirically derived direct growth curve and should properly be termed an 'age-size' curve.

Indirect dating methods have been widely applied in geomorphological studies. Most commonly, glacier end-moraines have been used as substrates of known age, their date having been determined from historical sources (for example, Andersen and Sollid, 1971; Bornfeldt and Österborg, 1958; Matthews, 1973, 1974, 1975, 1977; Mottershead and White, 1972, 1973). Other substrates of known age have included tombstones (Winchester, 1984), Indian Walls (Benedict, 1967, 1968), spoil tips (Karlen, 1973, 1979) and stone cairns (Beschel and Weidick, 1973).

In short, any substrate can be employed in lichenometric dating provided:

(i) It can be established that the substrate was lichen free when exposed to subaerial conditions or erected;

(ii) The substrate can be accurately dated;

(iii) It has not been cleaned since first exposed or erected; and

(iv) Competitive interactions between other lichens or higher plants have not begun to retard the lichen growth pattern.

Problems arise with the indirect method when isotope dating techniques are employed to provide substrates of known age. Benedict (1967), for example, used organic material buried beneath a mudflow levée to date the age of the mudflow. He then sampled the lichen population on boulders associated with it. Regrettably, Benedict's curve was based on the original half-life of radiocarbon (the Libby half-life) set at 5568 (5570) ± 30 ^{14}C BP; the half-life of radiocarbon has now been established at 5730 ± 40 ^{14}C BP. In addition to such a major error which involves a fundamental re-assessment of radiocarbon dating, the use of the technique in lichenometry is prone to errors associated with its application. Matthews (1980) has assessed these problems as;

(i) The separation of organic layers of different age;

(ii) Uncertainties over the degree of soil development;

(iii) The susceptibility of shallow organic horizons to contamination; and

(iv) The possibility of soil disturbance after burial.

For completeness it should be noted that attempts to calculate the minimum age of living lichens by radiocarbon dating have not been successful (Nydal *et al*, 1964).

Even when isotope dating is not used, problems still occur with the identification of substrates of known age. When tombstones are used for example, it is important to establish whether the monument was erected soon after the date of death inscribed or at some later time (Topham, 1977). Innes (1983, 1985) has noted that surfaces such as tombstones provide a very small surface for colonisation; a considerable scatter of lichen sizes is, therefore, often apparent. Whatever surface is used, it is vitally important to know if it has been cleaned since its erection, for any surface that has is bound to underestimate lichen age. A final consideration is the necessity of ensuring that both the surface of known age and the substrate to be dated occupy a similar environmental niche. All of the following factors should be common to both surfaces; lithology, moisture availability, sunlight, exposure, population dynamics, substrate stability, temperature, degree of pollution and aspect. A difference in any of these factors between the substrate of known age and the substrate to be dated will introduce a possible source of error.

5.1.4 Species Employed

Having selected to conduct lichenometric dating using the direct method, or having chosen surfaces of known age for the indirect technique, the geomorphologist needs to identify the lichen species that will be employed. A lichen thallus is a plant body where a fungal component has succeeded in establishing a symbiotic relationship with algae (Hale, 1974). All lichen species can be sub-divided into one of three classes; foliose, fruticose and crustose. Foliose and fruticose lichens are upstanding individuals easily destroyed by falling stones, damaged by wind or eaten by small animals. Their use in lichenometry is therefore precluded and the following discussion will concentrate on saxicolous crustose lichens only.

Saxicolous crustose lichens consist of three parts; an upper corticle layer of hyphae; a middle zone of algal cells and a lower layer of fungal components. In saxicolous crustose lichens there is usually a discernable band around the circumference of the thallus which contains no algal cells; this is known as the prothallus.

The taxonomy of lichens is extremely difficult and confused and, therefore it is essential before any lichenometric dating is carried out, to have the species that are to be used identified by an experienced lichenologist.

5.1.5 Applications

Lichenometry, as applied to the dating of glacier retreat in both arctic and alpine situations, has been dominant in the lichenometric literature. The reasons for this are clear; saxicolous crustose lichens adapt well to the high relative humidity of these regions and glacier end-moraines provide ideal substrates of known age with little ecological variation between historically dated end-moraines and those of unknown age.

The dominance of this technique in these regions does not preclude its use elsewhere or its application to other dating problems. Birkenmajer (1980) has used lichenometry to date the age of the Penguin Island volcano and raised marine beaches (Birkenmajer, 1981) in the South Shetland Islands (West Antarctica). Raised beaches and associated archaeological features in the north Swedish coastal region of Bothnia were dated by Broadbent (1986) and lake shoreline development in the Jotunheimen, south Norway by Matthews *et al* (1986). Winchester (1984, 1988) dated archaeological features at the neolithic stone circles of Rollright in Oxfordshire and Castle Rigg in the Lake District. Of more direct relevance to Maratea, Nikonov and Shebalina (1979) dated earthquake age in Central Asia by lichenometric studies on associated rockfall debris; Porter and Orombelli (1981) and Orombelli and Porter (1983) the hazard from Alpine rockfalls and Carton *et al* (1985) suggested the possible use of the technique in dating earthquake induced geomorphological features.

5.2 Lichenometry Applied to Maratea

5.2.1 Establishing the Age-Size Curve

Within the context of this project the direct approach to lichenometric dating is clearly impractical. Given this, a search was conducted in both the valley of Maratea and its surrounding regions for substrates of known age in order to construct an age-size curve for the purposes of indirect dating. It was important that all the substrates occupied a similar environmental niche to the feature that required dating, that is, the fault plane scarp.

Twelve substrates were found and although this figure may appear at first sight to be small, it is by no means unusual in lichenometric dating. Andersen and Soliid (1971) used only five substrates in their curve for Nigardsbreen as did Mottershead and White (1972) for Tunsbergdalsbreen, both in south Norway; Matthews (1971) was able to identify only four moraines of known age at Storbreen, also in southern Norway, although his data was considerably expanded by other surfaces of known age previously published for nearby glacial forelands. Benedict (1967) used twenty-four historically dated surfaces to fix the first 500 years of his curve for the Colorado Front Range, but then had only four substrates to extend the curve back a further 1500 years. The use of twelve substrates for Maratea covering only 197 years is, therefore, normal for lichenometric dating; the important requirement is not so much the number of substrates, although clearly the more the better, but the quality of the information they contain and how accurately they reflect the essential criteria for curve construction described in section 5.1.3. Moreover, if a lichenometric curve derived for a particular area, can be compared with similar curves for other areas, then this will provide useful supporting evidence (see section 5.2.1.6).

5.2.1.1 Substrates of Known Age

The positions of the substrates for Maratea described below are shown on Fig. 5.1.

1. *Road to the statue of Christ. Dated 1978.*

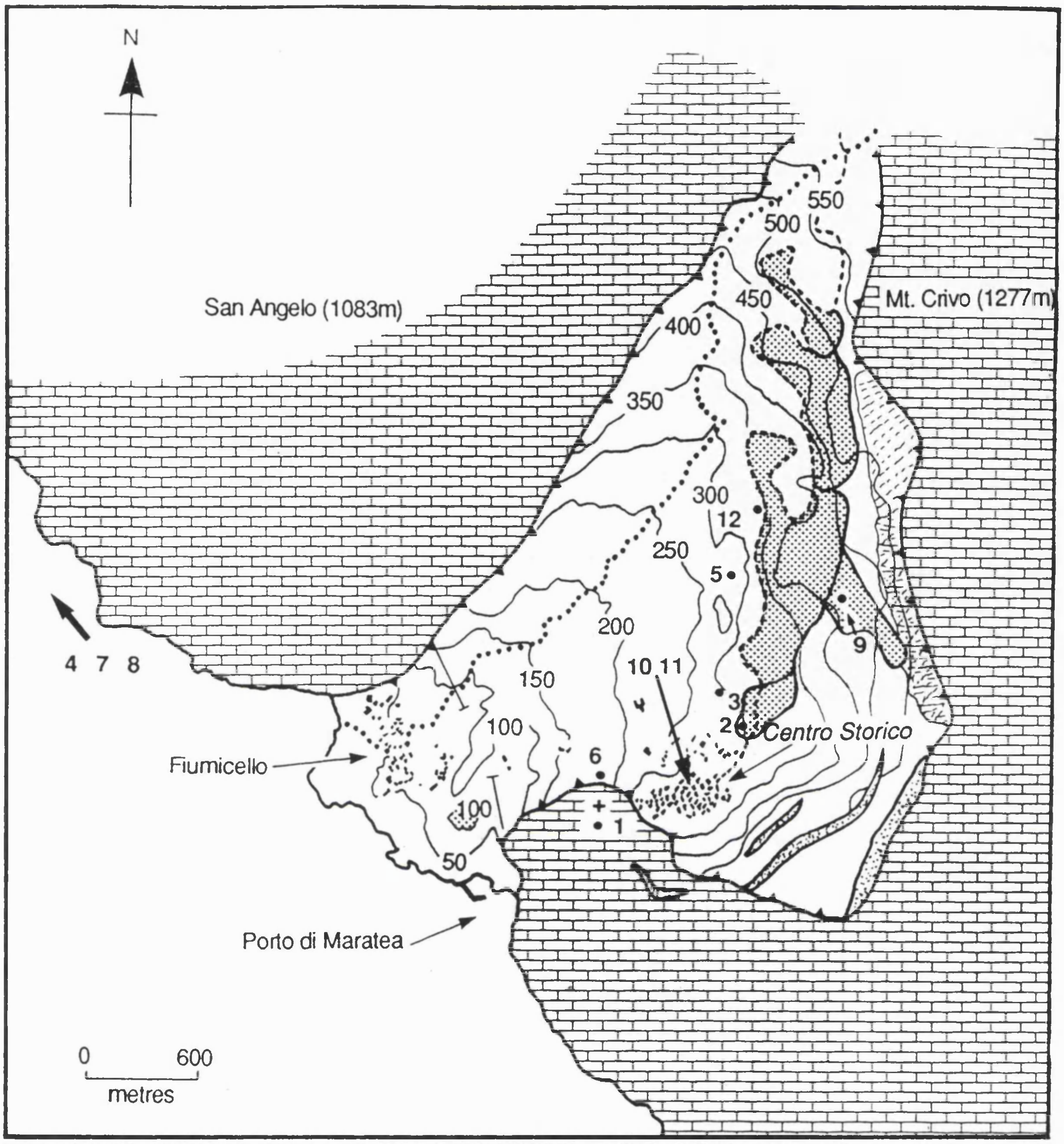
One of the most impressive features of Maratea is the figure of Christ which stands on the summit of Monte San Biagio (Plate 5.1). The statue was constructed in 1963 of steel reinforced concrete. Being of a different material to the fault plane scarp, it is not itself a suitable substrate for lichenometric dating. However, in 1978 a footpath leading to the statue was constructed for visitors (Lamarca, 1986) and it is this which provides the datable substrate.

The path is flanked on either side by a wall (Plate 5.1), constructed of local limestone extracted from a quarry at Brefaro in the adjacent valley. The wall is constructed of small blocks about 150mm - 200mm square and lichens may be observed over its entire length. Most of the wall blocks have been 'faced', that is they have been shaped and squared off; this process exposes a fresh substrate for lichen colonisation. Lichen measurements were only taken on faced blocks; any block that appeared to have its original surface was not considered as it may have supported a lichen community dating from a period before the construction of the wall.

2. *Crucifix on a rotated limestone block. Dated 1963.*

The position now occupied by the statue of Christ was formerly held by a large stone crucifix. In 1963 shortly before construction of the Christ began, the crucifix was moved to its present position on top of a large limestone block. The plinth on which the cross was situated was broken-up but the balustrading kept intact and moved to the new site. As with the statue of Christ a footpath with flank walls was built to the

SUBSTRATES OF KNOWN AGE



1 Road to Statue of Christ	7 Coastguard Station at Sapri
2 Crucifix on Block	8 Road to Sapri
3 Villa Comunale	9 "1869" House
4 Memorial in Aquafredda	10 Statue of the Madonna
5 Mausoleum in Maratea Cemetery	11 Cross in the Piazza Municipale
6 Memorial to San Biagio	12 Maratea - Trecchina Road

Fig. 5.1: Location of substrates of known age. For rest of key see Fig. 1.3

Plate 5.1: Substrate 1 - the road to the Statue of Christ constructed in 1978

summit of the block to allow access for visitors. Photographic evidence (Lamarca, 1986), illustrates that the path was built in 1963.

Lichenometric observations were confined to the flank walls of the footpath and the new plinth, but the balustrading was not sampled as it predates the 1963 transfer. The cross itself was totally lichen free; given that it too is of local limestone its condition argues for regular cleaning. This assertion is borne out by the Office of Public Works at the Comune di Maratea.

3. *Villa Comunale. Dated 1952.*

The *villa comunale* or town garden is a very common feature of most sizeable southern Italian towns. Generally it is a cleared area near the town centre with palm trees and benches. In Maratea, however, the *villa comunale* is a raised garden with seats, terraces and a small fountain, all of which is encircled by a stone balustrade which was laid out in 1952.

The construction of the flank walls of the garden is of a similar type to that of the paths to the Christ and the crucifix, except that the blocks used are larger, generally about 300mm square. The blocks are faced and, again, only those blocks that were obviously faced were sampled. The *villa comunale* supported a healthy lichen community; the *Comune* had no record of the garden walls being cleaned since their construction.

4. *Memorial in Aquafredda. Dated 1950.*

In order to fix the age-size curve with greater accuracy, it was decided to extend the search for substrates of known age beyond Maratea and into neighbouring towns. The hamlet of Aquafredda di Maratea about 6km north of Maratea was searched for substrates of known age. Only one was found which had a firm date; this was a memorial which was dated 1950. There was no evidence of cleaning and the memorial supported a strong lichen community.

5. *Mausoleum in Maratea Cemetery. Dated 1939.*

Although it has been suggested that tombstones often provide ideal substrates of known age (for example, Innes, 1983; Orombelli and Porter, 1983; Winchester, 1984), this is not the case at Maratea. Few tombstones of the type found in English cemeteries exist in Italy. The Italian people tend to bury their dead in stacked chambers with a slab of marble closing the entrance. There are problems with this method for lichenometrists; first, the area available for lichen colonisation is very small and second marble, being very smooth and highly polished, is not an ideal substratum. In addition to these problems, Italian cemeteries are generally scrupulously clean and care must be taken to ensure that the substrate in question has not been cleaned.

Larger, and more important, Italian families tend to bury their dead in mausoleums which are often of massive construction. One of these in the Maratea cemetery supported a small lichen colony and was selected as a suitable substrate. The date of its construction (1939) was etched into the gable and checked with the attendant, who confirmed its validity but could not be specific in reply to questions regarding its subsequent cleaning.

6. *Memorial to San Biagio. Dated 1932.*

On the site of a small promontory known as the Capo Casale, just off the road that leads from the *centro storico* to the statue of Christ is a memorial to San Biagio, patron saint of Maratea. The memorial is in the form of a small podium about 1.5m high and was constructed in 1932 to mark the twelfth centenary of the transfer of the remains of the saint from Armenia to Maratea (Plate 5.2).

The memorial supports a healthy lichen community on its flat top and around the base (Plate 5.2). Photographic evidence (Lamarca, 1986) shows the memorial to be totally lichen free when it was constructed and to support a healthy lichen community in 1982. The podium has a shaped and faced octagonal body of granite with

Plate 5.2: Substrate 6 - the memorial to San Biagio on the Capo Casale. Note the heavy lichen colonisation on the top and base. The fault plane scarp can be seen in the background.

a concrete base and capstone. The body is totally lichen free while the base and capstone support the lichen community. Officials from the Office of Public Works stated that there was no record of the stone having been cleaned.

7. *Former Coastguard Station at Sapri. Dated 1927.*

The town of Sapri, about 11km north of Maratea was, like that of Aquafredda, searched for substrates of known age. Only one was found which bore no evidence of cleaning and had a firm date. This was the former coastguard station.

A date of 1927 was etched into the plaster on a crest above the main door and purported to be the date of opening of the station. As this was only sixty years before the present it seemed unlikely that the date related to a possible replastering of the structure. This conclusion was reinforced by the physical state of the plaster which was loose and crumbling and testified to its age.

No lichens were found on the coastguard station itself but an adjoining wall which was tied into the main fabric of the building was found to support a lichen community. The wall was constructed of faced limestone blocks and again, only those that were obviously faced were used in the lichenometric study.

8. *Road to Sapri. Dated 1924.*

Photographic evidence (Lamarca, 1986), indicates that in 1924 a road tunnel from Maratea to Sapri was constructed about 8km along the coast from Maratea. Although the inner walls of the tunnel would have provided a fresh surface, it is unlikely that they would have favoured lichen growth because of darkness and traffic pollution. The barrier walls which flank the entry/exit of the tunnel were constructed shortly afterwards. They are, once again, built of faced limestone blocks and provide an ideal substrate of known age. It was not possible to carry out lichen sampling on the walls immediately adjacent to the tunnel opening as these had been removed to make way for new metal crash barriers. Fortunately, this situation was confined to the first 30m only. The wall after this point was also known to date from 1924 and supports a lichen community.

9. *House. Dated 1869.*

An abandoned house in the upper part of the Maratea valley has a date of 1869 etched into the plaster of the gable. In common with almost every other building in Maratea, the plaster had been painted and the house was devoid of lichen growth. A low patio-type terrace adjoining the wall of the house did, however, support a lichen community. The terrace was constructed of limestone blocks and covered with a limestone-based rendering.

Two uncertainties exist over the use of this substrate. The first concerns the date; does 1869 relate to the original construction of the house or to a later replastering or repair? It is common in Maratea for the large houses of the most prominent families to bear the date of construction of the house, together with the family name. In this way the most important citizens can be shown to have a worthy lineage. The practice is very uncommon amongst the poorer families, and this house is clearly one that belonged to a poor family. It is a two-storey building with one room on each floor although the floor/ceiling partition has long since collapsed. The date on the building has been inscribed by hand. Even with the richer families in Maratea, a complete replastering of a house is rarely observed. Often severe cracks in the plaster, generally due to earthquake shaking are repaired and the entire house repainted. With the poor families even such minimal work is often not carried out. On balance, the '1869' house seems to be the former dwelling of a farmer, probably one who left for South America in the early 1900s, and abandoned his farm. It is unlikely that such a man would have had much money for repair or maintenance and the date 1869 therefore almost certainly refers to the original construction.

The second uncertainty concerns the terrace and whether this is contemporaneous with the building of the house or is a later addition. Investigations at the base of the house, primarily breaking away plaster with a hammer revealed that the terrace was tied into the main fabric of the building. Although this can be achieved at a later stage, it does seem likely that the house and terrace are contemporaneous in age.

10. *Statue of the Madonna in the Piazza Cavour. Dated 1788; and*

11. *Cross in the Piazza Municipale. Dated 1781.*

These structures in the *centro storico* (Piazza Cavour) and outside the offices of the *comune* (Piazza Municipale) were examined for lichen colonisation. Both were found to be heavily covered with lichen growth and moss. As a consequence, lichen growth had certainly been retarded by competitive interactions between the lichens themselves (intraspecific competition) and between lichens and other higher plants (interspecific competition). This clearly would have an effect on the accuracy of the age-size curve and indeed, lichens were found to be considerably smaller on these substrates despite their considerable age. As a consequence these substrates were not included in any further analysis.

12. *Main Maratea-Trecchina Road. Dated 1910.*

The main Maratea-Trecchina road runs along the basal concavity of the limestone blocks noted in Chapter Four. The road was constructed in 1910 and involved blasting portions of the large displaced limestone blocks in order to preserve the continuity of the road line and avoid the need for tunneling.

Areas that were blasted provided fresh surfaces for lichen colonisation. One such area noted on Fig. 5.1 was selected as a substrate of known age.

5.2.1.2 Selection of Lichen Species

Virtually all published lichenometric studies have constructed an age-size curve based on a single species and then estimated the date of substrates of unknown age from it (for example, Andersen and Sollid, 1971; Benedict, 1967, 1968; Evans and Rogerson, 1986; Gordon and Sharp, 1983). Winchester (1984) has argued that 'an average of the dates established by different species measurements, produces a more reliable dating estimation than is possible using a single species alone'. Certainly, if independent age-size curves could be drawn for a variety of species and applied to the substrate of unknown age then, although the dated might vary slightly they should 'provide mutually supporting evidence for a likely time range' (Winchester, 1984, p.3).

Given this, all the substrates of known age were searched for the most commonly occurring lichens identified, at the first order stage, by colour. Samples of the these lichens, growing on loose stones or small boulders, were collected and sent to the Royal Botanic Garden in Edinburgh for identification. Species of lichens present in Maratea were:

(i) *Aspicilia calcarea* (L.) Mudd

(ii) *Verucaria nigrescens* Pers.

Both of these species are crustose lichens and characteristic of limestones, especially on the upper surfaces of outcrops or boulders in well-lit situations. Kershaw (1983) has argued that *A. calcarea* is 'always found on open and fully exposed rocks'. Both are widely distributed throughout Europe. *A. calcarea* is characterised by a white crust with no prothallus (Plate 5.3).

(iii) *Caloplaca alociza* (Massat.) migula

This is also a crustose lichen, with distinct white discs in the thallus. It is widely distributed in southern Europe but particularly favours hard, pure, limestones; the lichen is present in Britain on the Carboniferous Limestones and is abundant in Öland and Gotland in Sweden.

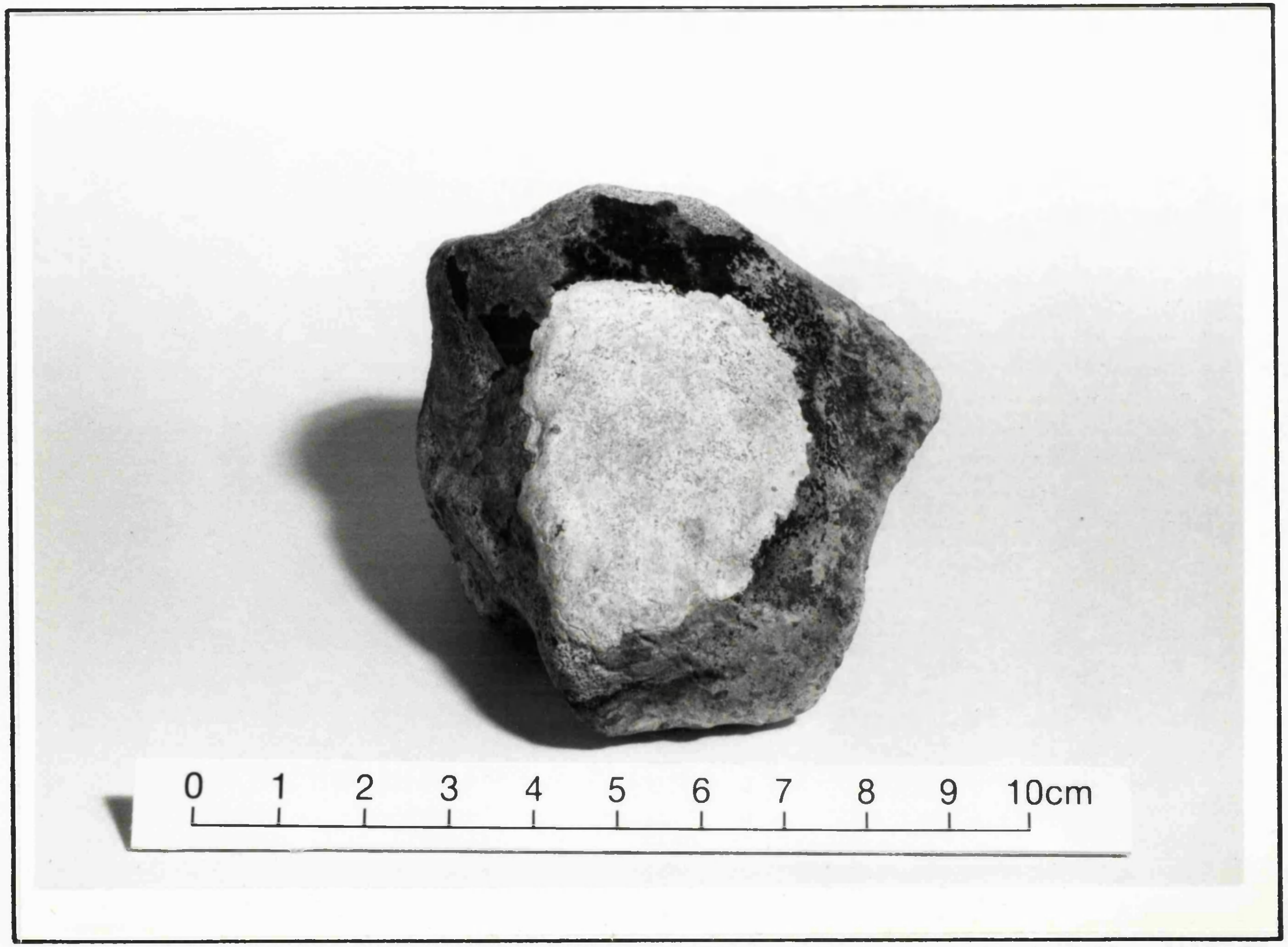


Plate 5.3: The saxicolous crustose lichen *Aspicilia calcarea*. This sample was carried in the field to aid identification

(iv) *Squamarina gypsacea* (Sm.) Poelt

(v) *Squamarina cartilaginea*

These species are both fruticose lichens and are widespread in the Mediterranean although they also colonise limestone outcrops in the Alps and are abundant in Gotland and Öland. They grow in well lit situations in crevices and small ledges of steeply sloping limestone outcrops or on the sides of large boulders.

While all of these lichens were present on the substrates of known age, an initial reconnaissance revealed that only *Aspicilia calcarea* and *Squamarina gypsacea* occurred along the fault plane scarp with any abundance. A handful of specimens of *Caloplaca alociza* and *Verrucaria nigrescens* were found but the number of lichens (six *Caloplaca* and eight *Verrucaria*) was not a sufficiently large sample on which to base dating estimates. A full search of the fault plane scarp later substantiated this view. Neither of these species were present in great number on the substrates of known age either, suggesting that the lichens are growing close to their tolerance limit for the environment. *Squamarina gypsacea* being a fruticose lichen was not used in lichenometric dating although its presence was revealing (see section 5.4.3). It is a lichen that colonises a substrate soon after exposure to subaerial conditions but which has a very short life-span of little more than sixty years (Winchester *pers. comm.*)

At Maratea it is clear that only the use of *A. calcarea* facilitates the construction of an age-size curve applicable to the fault plane scarp. While the assertion of Winchester (1984) is correct, in that a number of age-size curves will produce greater accuracy, the technique has clear limitations in the Maratea case.

5.2.1.3 Thallus Measurement

A number of workers (for example; Matthews, 1974; Haines-Young, 1983) have used Vernier scale calipers to measure lichens to ±0.1mm accuracy. Locke *et al* (1979) argue that for most studies ±1mm is sufficient, as does Innes (1985). Winchester (1984) agreed that ±1mm was good enough but concluded that the use of a semi-rigid plastic ruler was difficult and inaccurate on substrates which are often rounded or angular. Consequently, she uses a flexible acetate sheet marked with concentric circles in 5mm size classes and interpolates to the nearest 1mm between the circles. In this study all lichen measurements were taken using a 'Stanley' steel tape rule. It was felt that this combined the flexibility of the acetate sheet with the accuracy of a ruler marked in millimetres. All measurements were taken by the author to avoid operator variance (see Innes, 1982).

The lichen parameter to be measured has provided a source for considerable debate in the lichenometric literature. Most workers have attempted to determine the maximum growth rate of a lichen thallus, consequently they have measured the maximum thallus diameter (for example; Matthews, 1974, 1975; Mottershead and White, 1972; Winchester, 1984). The main problem with the longest diameter is that coalesced thalli may be mistakenly measured. Some workers have attempted to define the shortest diameter (Birkeland, 1973); this does not avoid the problem of coalesced thalli but the probability of their being included is lower (Innes, 1985). The use of the largest inscribed circle, which is equivalent to the shortest diameter, has been recommended by Locke *et al* (1979) although there seems to be no justification for this. The problem of coalesced thalli could be overcome by only measuring circular or near circular thalli. Innes (1985), however, has demonstrated that there is an increasing divergence from circularity with age. To measure only circular thalli would therefore seem to introduce inaccuracies into the method.

Bearing this discussion in mind, it would seem sensible to measure the maximum thallus diameter in order to establish the maximum growth rate of a lichen in a given area. This is the approach adopted in the construction of the age-size curve for Maratea. In cases of coalesced thalli, these were examined with a hand lens in order to determine the boundaries of the individual thalli.

5.2.1.4 Number of Thalli to be Measured

The number of thalli to be measured have also provided an area of considerable controversy, although this, in part, reflects the dominance of its application to glacial geomorphology. Beschel (1961) argued that only the single largest lichen should be used as an indicator of substrate age as this was likely to be the oldest growing under optimum environmental conditions. Matthews (1973) noted, on the basis of observations of lichen growth on an active medial moraine at Storbreen in the Jotunheimen, southern Norway, that already established lichens could survive redeposition and so be older than the age of the substrate they are assumed to represent. In further work at Storbreen, Matthews (1974, 1975, 1977) set out a strong case for the use of an average of the 'largest lichens' on a substrate. Although Matthews' work is not directly applicable to Maratea it is important to note his use of an average lichen size, as virtually all lichenometric work since Matthews has followed this principle.

Innes (1984) found that the use of the mean of the ten largest lichens produced results which were significantly younger than the mean of the largest five. Innes therefore, along with Locke *et al* (1979), recommends the use of the five largest lichens.

While accepting the problems caused by anomalous thalli, it is difficult to understand the preoccupation of lichenometrists with the use of the mean of five, ten or 'n' thalli. It is clear from the discussion so far that there are numerous possible sources of error associated with the technique. Selection of suitable substrates, determining the age of 'known age' substrates, thallus measurement, species identification and ecological variations affecting lichen growth, are among a number of factors which may influence lichenometric dates. Lichenometry cannot provide pin point dating accuracy and the technique should not be viewed as being able to do so. Given the possible sources of error inherent in the technique, it would seem reasonable to publish dating estimates based on more than one age-size curve constructed through a variety of points, such as the means of the largest five and ten thalli. In this way a range of dates will be available for the substrate of unknown age.

In Maratea the case of anomalously large thalli cannot be discounted. Although care has been taken in selecting substrates of known age and, on the wall substrates, there has been an attempt to identify 'faced blocks', it is possible that some blocks may have been colonised before their incorporation into the structure. While noting this caveat, all surfaces of known age were exhaustively searched for samples of *Aspicilia calcarea.* An exhaustive search was appropriate as each substrate of known age was small enough to be completely examined for lichen growth; a time search or quadrat sampling procedure was not required in the Maratea case (cf. Innes, 1985; Matthews, 1973, 1974, 1975, 1977; Mottershead and White, 1972). A sample of *A. calcarea*, on a small fist-sized boulder, was carried in order to make absolutely sure that a lichen from a similar species was not inadvertently measured. Age-size curves were constructed on the basis of the single largest lichen and the means of the five and ten largest lichens.

5.2.1.5 Construction of the Age-Size Curve

For each substrate of known age three points were plotted on the age-size curve; the largest single lichen, the mean of the five largest lichens and the mean of the ten largest lichens. To this type of data most lichenometric studies have fitted some form of regression analysis.

There has been considerable debate in the lichenometric literature over the form of the age-size curve or direct growth curve for saxicolous crustose lichens. Beschel (1961, p.1045-1046) argued that crustose lichens 'do not grow with constant velocity during their whole life. The diameter of a thallus increases at first very slowly and considerable time elapses before the lichen becomes visible. Then growth gathers speed and many thalli pass through a "great period" until the increase in a given time period drops to a constant value that is maintained for along time'. This pattern of lichen growth is consistent with the view of Armstrong (1974) who also argued for three growth stages:

(i) Prelinear;

(ii) Linear; and

(iii) Postlinear.

Innes (1985) has argued that most studies have described phases (ii) and (iii), where phase (ii) is equivalent to Beschel's 'great period' of lichen growth and phase (iii) a period of senescence. In the prelinear phase (i) the lichen is still too small to be seen.

The exact shape of the age-size curve will depend both on the species involved and the analysis employed. For example, Benedict (1967) established a sigmoidal curve for *Rhizocarpon geographicum* which closely mirrors the three phase growth pattern described above. Conversely, Andersen and Sollid (1971) describe a linear age-size curve for the same species although their data, from southern Norway, is based on only five surfaces of known age. Both Benedict (1967) and Andersen and Sollid (1971) plotted their data on an arithmetic graph. Mottershead and White (1972), on the other hand, suggest that for *Rhizocarpon geographicum,* growing only about 5km from Andersen and Sollids field site, the age-size curve is not linear but exponential (log-linear). Their assertions too, are based on only five data points, and could easily be interpreted differently. Semi-logarithmic transformations have been carried out by, for example, Orombelli and Porter (1983). Porter and Orombelli (1981) and Innes (1983) have used log-log constructions.

In short, age-size curves published hitherto have either been constructed on insufficient data, or it would seem on an *a priori* idea of how the curve should be, based on the work of previous authors. Because saxicolous lichens grow so slowly a full growth curve for any species has never been described. While it is therefore possible to make judgements on how an age-size curve might look it cannot be stated with certainty. Given this, it seems reasonable to follow the advice of Innes (1985, p.214) who stated that 'there appears to be no optimum form of curve. Instead it is recommended that a goodness-of-fit test be carried out to assess which curve fits the data best'.

For *Aspicilia calcarea* only one curve has been published, that of Winchester (1984). Her data was extracted from measurements on a number of tombstones near Avebury, in Wiltshire, and closely mirrors the sigmoidal three phase pattern envisaged for saxicolous crustose lichens by Beschel (1961). Similar results were obtained by Winchester (1988) at the Rollright stone circle and at Chipping Norton, both in Oxfordshire. These are the only available curves against which to check the Maratea results.

The data from Maratea are presented in Table 5.1 and graphed out in Fig. 5.2. They show clearly increasing maximum thallus diameter with age, although Table 5.1 illustrates the problem of anomalous thalli; surface 5 - the mausoleum - supports a lichen colony whose sizes are 35mm - 40mm smaller than would be expected for its age. Clearly this surface has been cleaned and it is not appropriate to use it in age-size curve construction. Similarly, surfaces 10 and 11 which, it was argued in section 5.2.1.1, probably supported lichen communities which had been retarded by competition, have specimens of *A. calcarea* that are significantly smaller than would have been expected.

A visual analysis of the data presented in Fig. 5.2 indicates that the samples of *Aspicilia calcarea* present on substrate 1, may still be experiencing the 'great period' of lichen growth. Accordingly, in the first instance, statistical analysis was applied only to substrates 2 - 4, 6 - 9 and 12. Three linear regressions were constructed through the means of the ten, five

Substrate	Date AD	Age Years BP (1987)	Lichen Diameters – mm										Mean Diameters		
			1	2	3	4	5	6	7	8	9	10	x5	x10	1
1 Road to Statue of Christ	1978	9	20	20	20	26	25	30	24	28	22	28	27.4	24.3	30.0
2 Crucifix on Block	1963	24	37	34	48	47	35	37	33	32	32	33	40.8	36.8	48.0
3 Villa Comunale	1952	35	41	50	50	41	42	42	42	46	41	41	46.0	43.6	50.0
4 Memorial in Aquafredda	1950	37	39	42	35	51	42	50	50	46	52	47	50.0	45.4	52.0
5 Mausoleum in Cemetery	1939	48	9	6	6	15	10	9	–	–	–	–	9.8	9.2	15.0
6 Memorial to San Biagio	1932	55	54	54	50	51	50	50	50	55	54	54	54.2	52.2	55.0
7 Sapri Coastguard Station	1927	60	48	48	59	52	54	62	50	55	53	54	56.4	53.5	62.0
8 Road to Sapri	1924	63	52	63	50	59	40	55	65	52	59	55	58.8	55.0	65.0
9 1869 House	1869	118	64	67	65	60	58	59	59	71	71	58	67.6	63.2	71.0
10 Statue of the Madonna	1788	199	27	26	24	37	32	–	–	–	–	–	29.2	29.2	37.0
11 Cross in Piazza Municipale	1781	206	29	22	34	25	25	25	–	–	–	–	27.6	26.7	34.0
12 Maratea-Trecchina Road	1910	77	62	56	62	58	65	68	62	58	62	64	64.0	61.7	68.0

Table 5.1: Measurements of *Aspicilia calcarea* on substrates of known age.

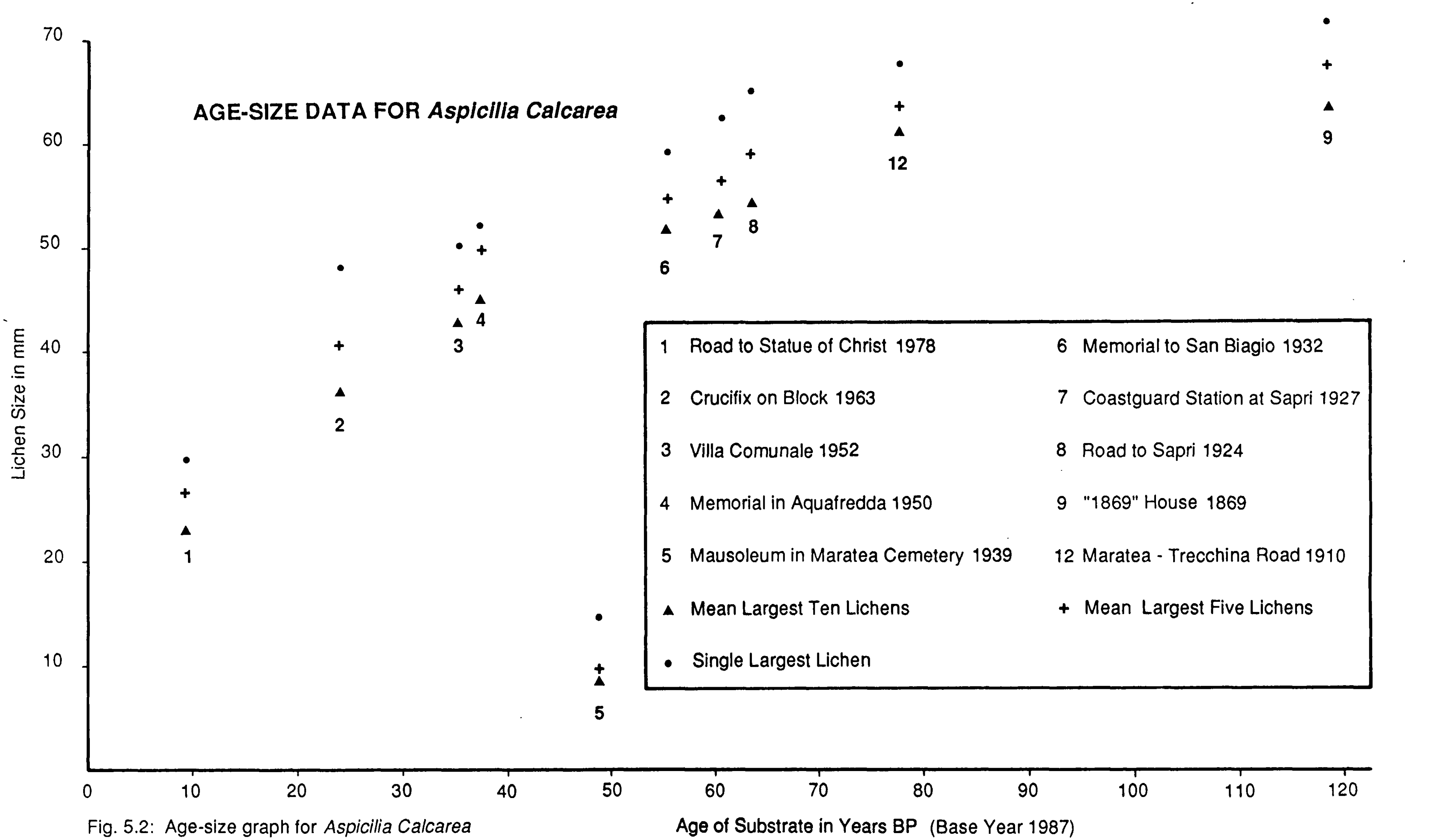


Fig. 5.2: Age-size graph for *Aspicilia Calcarea*

and single largest lichens per substrate. The regression lines were of the general form:

$$y = a + bx \qquad \text{(Equation 5.1)}$$

Where: y = The dependent or regressor variable whose values are to be predicted

x = The independent or predictor variable

a = The intercept of the regression line on the y axis

b = The slope of the regression line

Assuming that the assumptions of linear regression are satisfied (Ebdon, 1978), a and b can be calculated as follows:

$$b = \Sigma xy - nxy/\Sigma x^2 - nx^2 \qquad \text{(Eq. 5.2)}$$

$$a = y - bx \qquad \text{(Eq. 5.3)}$$

Applying these equations to the data yields the following regression lines:

(i) For the largest five lichens

$$y = 3.10x - 111 \qquad \text{(Eq. 5.4)}$$

Where: y = Date of exposure of the substrate of unknown age in years before present (base year 1987)

x = Maximum diameter of *Aspicilia calcarea* in millimetres

(ii) For the largest ten lichens

$$y = 3.01x - 96.2 \qquad \text{(Eq. 5.5)}$$

(iii) For the single largest lichen

$$y = 3.11x - 124 \qquad \text{(Eq. 5.6)}$$

Regression lines based on these values are shown in Figs. 5.3, 5.4 and 5.5 to which a further line representing the presumed 'great period' of rapid lichen growth has been added by eye. In

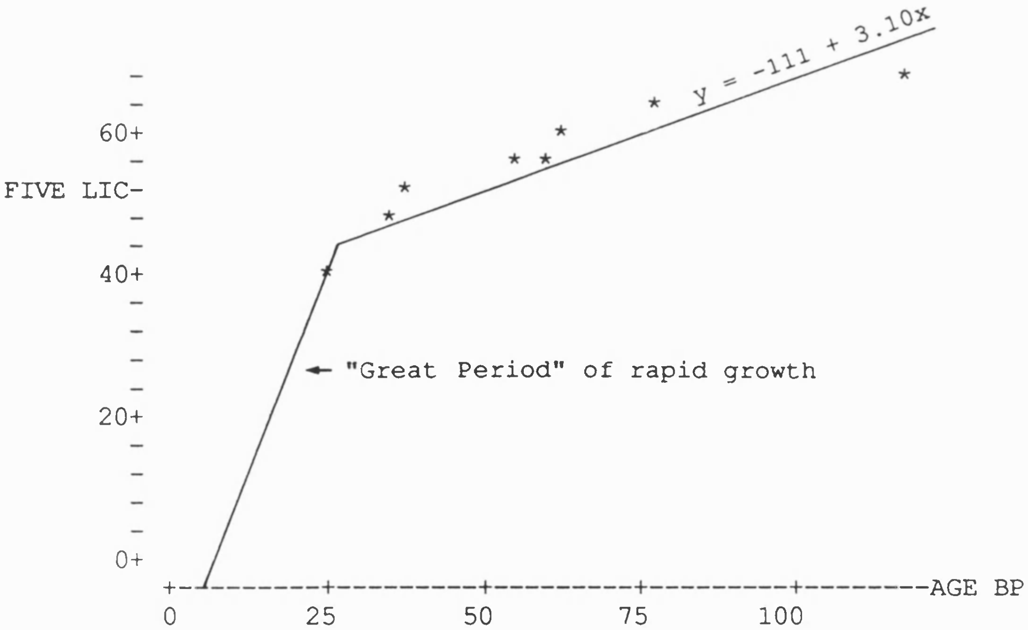
The regression equation is
AGE BP = - 111 + 3.10 FIVE LIC

Predictor	Coef	Stdev	t-ratio
Constant	-110.97	25.30	-4.39
FIVE LIC	3.0991	0.4570	6.78

s = 10.85   R-sq = 88.5%   R-sq(adj) = 86.5%

Analysis of Variance

SOURCE	DF	SS	MS
Regression	1	5415.3	5415.3
Error	6	706.6	117.8
Total	7	6121.9	



FIVE LIC: Mean of the five largest lichens (mm)

AGE BP: Age of substrate in years before present (base year 1987)

Fig. 5.3 (from Eq. 5.4): Linear regression on the mean of the largest five lichens per substrate of known age, excluding substrate 1.

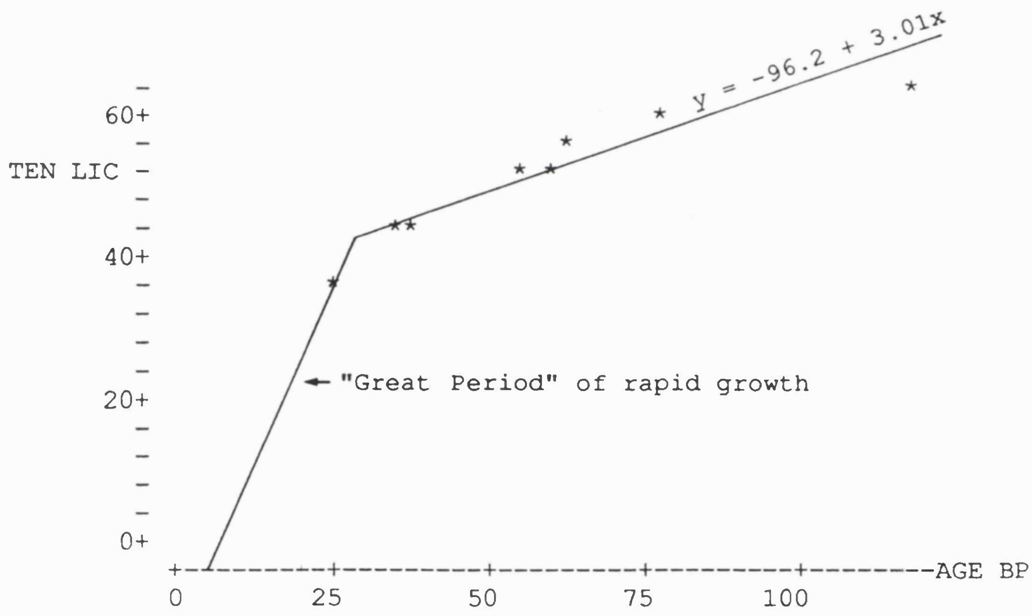
The regression equation is
AGE BP = - 96.2 + 3.01 TEN LIC

Predictor	Coef	Stdev	t-ratio
Constant	-96.23	27.06	-3.56
TEN LIC	3.0120	0.5194	5.80

s = 12.43   R-sq = 84.9%   R-sq(adj) = 82.3%

Analysis of Variance

SOURCE	DF	SS	MS
Regression	1	5194.8	5194.8
Error	6	927.0	154.5
Total	7	6121.9	



TEN LIC: Mean of the ten largest lichens (mm)

AGE BP: Age of substrate in years before present (base year 1987)

Fig. 5.4 (from Eq. 5.5): Linear regression on the mean of the largest ten lichens per substrate of known age, excluding substrate 1.

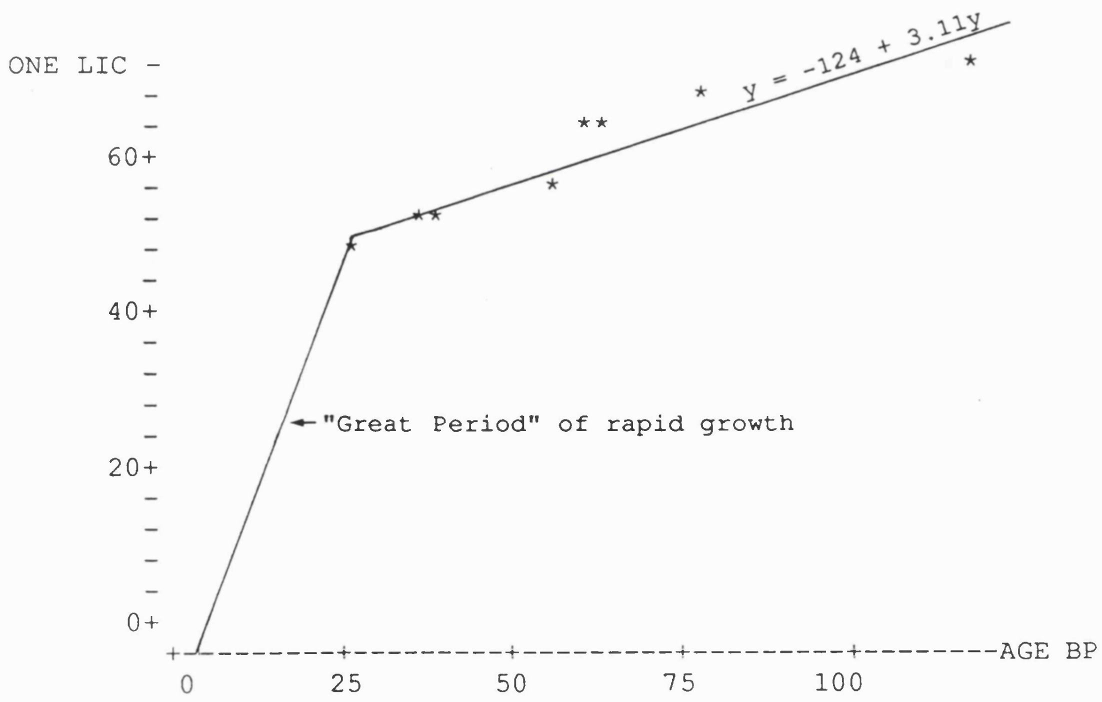
The regression equation is
AGE BP = - 124 + 3.11 ONE LIC

Predictor	Coef	Stdev	t-ratio
Constant	-124.25	32.14	-3.87
ONE LIC	3.1062	0.5408	5.74

s = 12.53 R-sq = 84.6% R-sq(adj) = 82.0%

Analysis of Variance

SOURCE	DF	SS	MS
Regression	1	5179.9	5179.9
Error	6	941.9	157.0
Total	7	6121.9	



ONE LIC: Size of the single largest lichen (mm)

AGE BP: Age of substrate in years before present (base year 1987)

Fig. 5.5 (from Eq. 5.6): Linear regression on the mean of the single largest lichen per substrate of known age, excluding substrate 1.

order to measure the goodness-of-fit of the regression, a test was carried out based on the variance of the observed values of y compared with the variance of the predicted values of y accounted for by the regression (y - y). The variance of the observed values of y is determined by the expression:

$$S^2y = \Sigma y^2/n - y^2 \qquad \text{(Eq. 5.7)}$$

Whereas the variance of the predicted values of y is calculated using the term:

$$S^2y = \Sigma y^2/n - y^2 \qquad \text{(Eq. 5.8)}$$

The ratio between these two variances provides a measure of the goodness-of-fit:

$$r^2 = S^2y/S^2y \qquad \text{(Eq. 5.9)}$$

The square root of r^2 is the Pearson Product Moment Correlation Coefficient which allows an estimate of the validity of the predicted values of y. If the correlation were perfect r would be equal to 1. In this case:

(i) For the largest five lichens:

$$r = 0.885 \qquad \text{(Eq. 5.10)}$$

(ii) For the largest ten lichens:

$$r = 0.849 \qquad \text{(Eq. 5.11)}$$

(iii) For the single largest lichen:

$$r = 0.846 \qquad \text{(Eq. 5.12)}$$

Although an extremely good goodness-of-fit is obtained using the mean of the largest five lichens per substrate, it is clear that, particularly if substrate 1 is included in the analysis, a non-linear relationship could fit the data equally well.

A non-linear relationship can be described by plotting the logarithm of the dependent variable (y) against the logarithm of the independent variable (x). A logarithmic transformation of equation 5.1 yields a transformed regression of the form:

$$\log_{10}y = a + b\log_{10}x \qquad \text{(Eq. 5.13)}$$

Where: $\log_{10}y$ = The natural logarithm of the dependent variable

By taking the antilogarithm of both sides y can be predicted directly from x:

$$y = \text{antilog}_{10}ax^{b} \qquad \text{(Eq. 5.14)}$$

For the data set in Table 5.1 the values are

(i) For the mean of the largest five lichens:

$$y = x^{2.70}\text{antilog}_{10}2.96 \qquad \text{(Eq. 5.15)}$$

$$r = 0.983$$

(ii) For the mean of the largest ten lichens:

$$y = x^{2.49}\text{antilog}_{10}2.52 \qquad \text{(Eq. 5.16)}$$

$$r = 0.991$$

(iii) For the single largest lichen:

$$y = x^{2.81}\text{antilog}_{10}3.24 \qquad \text{(Eq. 5.17)}$$

$$r = 0.957$$

In order to test the significance of the '1869' house (substrate number 9), about which there was some doubt, a non-linear regression was run excluding this point. The regression

$$y = x^{2.57}\text{antilog}_{10}2.75 \qquad \text{(Eq. 5.18)}$$

$$r = 0.993$$

This line had a goodness-of-fit only 0.01 better than a regression line based on the mean of the five largest lichens per substrate and employing all the substrates of known age (2 - 4 and

6 - 9) described in Equation 5.15. Graphs for these equations are shown in Figs. 5.6, 5.7, 5.8 and 5.9.

5.2.1.6 Comparison with Published Curves

Only one other age-size curve for *Aspicilia calcarea* has been published to date, that of Winchester (1984) for the neolithic stone circle of Avebury in Wiltshire. Winchester used a curve constructed by eye for both the great period and phase of steady growth, presumably through a mean of the largest lichens, though the details of her analysis and field technique are not well documented. The curve was compared with the 'best fit' linear curve from Maratea (Eq. 5.4 and Fig. 5.3). This was based on the mean of the largest five lichens per substrate for the phase of steady growth and a by eye construction for the great period. The two curves are illustrated in Fig 5.10 and display a considerable degree of similarity, although for any given age maximum thallus diameter is always larger at Avebury. The curves disagree in the early years of growth due to the different base years used. The major difference between the Avebury and Maratea curves is the duration of the great period; at Avebury this is some forty years while in Italy *Aspicilia calcarea* appears to enter its period of steady growth after about twenty-five years.

Growth rates have been estimated by dividing the change in thallus diameter (d) by the length of time (t) over which that change has occurred ($\Delta d/\Delta t$). These calculations show a very similar rate of growth during the great period and an identical growth rate during the linear phase between both sites. Thus, although maximum thallus diameter is always larger for Avebury the rate of growth of *A. calcarea* remains the same. These results lend considerable weight to the validity of the growth curves constructed in section 5.2.1.5.

The variation in size between the two sites can be accounted for by the difference in the climatic regimes of the two areas. Avebury (51°27'N, 01°51W, 160m asl) is situated on the wetter, western side of the United Kingdom. It has an annual average

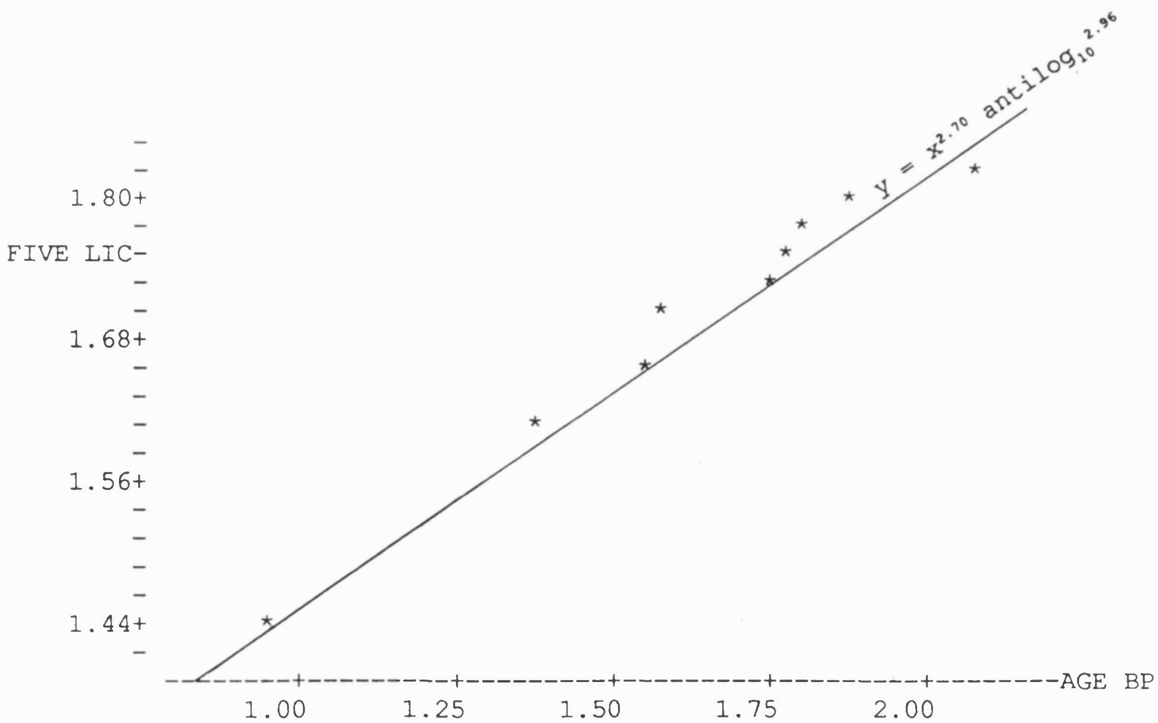
```
The regression equation is
AGE BP = - 2.96 + 2.70 FIVE LIC

Predictor        Coef          Stdev     t-ratio
Constant      -2.9589         0.2287      -12.94
FIVE LIC       2.7027         0.1342       20.14

s = 0.04550      R-sq = 98.3%      R-sq(adj) = 98.1%

Analysis of Variance

SOURCE        DF          SS           MS
Regression     1      0.83930      0.83930
Error          7      0.01449      0.00207
Total          8      0.85379
```



FIVE LIC: Logarithm of the mean of the five largest lichens

AGE BP: Logarithm of the age of the substrate in years before present (base year 1987)

Fig. 5.6 (from Eq. 5.15): Log-log regression on the mean of the largest five lichens per substrate of known age.

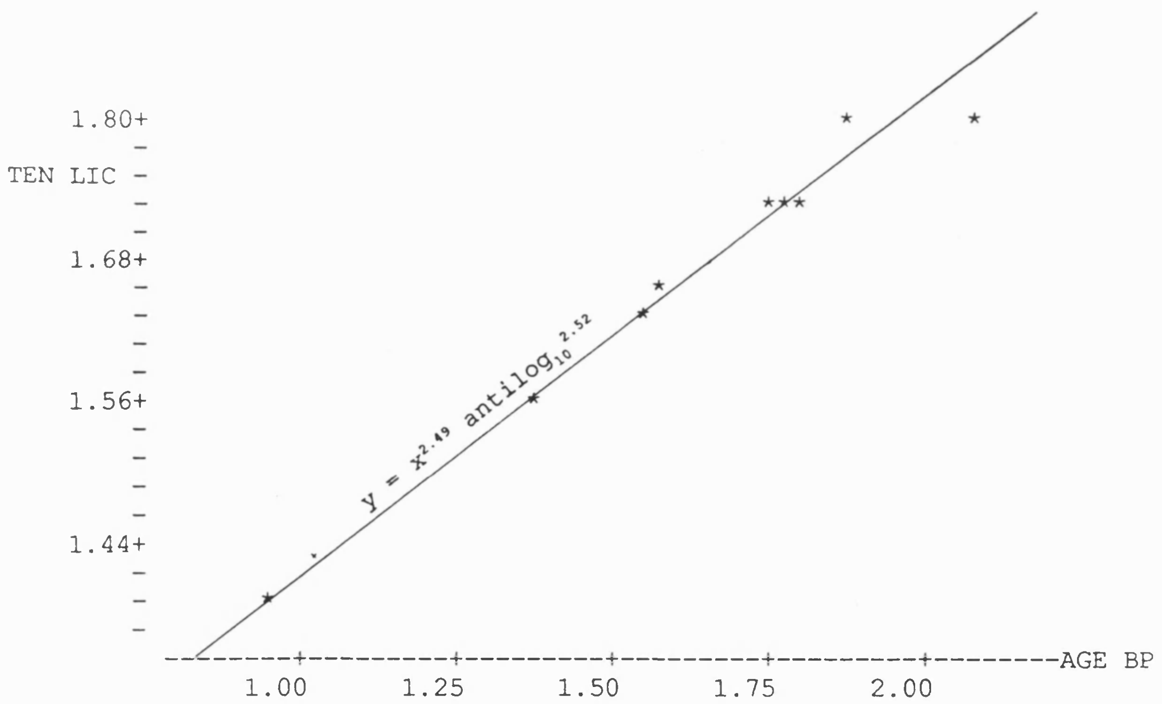
The regression equation is
AGE BP = - 2.52 + 2.49 TEN LIC

Predictor	Coef	Stdev	t-ratio
Constant	-2.5217	0.2254	-11.19
TEN LIC	2.4904	0.1346	18.50

s = 0.04945 R-sq = 98.0% R-sq(adj) = 97.7%

Analysis of Variance

SOURCE	DF	SS	MS
Regression	1	0.83667	0.83667
Error	7	0.01711	0.00244
Total	8	0.85379	



TEN LIC: Logarithm of the mean of the ten largest lichens (mm)

AGE BP: Logarithm of the age of substrate in years before present (base year 1987)

Fig. 5.7 (from Eq. 5.16): Log-log regression on the mean of the largest ten lichens per substrate of known age.

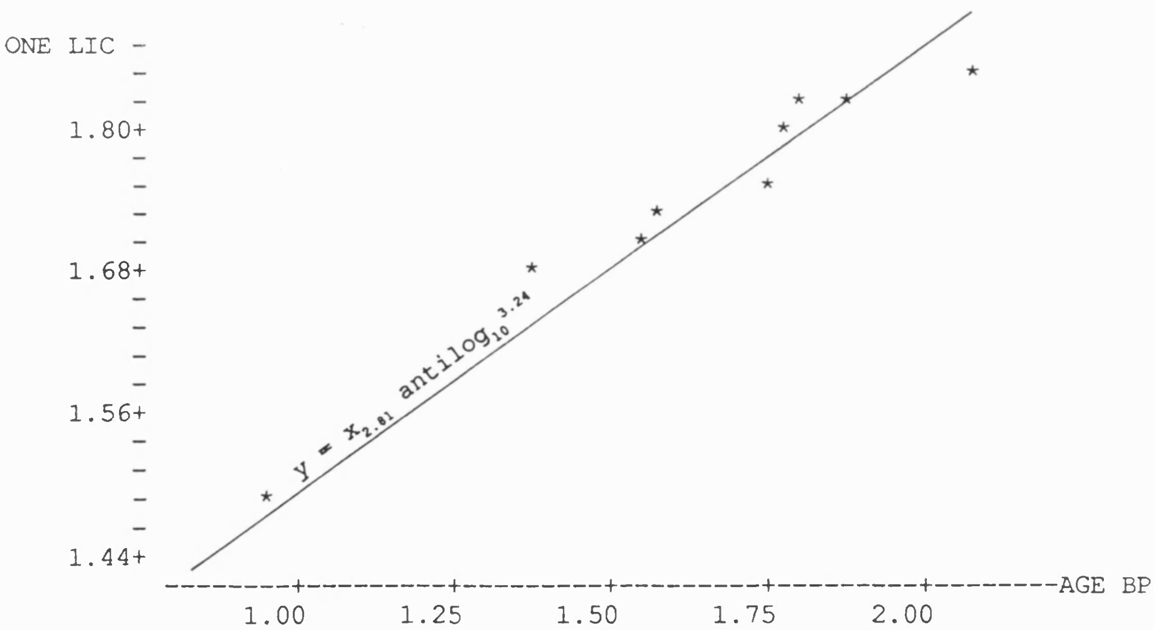
The regression equation is
AGE BP = - 3.24 + 2.81 ONE LIC

Predictor	Coef	Stdev	t-ratio
Constant	-3.2358	0.3920	-8.25
ONE LIC	2.8101	0.2257	12.45

s = 0.07259   R-sq = 95.7%   R-sq(adj) = 95.1%

Analysis of Variance

SOURCE	DF	SS	MS
Regression	1	0.81690	0.81690
Error	7	0.03688	0.00527
Total	8	0.85379	



ONE LIC: Logarithm of the size of the single largest lichen

AGE BP: Logarithm of the age of substrate in years before present(base year 1987)

Fig. 5.8 (from Eq. 5.17): Log-log regression on the mean of the single largest lichen substrate of known age.

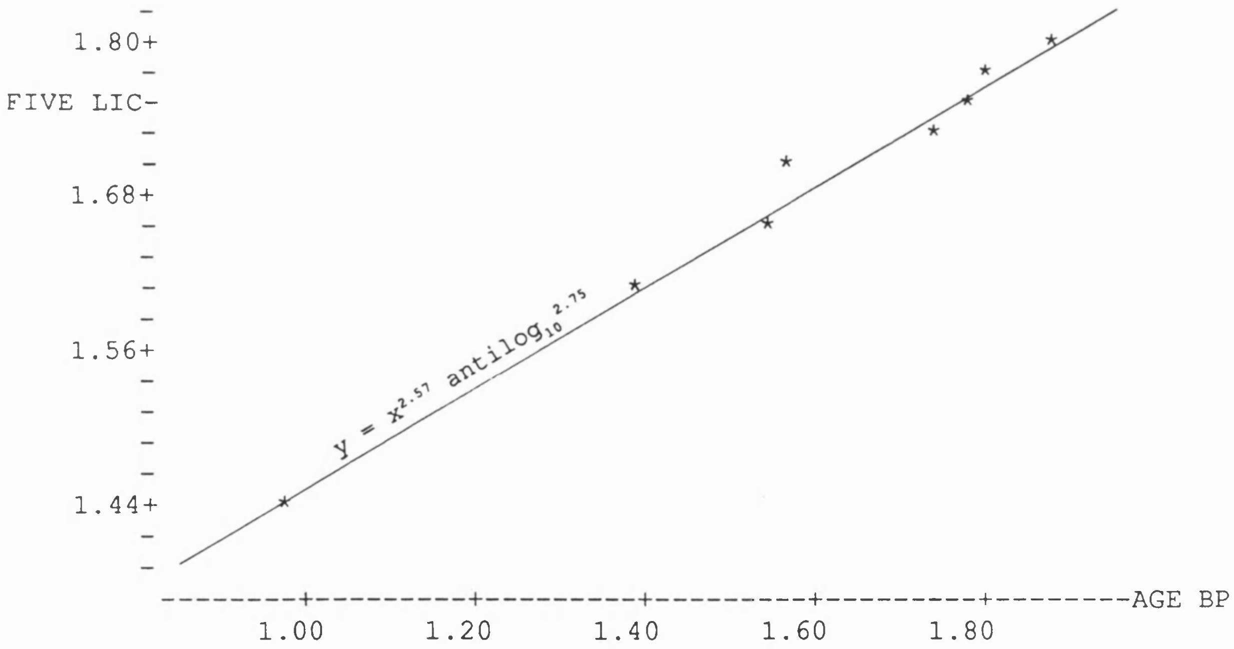
The regression equation is
AGE BP = - 2.75 + 2.57 FIVE LIC

Predictor	Coef	Stdev	t-ratio
Constant	-2.7514	0.1531	-17.97
FIVE LIC	2.57312	0.09073	28.36

s = 0.02810   R-sq = 99.3%   R-sq(adj) = 99.1%

Analysis of Variance

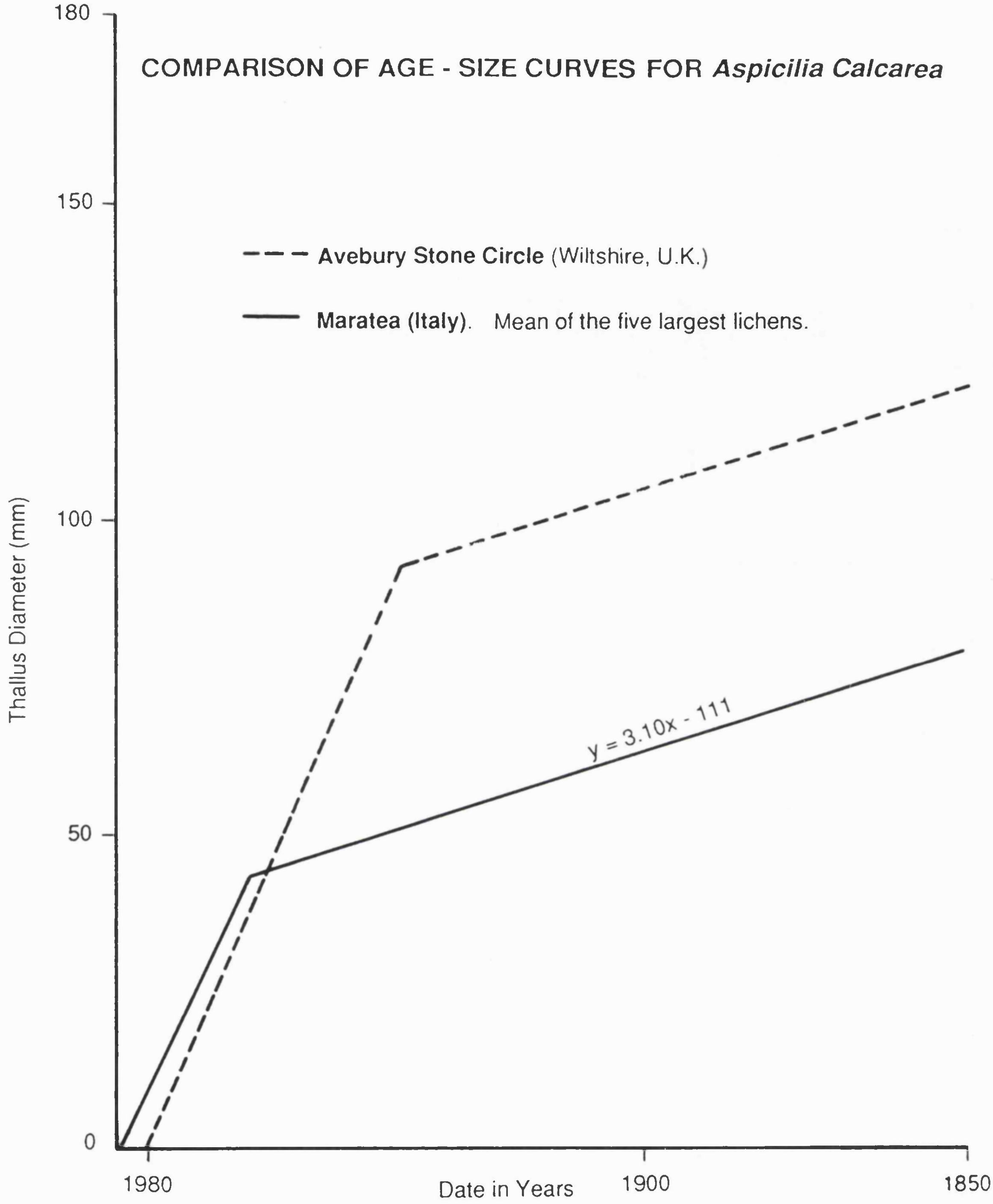
SOURCE	DF	SS	MS
Regression	1	0.63519	0.63519
Error	6	0.00474	0.00079
Total	7	0.63993	



FIVE LIC: Logarithm of the mean of the largest five lichens per substrate (excluding subtrate 9 - the "1869 House"

AGE BP: Logarithm of the age of substrate in years before present (base year 1987)

Fig. 5.9 (from Eq. 5.18): Log-log regression on the mean of the five largest lichens per substrate of known age, excluding substrate 9 - the "1869 House"



	Rate of Great Period Growth (mm/year⁻¹)	Length of Great Period (years)	Steady Growth Rate (mm/year⁻¹)
Avebury	2.3	40	0.24
Maratea	2.0	25	0.24

Fig. 5.10: Comparison of age-size curves for *Aspicilia calcarea*.
From Winchester (1984) for Avebury and present author for Maratea.

rainfall of 826mm with maximum and minimum monthly mean temperatures of 12.6°C and 4.8°C respectively (Winchester, 1984; from 1981 figures of the Marlborough College meteorological station). On the other hand Maratea (39°59'N,15°46'E, 300m asl [*centro storico*]), has an average annual rainfall of only 124mm much of it seasonal, with very little falling in the summer months - May to August; 1979 figures from the Meteorological Office, Bracknell, copied from the Italian Annual Meteorological Statistics, 1959 - 1980.

There is a relationship between lichen growth and continentality (Beschel and Weidick, 1973; Ten Brink, 1973) although Beschel's assertion that lichens can grow only when completely saturated has proved to be incorrect. Innes (1985), in a review of lichenological work on the affect of moisture availability on thallus diameter, has argued that growth depends on the rate at which a lichen can assimilate carbon (the net carbon assimilation rate - NCAR). The NCAR may actually be retarded if excessive wetting occurs or if the thallus is subjected to rapid wetting and drying. Clearly this is a situation which is likely to prevail in Maratea, where thalli would spend most of the winter months in a heavily saturated condition. Summer rainfall in Maratea tends to be concentrated in heavy cloud bursts followed by a rapid return to hot, intense sunshine conditions.

The best-fit curve to the Maratea data is of a log-log form based on the means of the largest five lichens per substrate of known age. Such a curve has not been published for Avebury. As a consequence the comparison between the two sites has had to be made on the basis of the best-fit linear curves. Such a comparison does not destroy the validity of the data; the important fact is that the rate of lichen growth between two geographically separate sites is the same. Differences in lichen diameters between the two sites are a result of the duration of the 'great period', which is longer for Avebury. This, in turn, is a function of climate, rapid early growth being favoured by the cooler, wetter conditions at Avebury.

Although empirical evidence, based on direct thallus measurements is lacking, the available data strongly suggest that the observed variations in lichen diameters between Avebury and Maratea are a result of differences in climatic regime. Given this, the Avebury data provide firm supporting evidence for the validity of the Maratea age-size curves and for the results that can be predicted from them.

5.3 Application of the Age-Size Curve

One of the main advantages of lichenometric dating is that, once established, age-size curves can be used to date any substrates of unknown age within the area in question. In Maratea the main concern has been to date movements along the fault plane scarp although a number of dating problems which may be amenable to lichenometry also suggest themselves. These are dating movements of the limestone blocks, dating movements of the sackung and establishing the age of other features in the area such as rockfalls.

Many lichenometric studies have focussed on the choice of sampling design when searching for dateable thalli. Often the problem is that many substrates of unknown age are too large for an exhaustive search and so an element of sampling must be introduced. This is the case with both the sackung and a minor tear associated with it, both of which are described and dated below. The sampling procedures described, which are based on a quadrat survey, are techniques commonly used in lichenometric dating (for example see Matthews, 1973, 1974, 1975, 1977; Mottershead and White, 1972).

5.3.1 Limestone Blocks

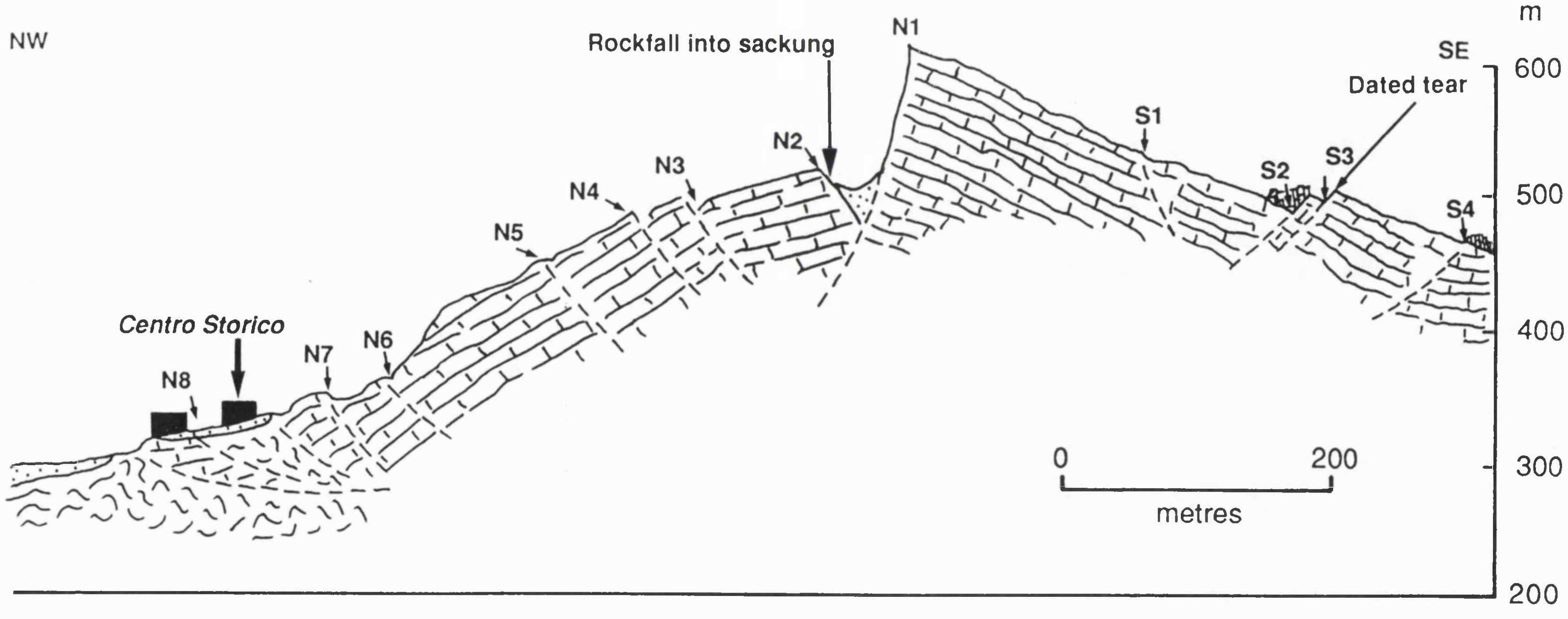
To date the point in time at which the limestone blocks came to rest by lichenometry requires two assumptions to be made. First, the limestone blocks were lichen free at the time they came to rest; clearly this is an assumption which cannot be substantiated for the blocks may have supported lichen growth before they were calved or may have come to rest temporarily during transport to their present location or may even have gradually moved to their positions over a period of time. In this second case, a lichen date would represent some mid-point. The second assumption is that the faces of the limestone blocks have not been substantially altered. In the case of all the blocks, apart from the one used for radiocarbon dating, this assumption cannot be substantiated. The faces of the blocks were blasted during the construction of the Maratea - Trecchina road to avoid the need for tunneling or realignment. Any date obtained would therefore represent the date of blasting rather than the date of the last block movement.

As a result of these problems, lichenometry cannot be applied to the limestone blocks with any confidence and therefore has not been attempted as part of this study.

5.3.2 Sackung

Large lichens were found over the whole of the major ridge crest associated with the sackung (N1 on Fig. 5.11); the tear associated with the ridge trends northwards into the fault plane scarp. An initial reconnaissance of the ridge revealed the presence of the largest lichens found anywhere in the Maratea valley. The size of the ridge meant that an exhaustive search of the whole area for the largest lichens was not a feasible option. Instead a 100m x 1m area of the central section of the ridge was searched in 1m x 1m quadrats with a quadrat sample at every 10 metres. In this way 10 quadrats were sampled with the largest lichen in each quadrat recorded. Care was taken not to measure coalesced thalli and any suspected examples were examined with a hand lens. Thalli suffering intense competition from other lichens or higher plants were similarly excluded. The results showed a mean maximum thallus diameter for *Aspicilia calcarea* of 346mm and 358mm for the largest 10 and 5 lichens respectively. Applying the best-fit log-log and linear curves, based on the mean of the largest five lichens per substrate of known age, to

DIAGRAMMATIC SECTION OF THE SACKUNG



Limestones of the Panormide Complex

Black Clays

Detritus

Terrace walling against sackung tear

Fig. 5.11: Diagrammatic section of the sackung showing locations of dated substrates.

For section location see Fig. 3.4

the mean of the largest five lichens on the sackung ridge, yields ages of 8619 and 998 years BP respectively. The very large discrepancy between these figures results from the fact that the log-log curve is describing an exponential decrease in the rate of lichen growth as opposed to the linear curve which is predicting a constant rate of increase; the difference between the two will become more marked as lichen diameter increases.

The size of the lichens on the ridge crest is approximately seven times that of the largest specimen found on the oldest substrate of known age - the 1869 House. Thus an age of c.1000 years BP may well be older than the life-span of a lichen in the valley and c.8000 years probably far in excess. The lichens on the sackung crest are, therefore, probably growing in the most favourable environmental conditions found anywhere in the valley and hence achieving a higher rate of growth than those on the substrates of known age. Although rainfall is the same, the sackung crest has a well developed soil structure capable of retaining moisture and which even in the summer months was found to be wet underfoot. Such conditions - a moist micro-climate with plenty of sunshine - would seem to provide ideal growing conditions. The Avebury curve provides good supporting evidence for this view. Referring to Fig. 5.10, a lichen of 358mm found at Avebury would be around 1400 years old, a figure which is close to the linear curve date for Maratea. It has already been demonstrated in section 5.2.1.6 that the difference between the Maratea and Avebury curves is the result of a different climatic regime. It is, therefore, reasonable to assume that lichen gowth on the Maratea sackung ridge is more closely described by an age-size curve derived from an area of cooler, wetter, climate. In short, the sackung crest lichens can only be dated with a curve developed specifically for the area. Lack of dateable substrates of known age meant that this could not be attempted.

It was also possible to date, with the aid of lichenometry, a minor sackung tear behind the main ridge and a large rockfall which had fallen into the major tear (see Fig. 5.11). Three tears were noted, all small features no more than 1m high, with the downthrown side facing away from the main ridge crest. The tears are not dissimilar in form to the fault plane scarp and provide a substrate which occupies a closer environmental niche to the substrates of known age than does the sackung crest Unfortunately only one was available for dating as the other two been remodelled for use as terrace walls; any lichenometric dates would therefore reflect the date of the building of the walls rather than the age of the tears.

Sampling was based on a 1m x 1m quadrat survey taken along a 100m section of the tear. A quadrat was sampled at 10m intervals enabling 10 quadrats to be measured; the largest lichen in each quadrat was noted. Mean lichen diameters were 149mm for the largest 5 lichens and 138mm for the largest 10. Ages obtained employing the best-fit log-log and linear curves for the mean of the largest five lichens per substrate of known age were 808 years and 251 years BP respectively for the mean of the largest five lichens on the tear.

The rockfall into the sackung tear was a more recent feature. Dating was possible because the fall exposed a fresh area of ridge wall for lichen colonisation. Sampling was based on an exhaustive search of those areas of ridge wall that it was possible to reach. Mean lichen diameters were 87mm for the largest 5 and 79mm for the largest 10. Again employing the best-fit log-log and linear curves for the mean of the largest five lichens per substrate of known age gave ages of 189 and 159 years BP respectively. This suggests that recent slope erosion processes have been operating in the sackung area. The significance of these results will be discussed below in section 5.4.2.

5.3.3 Fault Plane Scarp

5.3.3.1 Search Methods and Sampling

The size of the fault plane scarp at Maratea is such that an exhaustive search was a feasible option. The easiest method of doing this was to search the fault plane scarp in sections, each section (termed here a 'leg') being the distance between two marker pins on the fault plane scarp survey; the leg was given a reference number based on the lowest number of the two pins that it fell between, thus the leg between pins 45 - 46 was leg 45; the reader is asked to refer to the detailed fold-out map of the fault plane scarp which accompanies this thesis for details of leg numbers and pin positions. This method had the dual advantage of simultaneously recording the position of each measurement along the fault plane scarp and ensuring that no sections were missed. Each thallus was measured according to the method described in section 5.2.1.3. The location of each thallus was noted with respect to position along the fault plane scarp and height above the fault plane scarp/talus interface.

5.3.3.2 Results

An exhaustive search of the fault plane scarp revealed scattered small clusters of *Aspicilia calcarea*. Of the 86 surveyed legs searched only 18 revealed lichens and of these, 10 were located in the section between marker pins 68 - 80 (see the fold-out map in the back pocket for location). The abundance of *A. calcarea* in this section is significant; it is both the section of fault plane scarp which has the lowest angle of dip (50° -60°) and the one which displays the highest degree of weathering because of the poor cementation of the limestone matrix. The poor cementation and high degree of weathering cause the surface of the fault plane scarp to be highly pitted allowing lichen thalli the surface roughness they require to become established. This could mean that there may be a delay in lichen colonisation until the substrate becomes sufficiently weathered for lichens to become established; in this case the dates that are obtained should be regarded as minimum figures only. Nonetheless, this section of the fault plane scarp clearly provides the optimum environmental niche for lichen growth. In addition, high rates of wetting and drying which may reduce carbon uptake and so retard growth are lessened by the lower angle of slope.

No lichens were found higher than 14.7m above the talus indicating that lichen growth is probably being destroyed as erosion breaks down the top sections of the upstanding scarp plane face (see Fig 4.1). Lichens were found at low elevations (less than 1m above the talus), generally in small crevices or hollows within the scarp face. Colonies were very few however, (only nine were found) and the number of lichens in a colony correspondingly small; a lichen colony at <1m above the talus was never found to support as many as ten lichens, although all had at least five. Lichens were found in the central sections of the fault plane scarp, that is between 1m - 5.6m above the talus base but their occurence was very sporadic and in too few numbers to be considered for dating purposes. It is therefore likely that lichen colonisation takes two forms; the first is at low level when substrate exposure reveals sheltered hollows which encourage lichen growth. The second is where the fault plane scarp becomes weathered enough for lichen establishment, a situation which only prevails at higher elevations. In between these two areas of colonisation lies a band of the fault plane scarp which is gradually becoming more weathered until its surface roughness becomes sufficient for lichen establishment.

In each surveyed leg of the fault plane scarp the mean of the largest five and ten lichens and the size of the single largest was taken and applied to the age-size curves described in section 5.2.1.5 (see Table 5.2, columns 3 - 5). This allowed seven dates to be produced for each leg as is shown in Table 5.2 (columns 6 - 12). Considerable variation in dates is produced depending on whether a linear age - size relationship or a log-log regression has been applied. As noted previously, this variation is to be expected as a log-log transformation will always produce older dates which will be most apparent at the upper end of the range. This is simply because a log-log transformation is describing an exponential decrease in growth rate whereas a linear regression is, by definition, predicting a constant rate of increase.

To convert the age of the fault plane scarp exposure into a meaningful AD date, the results obtained from the best-fit log-log and linear regression curves based on the mean of the five

Column Nº. 1	2	3	4	5	6	7	8	9	10	11	12	13	14
Leg Nº.	Height of Largest Lichen in Leg(m)	Mean Lichen Diameter (mm)			Date of Exposure of Fault Plane Scarp in Years BP (Base Year 1987)							Date of Exposure Years AD	
		1	$\bar{x}5$	$\bar{x}10$	1 ▲	$\bar{x}5$ ▲	$\bar{x}10$ ▲	1 ■	$\bar{x}5$ ■	$\bar{x}10$ ■	$\bar{x}5$ ★	$\bar{x}5$ ▲	$\bar{x}5$ ■
75	5.6	121	94	90	252	180	175	410	233	221	209	1807	1754
74	5.9	114	93	91	231	177	178	347	226	228	204	1810	1761
61	6.4	184	100	97	448	199	196	1331	275	267	245	1788	1712
55	6.6	115	100	99	234	199	202	355	275	281	245	1788	1712
78	8.4	161	102	101	377	205	208	914	291	296	258	1782	1696
81	8.6	124	102	101	262	205	208	439	291	296	258	1782	1696
27	8.7	122	102	101	255	205	208	419	291	296	258	1782	1696
79	9.0	122	104	102	255	211	211	419	306	303	271	1776	1680
80	9.2	105	104	103	203	211	214	275	306	310	271	1776	1680
71	9.2	109	107	105	215	220	220	306	330	326	292	1767	1656
66	9.4	147	103	102	333	208	211	708	298	303	265	1779	1688
69	9.8	152	103	102	349	208	211	778	298	303	265	1779	1688
48	10.2	120	116	114	249	249	247	400	411	399	359	1738	1576
40	10.5	120	120	118	249	261	259	400	451	435	392	1726	1536
47	10.6	184	106	102	448	217	211	1331	322	303	285	1770	1665
39	11.2	126	124	121	266	273	268	459	492	464	427	1714	1495
70	12.4	134	126	120	283	280	265	546	514	454	444	1707	1473
77	13.1	167	131	120	395	295	265	1013	571	454	491	1692	1416
79	13.6	181	132	117	439	298	256	1270	583	426	501	1689	1404
44	14.1	174	135	121	417	308	268	1137	619	464	531	1679	1368
68	14.7	171	139	132	408	320	301	1083	670	575	572	1667	1317
Lichens < 1m Above Talus Base													
77	0.09	24	22	–	◆	→ 12	–	4	5	–	5	1975	1982
48	0.10	36	31	–	◆	→ 18	–	14	16	–	12	1969	1971
78	0.10	34	32	–	◆	→ 19	–	12	13	–	13	1968	1974
59	0.19	48	40	–	◆	→ 24	–	30	23	–	23	1963	1964
69	0.22	48	44	–	25	25	–	30	30	–	37	1962	1957
67	0.21	49	44	–	28	25	–	44	30	–	39	1962	1957
69	0.20	52	46	–	37	32	–	38	34	–	46	1955	1953
78	0.20	58	47	–	56	35	–	52	36	–	61	1952	1951
82	0.25	61	53	–	66	53	–	60	50	–	69	1934	1937

▲ Linear curve (Equations 5.4 - 5.6) ■ Log-log curve (Equations 5.15 - 5.17) ★ Log-log curve without the "1869 House" (Equation 5.18)

◆ Lichens still within the "Great Period" - linear curve does not apply → dates based on Fig. 5.10

Table 5.2: Lichenometric results for the fault plane scarp.

largest lichens per substrate of known age, were subtracted from the base year 1987. The results are displayed in Table 5.2 (columns 13 and 14), and show a consistent increase in age with height above the base of the fault plane scarp when compared with column 2 which arranges the data by the height of the largest lichen in each surveyed leg. Deviations from this pattern may be explained by small-scale variations in micro-climate along the fault scarp. For example, a number of lichens in legs 66 and 69 (see Table 5.2 column 1) produce a date of 1688 AD at 9.4m - 9.8m above the scarp base, although their height above the scarp base suggests that they should be larger (that is producing a more 'ancient' date). Clearly their growth has been retarded in some way by about 3mm - 4mm. This could well be due to a number of environmental factors such as:

(i) Exposure to abrasion;

(ii) Temperature;

(iii) Moisture availability and the frequency of wetting and drying;

(iv) Substrate stability;

(v) Shading (see Kershaw, 1983); and

(vi) Competition (see Mather, 1961; Miyanishi *et al*, 1979; Pentecost, 1980; Steel, 1983)

Changes in any one or all of these could account for the observed deviations from the pattern of increasing size with height. Nonetheless, despite these variations there is a clear relationship between lichen size and height above the scarp base.

5.4 Discussion

5.4.1 The Lichenometric Curve

The close fit between the growth rates obtained from Maratea and those from Avebury, suggests that considerable confidence can be placed in the Maratea results. Nonetheless, the errors inherent in the technique combined with the ecological controls on lichen growth, argue that lichenometry can never achieve the precision of other absolute dating techniques. This assertion does not weaken the value of the technique; rather lichenometry should be regarded as a simple, cheap and quick tool that can produce reasonably accurate results although these results will never be very precise, that is reproducible or having a small standard error. In other circumstances, such as dating the exposure of the Maratea fault plane scarp, lichenometry may provide the only available means of absolute dating. In yet other circumstances, lichenometry is a valuable first-order dating technique, enabling further research and more expensive dating techniques to proceed with greater confidence.

5.4.2 Date of the Sackung and Sackung Tears

The uncertainties of dating the sackung crest using the age - size curve developed for the fault plane scarp, have been discussed in section 5.3.2. Dates of around 1000 - 8000 years BP, depending on curve construction, are probably beyond the life-span of the lichen and must be treated with considerable caution.

A date from a minor tear to the south of the main ridge (c.800 - 300 years BP), indicates that rupturing movements could still be occuring in the sackung. The tears in this area seem to have been caused by an outward movement of the sackung resulting from a loss of support along the ridge front when the sackung moved apart (see Fig. 5.11). The tears in this area are thus extremely young and could indicate major stresses within the main body of the sackung. As a result, the stability of the sackung is probably more precarious than hitherto believed (see Guerricchio *et al*, 1986a).

5.4.3 Exposure of the Fault Plane Scarp

Lichenometric work on the fault plane scarp has demonstrated that there is a consistent increase in lichen age with height above the base of the scarp. This relationship clearly provides firm supporting evidence for the progressive exposure of the fault plane scarp by mass movement either settling the adjacent talus deposits or causing movement along an underlying slip plane.

When the data in Table 5.2 are compared with the map of earthquake distribution in the region (Fig.2.6 and Table 4.1), it is apparent that there is a close fit between the dates of known earthquakes and the lichenometric dates. For lichens less than 1m above the talus all the lichen dates lie close to dates of known earthquakes. All the earthquake epicentres are within a 50 mile (80km) radius of Maratea and all had maximum impacts at or above VI - VII on the Modified Mercalli Scale. It may be, therefore that the slip or settling movements noted above are the direct result of earthquake shaking. The dates obtained from the colonies of *A. calcarea* at <1m above the talus can be substantiated by reference to the fruticose lichen *Squamarina gypsacea* (Sm.) Poelt. It was noted in section 5.2.1.2 that this lichen was an early coloniser but had a very short life span of only about 60 years. Its presence, therefore, at low elevations on the fault plane scarp suggests the relatively recent exposure of this section of the scarp.

Lichenometric dating has revealed a rapid rate of exposure for the fault plane scarp corresponding to about 15m in the last 300 - 600 years BP. As a result it is evident that movements along the fault plane scarp are not, as the Geological Office of the Regione Basilicata contend, Pleistocene in origin (Ufficio Geologico, Regione Basilicata, *pers. comm.*; Lazzari, *pers. comm.*). More likely, based on the Uranium Series date discussed in the previous chapter, the fault plane scarp is around 40,000 years old but is graduallly being exposed or exhumed by the processes of mass movement. These mass movement processes are not fossil Pleistocene features but are part of a large slope stability phenomenon affecting the whole of the area of the fault plane scarp and periodically accelerated by earthquake shaking. It is essential that these widespread slope movements are recognised by the *Comune di Maratea* and acted upon in future planning decisions.

No lichens were found on any of the pale grey colour bands at the base of the fault plane scarp (the 'white line' noted in section 1.5.1). Lichenometric dating cannot therefore, reveal the date of the 'white line' phenomenon and hence give any clues as to its formation. This problem clearly requires a separate solution which will be dealt with in the following chapter.

CHAPTER SIX

CHRONOLOGICAL FRAMEWORK

III

RECENT MOVEMENTS ALONG THE FAULT PLANE SCARP

6.1 Introduction

In Chapter Four it was argued that, for at least the last millenium, there has been no active faulting in the Maratea region and that the presence of the fault plane scarp is the result of its exhumation from beneath covering deposits. Chapter Five examined the rate of exhumation and concluded that about 15m of scarp face has been exposed in the last 600 - 700 years. There are, however, signs that the Maratea fault scarp has experienced even more recent movements. This section will examine the nature, scale and date of these movements.

6.2 Recent Movements

The exposed fault plane scarp is for the most part dark grey in colour, but towards its base and just above its junction with the talus, there is often a band of pale-grey colouration (a 'white line'). This pale colouration indicates a relative lack of weathering compared to the remainder of the fault plane scarp, thereby suggesting shorter exposure due to recent movement (Plate 6.1). The white line has a maximum width of 210mm, although is more frequently found to have a width in the range 15mm - 50mm. Along many parts of the fault plane scarp bands of intermediate colouration can be identified. A maximum of four belts of colouration can be seen, indicating three phases of movement: a white line at the base trending in discrete colour bands through a light grey, then grey, to the dark grey that characterises the majority of the fault plane scarp surface.

Plate 6.1: The "White Line" at the base of the fault plane scarp. A band of darker colouration can be seen above the white line indicating an earlier phase of movement.

The white line phenomenon is very similar to that observed at Senerchia (southern Italy) on comparable lithological units, which is thought to have been produced by the major earthquake of 23 November 1980 (Rizzo, *pers. comm.*). A characteristic white line, termed a "refreshening" by Guerricchio and Melidoro (1981), can also be seen at Monte La Falconara, a fault line in the Pollino mountain chain south-east of Maratea.

The importance of the 'white line' or "refreshening" is that it indicates relatively brief exposure due to recent movement (Plate 6.2), although the form of this movement is not known. In order to investigate the nature of these movements and the time scale over which they have occurred, the following investigations were carried out.

(i) Observations of the occurrence of the white line.

(ii) Detailed geomorphological mapping of areas of recent movement.

6.2.1 White Line Observations

The occurrence of the white line was plotted on the survey of the fault plane scarp described in Chapter Four and is shown on the fold out map of the fault plane scarp contained in the back pocket of this thesis. At each occurrence of the white line the following points were noted:

(i) The depth of the white line in millimetres.
(ii) The length of the white line in (a) its longest unbroken length (b) its broken length (a greater than 10m break qualified for a new entry).
(iii) The number of phases of movement, represented by the number of observed colour bands.
(iv) The condition of the fault plane scarp coincident with the white line occurrence. Principally whether a hard, unbroken, polished scarp surface existed (for example, the

Plate 6.2: The difference between weathered and newly exposed fault plane scarp, most dramatically seen at the abandoned quarry near pin 53.

section between pins 5 - 18 and 28 - 41) or the fault plane scarp was very broken up and thereby depositing weathered material onto the adjacent talus slopes (for example, between pins 19 - 27 and 66 - 79).

(v) The vegetational conditions at the fault scarp/talus interface, assuming that the greater the vegetation cover adjacent to the fault plane scarp the more stable that area would be.

Observations by the author, highlight a number of points. First, although the fault plane scarp is 2.08km long, the most recent movement, as represented by the 'white line' is only observed over 14% of its length (300m). Nonetheless, although evidence for movement is in discrete sections, these sections can be observed over the whole length of the fault plane scarp (see fold-out map of the fault scarp). Second, 11 observations (that is, eleven separate lengths of white line; nearly half the total number recorded) were on the area of the fault plane scarp between marker pins 11 - 30 (see fold-out map and Table 6.1). This section runs along the crest of a large debris cone at the inland extremity of the fault plane scarp. In addition,this was the only area where evidence of multiple movement was seen and the area where the width of the white line was at a maximum (Table 6.1). Third, over any given unbroken length of the white line, the feature maintains a relatively consistent width; for example between pins 24 - 26 a distance of 32m the width only varies by 5mm (25mm - 30mm). Fourth, 19 out of the 23 occurrences of the white line were in areas where the fault plane scarp does not have a hard polished surface (Table 6.1), and the surface that remained could be fractured with a light blow from a geological hammer. Moreover, over the lengths where there was no hard polished scarp face the slopes above the fault plane scarp also displayed signs of intense weathering; this situation was particularly prevalent between pins 20 - 26 where material deposited onto the talus slopes by free fall, made working in the area hazardous. In all of these areas, vegetation was observed on the talus adjacent to the fault plane scarp, although it tended to be sparse. As noted, this was a situation largely confined to the area along the top of the major debris cone,

Pin Reference	Local Conditions	Length of White Line m 1	2	Width of White Line ♦ mm
84	Small active debris slide, approx 6m x 4m. Sparse vegetation 1m downslope.	0.86		32
79 - 78	Small gully. Sparse vegetation 2m downslope.	0.38		34
77	Fault plane scarp very heavily eroded, beginnings of small gully. Scrub vegetation next to fault plane scarp.	0.5	5.3	36
77 - 76	Fault plane scarp very heavily eroded. Sparse vegetation 1.5m downslope.	0.35	14.0	15
75	Fault plane scarp very heavily eroded and small 'cave' forming behind scarp face. Sparse vegetation 10m downslope. Much loose debris next to fault plane, talus cone formed of small clasts 30 - 40mm diameter.	12	22	52
73 - 72	Fault plane scarp heavily eroded and only 2.5m high, beginnings of gully above. Sparse vegetation 3m downslope.	0.11	15.5	22
69	Small talus cone formed of fine clasts 10 - 15mm diameter. Sparse vegetation 1.5m downslope.	3.2		45
68 - 67	Fault plane scarp very heavily weathered Sparse vegetation 0.5m downslope.	5.7	12.2	43
60	Small rock fall 6m x 2m. Heavy vegetation 12m downslope.	1.5		26
47	Active talus cone. Fault scarp completely broken through. Vegetation 2m downslope.	8		15
41 - 42	Fault plane scarp very weathered and only 1 - 1.5m high. Very active gully erosion above fault scarp. Vegetation 1m downslope.	4.5		22
33	Large debris cone. Fault plane scarp very variable in height (1.5m - 13m) and very broken-up. Gully erosion immediately above fault plane scarp, rockfalls from higher up. Vegetation 1m downslope, channel of large boulders begins 6m from pin 33.	3.5		48
30	Summit of large debris cone. Fault plane scarp 6m high but very broken-up above. Channel of large boulders begins 11m from scarp face. Vegetation 1m downslope.	27		52
25 - 26	Fault plane scarp 4m - 12m in height with very strong erosion above. Sparse vegetation begins 2m downslope. Two "white lines" clearly visible.	32		32 White Line at bottom of fault plane 87 Grey line above white line
24 - 25	Fault plane scarp 4m high with very strong erosion above. Vegetation 2m downslope. Active gully midway between two pins.	12		15 White Line at bottom of fault plane 22 Grey line above white line
23	Fault plane scarp very broken-up, strong erosion above. Vegetation 5m downslope.	1		50
23 - 22	Fault plane scarp very broken-up, strong erosion above. Vegetation 5m downslope. Three "white lines" clearly visible.	22		15 White Line at bottom 120 Grey line above white line 210 Darker grey band above
22 - 21	Fault plane scarp very broken-up, strong erosion above. Vegetation 5m downslope. Three "white lines" clearly visible.	23		15 White Line at bottom 120 Grey line above white line 210 Darker grey band above
21 - 19	Fault plane scarp very broken-up, strong erosion above. Vegetation 5m downslope. Three "white lines" clearly visible.	1	23	15 White Line at bottom 120 Grey line above white line 210 Darker grey band above
16 - 15	Fault plane scarp very broken-up, strong erosion above. Vegetation 5m downslope. Three "white lines" clearly visible.	4		15 White Line at bottom 38 Grey line above white line 62 Darker grey band above
11	Fault plane scarp very broken-up, strong erosion above. Vegetation 5m downslope. Three "white lines" clearly visible.	4		25 White Line at bottom 68 Grey line above white line 103 Darker grey
8	Fault plane scarp 10m high heavily vegetated above.	4		85
4 - 1	Fault plane scarp 4 - 6m high broken-up in places. Heavy vegetation next to fault plane scarp.	3		34 White Line 62 Grey line above white line

1 Length of White Line in its longest unbroken length   2 Length of broken line (a >10m break qualifies for a new entry)

♦Width of line at its widest point

Table 6.1: Details of the colour banding found on the Maratea fault plane scarp

where three phases of movement could often be observed (Table 6.1). However on the flanks of the cone (marker pins 1 - 10 and 31 - 42) the white line was much less prevalent and sporadic; here there was a relatively high fault plane scarp, no signs of erosion and heavy vegetation adjacent to the scarp face. In consequence, it would appear from the authors' observations of the white line, that it only tends to occur where the talus accumulations have a good supply of debris from a highly weathered fault plane scarp surface and higher slopes of Monte Crivo.

6.2.2 Geomorphological Mapping

To supplement the information obtained from the 'white line' observations, a detailed geomorphological map of the large debris cone (marker pins 1 - 42) was drawn. This section was chosen for a detailed case study because of the high degree of recent movement that is displayed along the fault plane scarp in this area.

The technique of geomorphological mapping requires the recognition of breaks or changes of slope in the landscape. Once plotted, the breaks of slope form a morphological map of the area. The morphological map is then used as a base on which to interpret the underlying geomorphological features, thereby leading to the production of a geomorphological map. The technique was developed by Waters (1958) and Savigear (1965) although as Jones (1980, p.51) notes, it was 'for many years..considered a sterile technique of little value'. In the British context, geomorphological mapping was first used in applied work by Brunsden and Jones (1972) in Dorset, enabling the authors to map the distribution of landslide units which had been affecting the alignment of a road. The technique was extended by Verstappen and Zuidam (1968) who proposed the I.T.C. (International Institute of Aerial Survey and Earth Sciences) legend for geomorphological mapping. Similarly, a geomorphological legend for engineering geology maps has been outlined by the Geological Society of London (Geological Society

Engineering Group Working Party, 1972, 1983). The literature on the use of geomorphological mapping in applied work is now extremely large, but the reader will find good summaries in Demek (1972) Cooke *et al* (1982) and Cooke and Doornkamp (1989).

Geomorphological mapping is useful as it can be used to interpret landforms and hence process, and also provides a framework for the planning of specific site surveys such as trial pits and boreholes (eg Doornkamp *et al*, 1979). In addition, geomorphological mapping can be used to identify hazardous areas. Bush *et al* (1980), for example, employed geomorphological mapping to prepare a flood hazard map for Suez, while Hearn and Fulton (1986) mapped deep seated rotational landslides along the proposed route of the Dharan-Dankuta highway in the Himalayas. Doornkamp *et al* (1980), derived an aggregate resources map for Bahrain, using morphological and geomorphological mapping.

In Maratea geomorphological mapping was originally based on the available 1:2,000 topographic maps prepared for the *Comune* (local town council) in 1972. Unfortunately, field analysis revealed that those maps were unreliable in that many features on them were not accurately placed. The area to be mapped was, for the greater part, heavily vegetated and an accurate map could only be obtained by tying in fixed points on the ground to known points on the topographic map, such as abandoned buildings or marked tracks. In reality, a number of the buildings had been demolished and, in many areas the track deviated substantially from its mapped line. In short, accuracy could only be obtained by a complete re-survey of the area. This survey was undertaken by using the accurately mapped fault plane scarp and pin monitoring network as fixed reference points and relating all breaks of slope to them. Measurements were taken using poles, tapes, compasses and inclinometers. The full geomorphological map is illustrated in the next chapter; this chapter will concentrate on the extract of the large debris cone which is taken from it.

The debris cone can be divided into three zones, (Fig. 6.1 and Plate 6.3). Zone 1 from the fault plane scarp/talus interface to

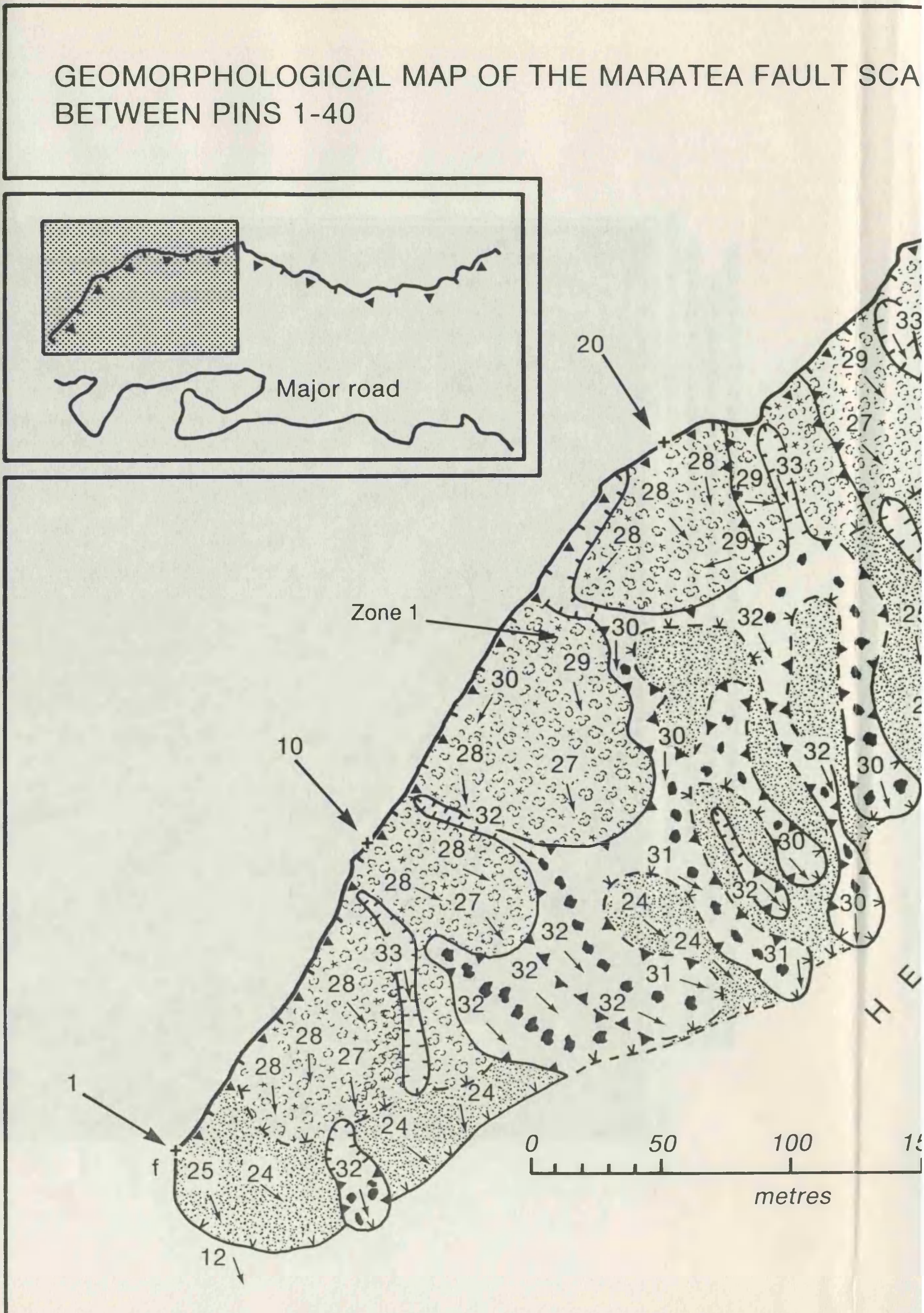
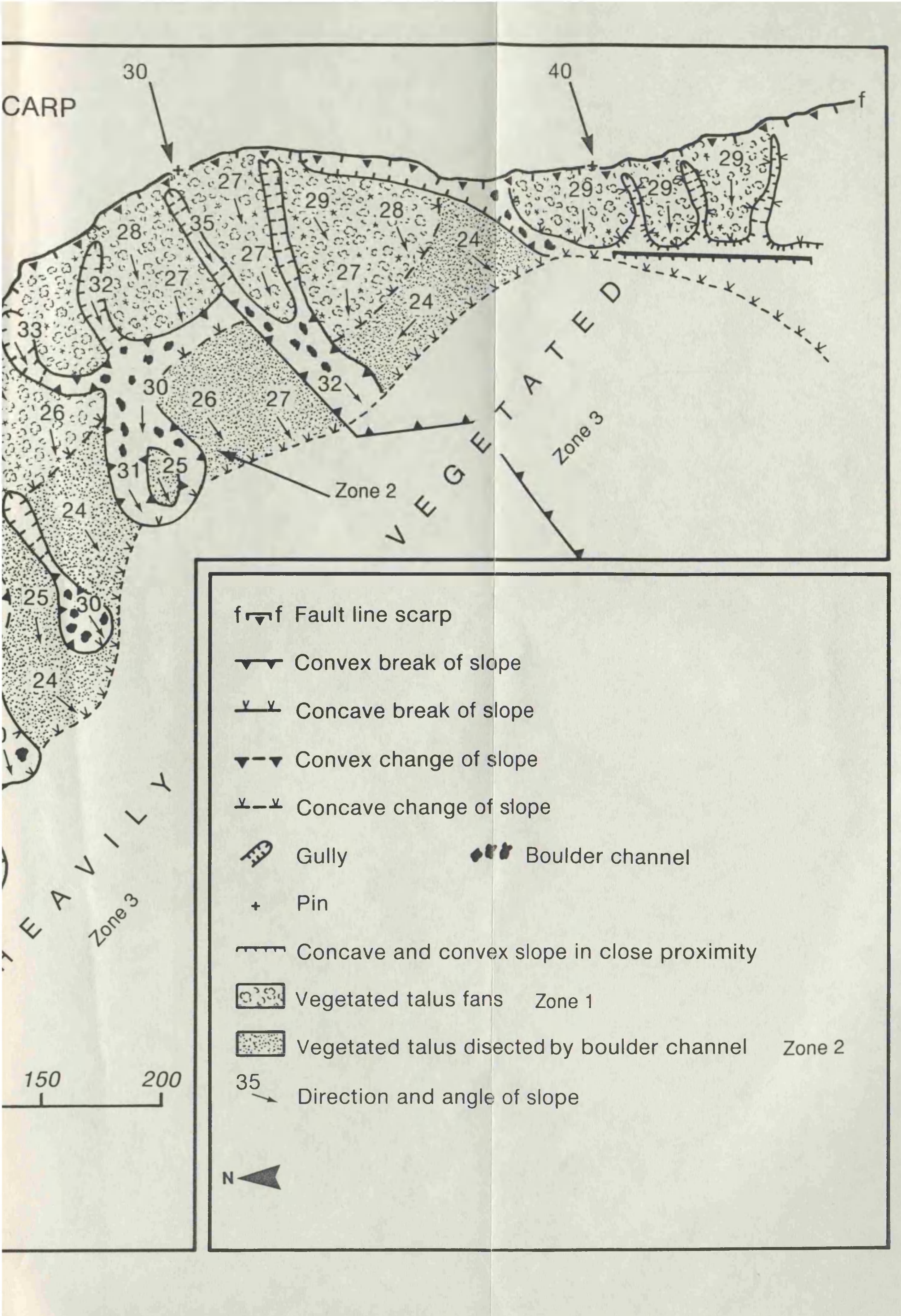


Fig: 6.1: Geomorphological map of the major debris cone at the head of the valley between pins 1 - 40.



CARP
30
40
f
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33
30
26
27
32
26
31
25
Zone 2
24
25
30
24
VEGETATED
Zone 3
EAVILY
Zone 3
150
200
f f Fault line scarp
Convex break of slope
Concave break of slope
Convex change of slope
Concave change of slope
Gully
Boulder channel
Pin
Concave and convex slope in close proximity
Vegetated talus fans Zone 1
Vegetated talus disected by boulder channel Zone 2
35 Direction and angle of slope
N

Plate 6.3: The major debris cone at the head of the valley. The three zones can be clearly seen in the photograph; the upper zone (Zone 1) nearest to the fault plane scarp is composed of vegetated talus; the middle zone (Zone 2) spans the middle third of the cone and is composed of less well vegetated talus, heavily disected by boulder channels; Zone 3 is the heavily vegetated area at the base of the cone.

about one-third of the distance down the cone is composed entirely of vegetated talus with the vegetation becoming progressively more sparse toward the centre of the cone. In Zone 2, which spans the middle third of the cone, are found vegetation covered talus slopes. This zone marks the beginning of the cone proper, that is the transition from talus slopes to cone. Zone 2 is heavily dissected by debris channels which have their source in areas of rapid weathering above the fault plane scarp. The debris channels are also represented in the middle zone by lobe shaped features supplied by free fall material from the area above the fault plane scarp. Zone 3 is composed of stable, heavily vegetated, talus. Angles of repose for the Zone 1 of the cone are in the order of 27^{o} - 30^{o}. In contrast, Zone 2 displays angles of between 24^{o} - 27^{o} as material is being moved away from the upper talus slopes to lower angled cones, and Zone 3 is characterised by much lower slope angles 10° - 15° as the debris cone begins to give way to the top of the limestone blocks.

The geomorphological map also illustrates the way in which debris is moved away from the scarp face and upper slopes of Monte Crivo. This movement takes two forms:

(i) Debris deposited by free fall onto the cone. This material is found in Zone 2, where debris channels dissect vegetated talus slopes, and in Zone 3 where lobe shaped accumulations are found; these channels and lobes are simply elongate features composed of large boulders 0.5m - 1m in diameter. They are completely unvegetated and appear to be highly unstable with angles in excess of 30°. The source material for the debris is the higher slopes of Monte Crivo, above the fault plane scarp face. The geomorphological map illustrates quite clearly that this material has not been transported from the fault plane scarp face; if it had been then debris channels emanating from the scarp face would have been observed.

(ii) Debris moved away from the scarp face in debris channels is, however, found. In these areas, the majority of which are in Zone 1, the fault plane scarp often displays signs of burial and no white line is visible. Although gully debris is continually being moved away from the fault plane scarp, the supply of material in these areas tends to exceed the rate of mass transport away from the base of the fault plane scarp. Except in these gully areas, vegetation is often found adjacent to the fault plane scarp, although tends to be sparse where the white line is most prevalent, that is between pins 20 - 26.

These observations suggest that the white line is not caused by the erosion and downwashing of material at the fault plane scarp/talus interface. Moreover, the remarkable consistency in the width of the white line over a given length, its well defined upper limit and the marked difference in colour with the higher portion of the fault plane scarp, all argue for its formation at a specific time rather than as the result of slow on-going movement. The existence of definite colour banding also indicates a similar conclusion; each distinctly coloured band on the fault plane scarp surface has been subjected to a different, and distinct degree of weathering compared to the other coloured bands of fault plane scarp both above and below. At no point along the fault plane scarp could the different colours be seen to grade imperceptibly one into another.

It is therefore clear, that the existence of definite colour banding suggests the exposure of sections of the fault plane scarp from beneath covering deposits at a specific time rather than as a result of progressive and on-going exposure. Measurements by the author of the displacement of the talus lead to the same conclusion. As noted in Chapter Four, 87 metal marker pins were placed in the surface of the fault plane scarp to act as fixed reference points for future surveys. These also acted as monitoring stations for a survey of talus movement. At each pin station a plumb line was hung from the pin to the talus, and a measurement taken of the distance between the two. Measurements were taken by the author during the summers of 1986, 1987 and 1988 - the plumb line ensuring that the same section was measured on each occasion. The survey contained a number of potential sources of measurement error; among these were pins working loose from the fault plane face and the plumb line not being in exactly the same line. As a result a measurement of ±10mm of the original (1986) survey was deemed to show no movement of the talus relative to the pin in the fault plane scarp; this error factor was smaller than the width of the white line at its narrowest point anywhere on the fault plane scarp. The results of the survey are shown in Table 6.2 and clearly show that the talus deposits during the period 1986 - 1988 experienced no progressive downward movement. As a result it is clear that, for this period at least, the pin survey bears out the conclusion to emerge from the white line survey, that is that there is no progressive movement of talus downslope and that the observed movements have occured at a specific time.

6.2.3 Date of the White Line

No lichens were found on any of the colour bands described above, clearly therefore, the technique of lichenometry is not applicable to the dating of the white line phenomenon. Lichens were, however, found at quite low elevations (90mm - 250mm above the talus) on the fault plane scarp (see Table 5.2). Dates for these lichens, which were in the range 1982 - 1937, suggest recent exposure of the lower sections of the fault plane scarp and hence a recent date for the colour banding. Alternative absolute dating methods, are thus similarly inappropriate to the dating of the white line, because of the very short time period involved.

The colour banding observed along the fault plane scarp indicates a basis for dating, particularly if some semi-quantitative value could be ascribed to each colour band. The Munsell Soil Colour notation scheme provides a standard for the description of colour which is applicable in this instance. Colour is described by three levels of notation; hue, value and chroma. These are described by Munsell Colour (1975) as follows: 'the Hue notation

PIN REFERENCE	DISTANCE FROM PIN TO TALUS (MM)		
	1986	1987	1988
1	1316	1311	1310
2	1209	1209	1209
3	1180	1185	1186
4	1308	1311	1311
5	965	965	965
6	857	858	858
7	2170	2175	2175
8	2040	2035	2035
9	1360	1365	1360
10	1390	1384	1390
11	1102	1100	1100
12	1075	1082	1073
13	1688	1688	1688
14	1379	1379	1379
15	1832	1842	1833
16	1768	1770	1170
17	792	792	792
18	1031	1030	1131
19	2588	2587	2588
20	1360	1365	1360
21	825	825	825
22	2016	2016	2016
23	1507	1507	1507
24	1405	1405	1405
25	1910	1910	1910
26	1579	1579	1579
27	1959	1959	1959
28	1730	1730	1730
29	1351	1351	1351
30	1530	1530	1530
31	1578	1578	1578
32	1606	1606	1606
33	1083	1083	1083
34	1510	1510	1510
35	1490	1490	1490
36	1645	1645	1645
37	1918	1918	1918
38	1485	1485	1485
39	828	828	828
40	1190	1195	1190
41	1261	1264	1263
42	1149	1146	1147
43	745	745	745
44	1752	1753	1752
45	776	767	767
46	1161	1171	1167
47	1305	1307	1307
48	1590	1585	1585
49	2794	2784	2793
50	1409	1403	1405
51	1374	1375	1374
52	591	591	591
53	1512	1514	1513
54	1471	1469	1467
55	1773	1772	1774
56	844	844	844
57	1795	178	1793
58	1725	1725	1725
59	1465	1470	1471
60	1860	1865	1865
61	1955	1950	1950
62	1260	1254	1255
63	1449	1448	1448
64	1994	1996	1996
65	1549	1539	1540
66	1465	1465	1465
67	773	773	773
68	1765	1765	1765
69	1942	1945	1942
70	910	900	900
71	1630	1635	1630
72	1659	1659	1659
73	1864	1865	1865
74	642	642	642
75	547	547	547
76	990	990	990
77	367	367	367
78	1010	1015	1015
79	1047	1047	1047
80	1034	1044	1044
81	2078	2078	2078
82	1095	1095	1095
83	1512	1517	1516
84	1743	1740	1741
85	1954	1953	1954
86	948	948	948
87	1403	1401	1402

Table 6.2: Pin survey measurements 1986 - 1988

of a colour indicates its relation to Red, Yellow, Green, Blue and Purple; the Value notation indicates its lightness; and the Chroma notation indicates its strength (or departure from a neutral of the same lightness)'.

Along the fault plane scarp each band was assigned a value based on the Munsell notation. Two readings were taken on each colour band, one in the sunlight and the other in the shade. All the readings were taken on the colour bands between pins 20 - 26 as this was the area where multiple banding was observed. Results indicated that all the colour bands along the Maratea fault plane scarp have absolute achromatic colours. That is they have no hue and a zero chroma value, in other words they are whites, greys or blacks and are found on a scale ranging from a value of N8/0 (white) through to N3/0 (very dark grey). The values for the three colour bands and the general background colour of the fault plane scarp are as follows:

• White line:	N8/0 - N7/0	(Sunlight)
	N7/0	(Shade)
• Second Band	N5/0	(Sunlight)
	N5/0 - N4/0	(Shade)
• Third Band	N4/0	(Sunlight)
	N4/0 - N3/0	(Shade)
• Fault Plane Scarp	N3/0	(Sunlight)
	N3/0	(Shade)

These figures can be used to calculate the age of colour banding if calibrated against other surfaces, composed of the same material, whose date is known and which have a similar Munsell Colour notation. Such surfaces must be selected with care and, as with the lichenometric dating, a number of important points should be taken into account.

(i) The date of the surface must be accurately established;
(ii) It must not have been cleaned since it was erected;
(iii) It must be of the same type of dolomitic limestone of which the fault plane scarp is composed; and

(iv) It should occupy a similar 'weathering niche' to the fault plane scarp, that is it should have the same aspect and exposure and not be in a position where it has suffered more or less weathering than the scarp.

In the last chapter a number of such surfaces were described in detail and used in the construction of a lichenometric age - size curve. The five surfaces found in the Maratea valley were sampled for their Munsell colour. These surfaces are described briefly below; the reader is requested to refer back to section 5.2.1.1 for a more detailed description of them.

1. Road to the statue of Christ. Dated 1978.

The surface is the flank wall of a road constructed to the statue in 1978. The walls are of local limestone quarried from the village of Brefaro in the adjacent valley.

2. Crucifix on a limestone Block. Dated 1963.

The surface is the plinth of a cross and was constructed in 1963 of local limestone.

3. Villa Comunale. Dated 1952.

This surface is the flank wall of the town garden, constructed in 1952 of local limestone.

6. Memorial to San Biagio. Dated 1932.

The surface is the capstone of a small memorial dedicated to the memory of San Biagio, the patron saint of Maratea.

12. Main Maratea - Trecchina Road. Dated 1910.

This road, constructed in 1910, involved blasting the face of some of the limestone blocks in order to clear the roadline. The new face was assumed to be light in colour and unweathered.

The results of applying a Munsell Colour notation to these surfaces is detailed below in Table 6.3.

COMPARISON OF MUNSELL COLOUR NOTATION

Munsell Value (Sunlight Value)	No. of Colour Band	Name & date of known age surface
N8/0 (White)	'White Line'	None
N7/0 (Light Grey)	'White Line'	1. Road to statue 1978
N6/0 (Grey)	None	2. Crucifix 1963
N5/0 (Grey)	Second Colour Band	3. Villa Comunale 1952
N4/0 (Dark Grey)	Third Colour Band	6. Memorial 1932
N3/0 (Very Dark Grey)	Fault Plane Scarp	12. Main Road 1910
N2/0 (Black)	None	None

Table 6.3: Dates of the colour bands based on substrates of known age .

These figures allow approximate ages to be placed on the colour bands. Thus the 'white line' is a relatively recent phenomena dating to the late 1970s or possibly early 1980s, that is less than 20 years. The second and third colour bands relate to the early 1950s and 1930s respectively, that is 30 - 40 years and 50 - 60 years. Thereafter the fault plane scarp achieves a uniform colour, indicating exposure for at least 70 years.

The results are compatible with the lichenometric dating described in Chapter Five. Although no lichens are found on any of the colour bands, lichens are found 90mm above the talus dating from 1975 - 1982 (see Table 5.2). Similarly the maximum width of the lowest colour band - the "white line" is 85mm, indicating a comparable date of exposure, that is in the late 1970's - early 1980's. Moreover the maximum width of all three colour bands is 345mm (between pins 19 - 23), suggesting that a date for the exposure of the top band should be in the 1930's. Again lichens at 250mm above the talus have a very comparable date (see Table 5.2).

6.2.4 Mechanism of Formation of the 'White Line'

From the above discussion it is clear that the white line phenomenon is the result of a specific mechanism acting at specific times. The "white line" is, however, not found over the entire length of the fault plane scarp. If it were, then fault movement, possible generated by seismic activity, might be inferred. As this inference cannot be made it suggests that a more localised mass movement rather a seismic mechanism is operating. The displacement appears to occur in those areas where there is a continual supply of slope debris which never allows the talus slopes to reach a condition of equilibrium. These areas may thus be considered to be only marginally stable and readily react to increased loading. The white line is therefore considered to be the consequence of mass movement occurring in areas of marginal stability. The movement could be related to the settlement of poorly consolidated sediments within the coalescent talus cones or to a movement of the talus as a body along a deeper slip plane. Uncertainty remains as to whether or not these larger-scale movements could involve the displacement of the limestone blocks. Such movements are most likely to occur either as the consequence of major rockfall activity on the slopes of Monte Crivo, or as a response to seismic shaking. Seismic shaking is seen to be the most plausible explanation and examination of the earthquake record (Table 4.1) indicates that the currently visible white line at the base of the fault plane scarp is most likely to have been caused by a mass movement of talus downslope, triggered by the 1982 Gulf of Policastro earthquake. Similarly, the second and third colouration zones most probably relate to movements triggered by the 1955 and 1934 earthquakes, both of which had epicentres within a 30km radius of Maratea and had the same shock intensity at Maratea, namely VI - VII on the Modified Mercalli Scale.

CHAPTER SEVEN

CHRONOLOGICAL FRAMEWORK

IV

MOVEMENTS OF THE LIMESTONE BLOCKS

7.1 Block Nature and Position

To establish both the number and size of limestone blocks present within the valley, a geomorphological map was prepared at a scale of 1:2000 (see section 6.2.2). The area covered extended from the crest of the fault plane scarp to the main Maratea-Trecchina road (see Fig. 7.1). This road runs along, and is frequently cut into, a major concavity which appears to be the basal concavity, or leading edge, of the limestone blocks. The left and right extremities of the map (in this case the north and south boundaries respectively) are taken from the first visible occurrence of the fault plane scarp at the head of the valley, to the point where it trends into the sackung deformation; this latter point is marked by the disappearance of the smooth grey fault plane scarp (see section 3.3.1) and the beginning of a much more weathered face. During a survey of the fault plane scarp (see section 4.2.2), 87 metal marker pins were placed at regular intervals in the scarp face itself. Marker pins 1 and 87 coincide with the north and south map boundaries respectively (see Fig. 7.1 and fold-out map of the fault plane scarp).

The mapping programme was supplemented by an air-photographic analysis of the valley (see Plate 7.1 and stereo pair of photographs in the back pocket of this thesis)), beyond the confining boundaries of the geomorphological map itself. The air-photograph interpretation was carried out according to well accepted practice (for example, see, Cooke and Doornkamp, 1989; Doornkamp, 1984; Verstappen and Zuidam 1968, and for photographic interpretation of southern Italian landslide-prone area, Nossin, 1973). In the Maratea valley an air photograph interpretation

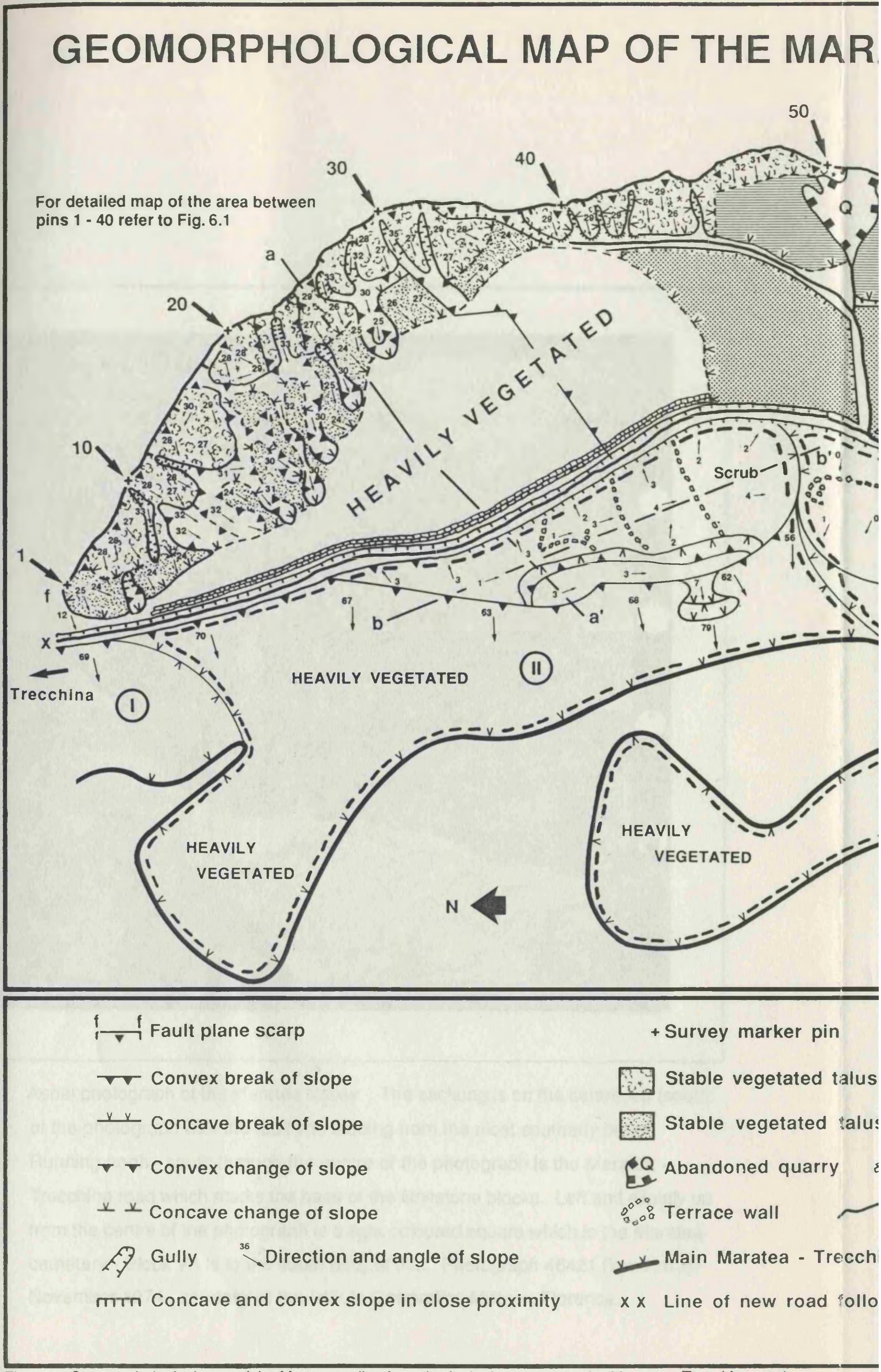
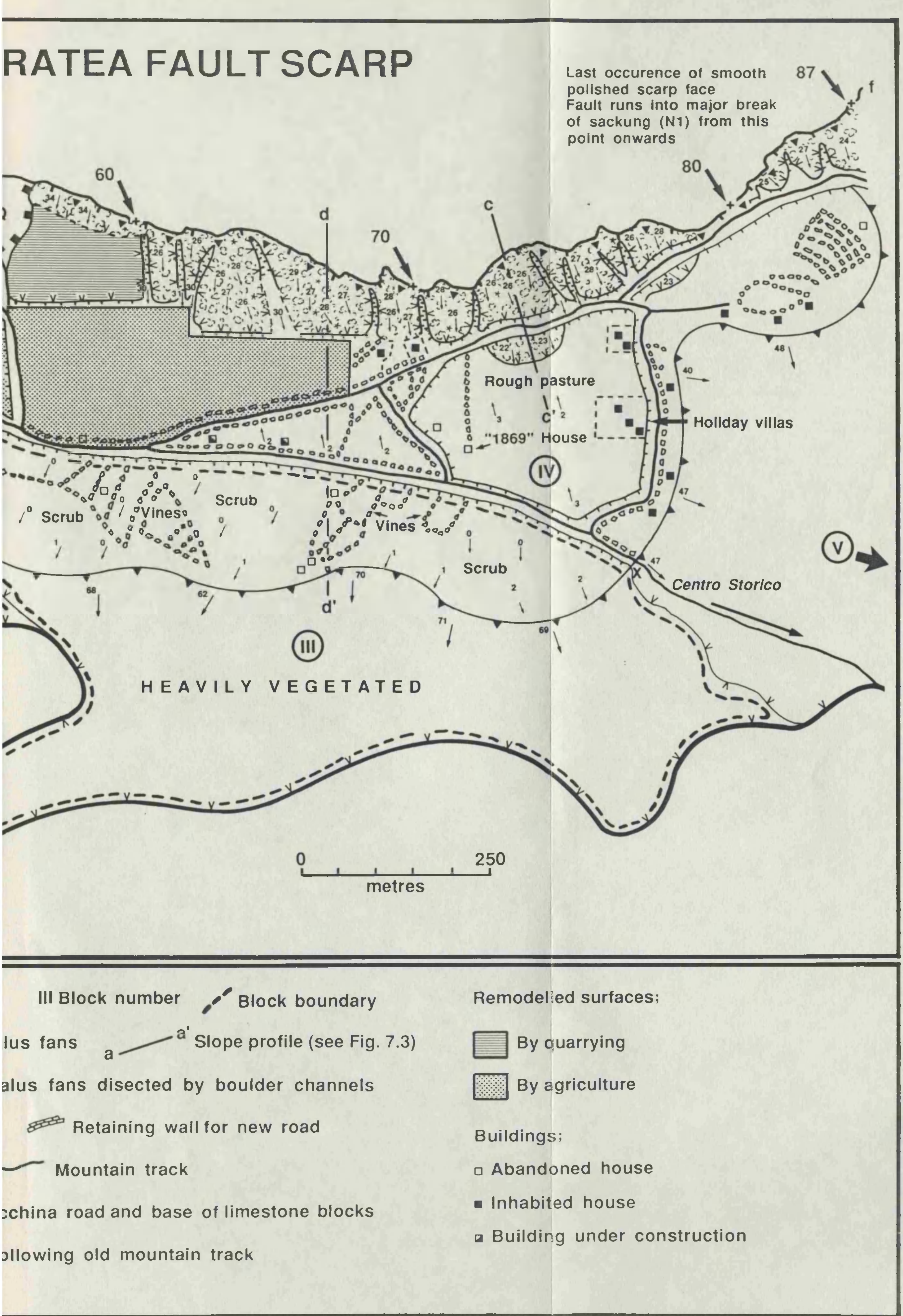


Fig. 7.1: Geomorphological map of the Maratea valley from the fault plane scarp to the Maratea - Trecchina road.


RATEA FAULT SCARP
Last occurence of smooth polished scarp face
Fault runs into major break of sackung (N1) from this point onwards
87
f
80
60
70
d
c
Rough pasture
c'
"1869" House
Holiday villas
IV
Scrub
Vines
Scrub
Vines
Scrub
d'
III
V
Centro Storico
HEAVILY VEGETATED
0
250
metres
III Block number
Block boundary
Remodelled surfaces;
lus fans
a
a'
Slope profile (see Fig. 7.3)
By quarrying
alus fans disected by boulder channels
By agriculture
Retaining wall for new road
Buildings;
Mountain track
Abandoned house
Inhabited house
cchina road and base of limestone blocks
Building under construction
ollowing old mountain track

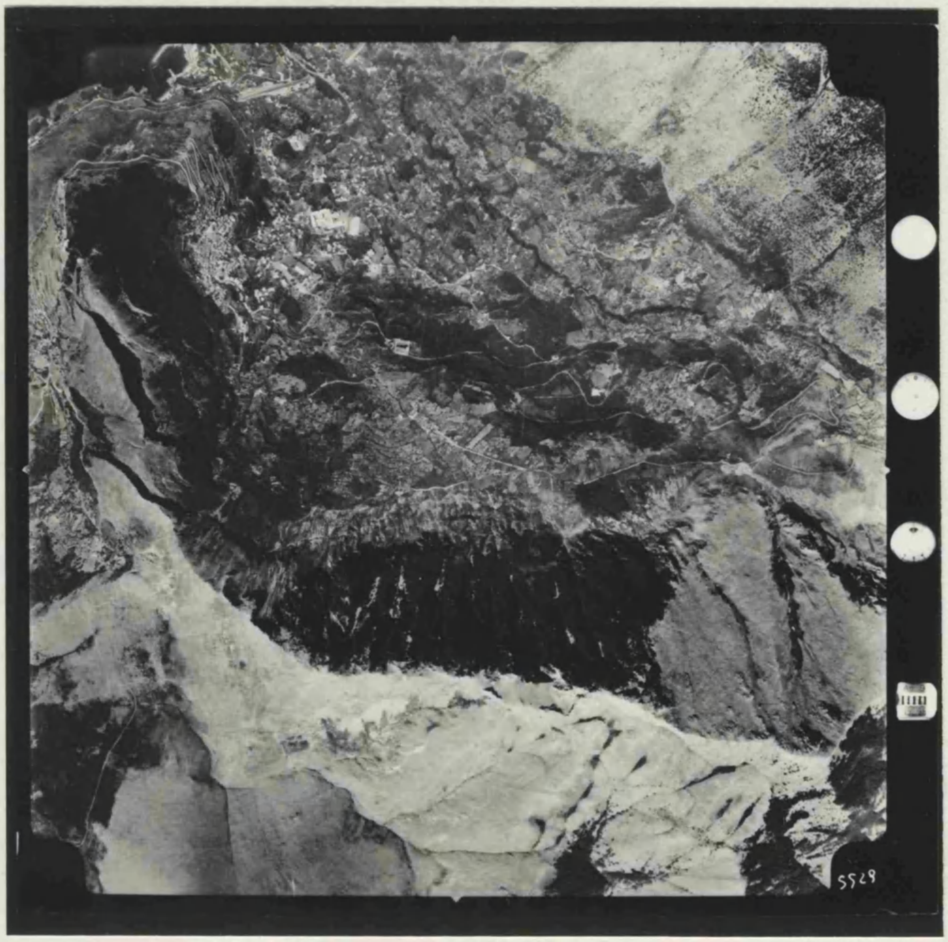


Plate 7.1: Aerial photograph of the Maratea Valley. The sackung is on the centre left (south) of the photograph with the fault line leading from the most southerly break. Running north - south through the centre of the photograph is the Maratea - Trecchina road which marks the base of the limestone blocks. Left and slightly up from the centre of the photograph is a light coloured square which is the Maratea cemetery - Block VA is to the south (left) of this. Photograph 46421 flown on 20 November 1974 - courtesy of the Istituto Geografico Militare, Florence.

was desirable because the density of vegetation in the area is very high and can obscure some geomorphological features. These features are more readily apparent on an air photograph and can be more easily mapped in the field once their general form is known. Aerial photographs of the valley were obtained from the Italian Institute of Military Geography in Florence at a scale of 1:19,000. The photographs dated from 1974 and were the most recent available for the area.

A combination of the geomorphological map and air-photograph interpretation revealed the presence of six limestone blocks (Plate 7.2). Four were situated in the area of the geomorphological map (see Fig. 7.1, blocks I - IV) and one immediately outside its south-west boundary (block V, see Fig. 7.2). These five blocks were adjacent to talus slopes beneath the fault scarp. A sixth block (block VI) was identified near the coast at the Porto di Maratea (Fig. 7.2). In the case of the five blocks adjacent to the talus, a common and diagnostic feature is a marked concave break of slope at the base of the talus. Blocks II and III shown on the geomorphological map have a track cut into this concavity. Talus angles immediately eastward of the break of slope are in the order of 23° - 25°, although the central section of the map (approximately between pins 45 - 68) has been heavily remodelled by ploughing for agriculture. A more accurate picture is, therefore, seen with the example of Block IV; here talus angles east of the break of slope are in the range 26° - 28°, indeed a small talus cone (seen on Fig. 7.1 above the legend 'rough pasture'), is bisected by the concavity and the path. Westwards of the concavity there is either level ground (noted on Block III) or a reverse angle of 2° - 3° trending back towards the fault scarp (Blocks II and IV). The leading edge of the blocks is usually marked by a clear convex break of slope with slope angles in the range 60° - 70°. The cross sectional form of the blocks can be seen in Fig. 7.3. It can thus be seen that the limestone blocks may be accurately described as blocks rather than mounds of debris or talus. In the area of the geomorphological map they all have a definable and clear rear boundary, a flat or back-sloping top and a steep front edge leading to a definite base.

Plate 7.2: The limestone blocks in the valley floor - Block VA can be seen in the foreground.

POSITION OF THE LIMESTONE BLOCKS WITHIN THE MARATEA VALLEY

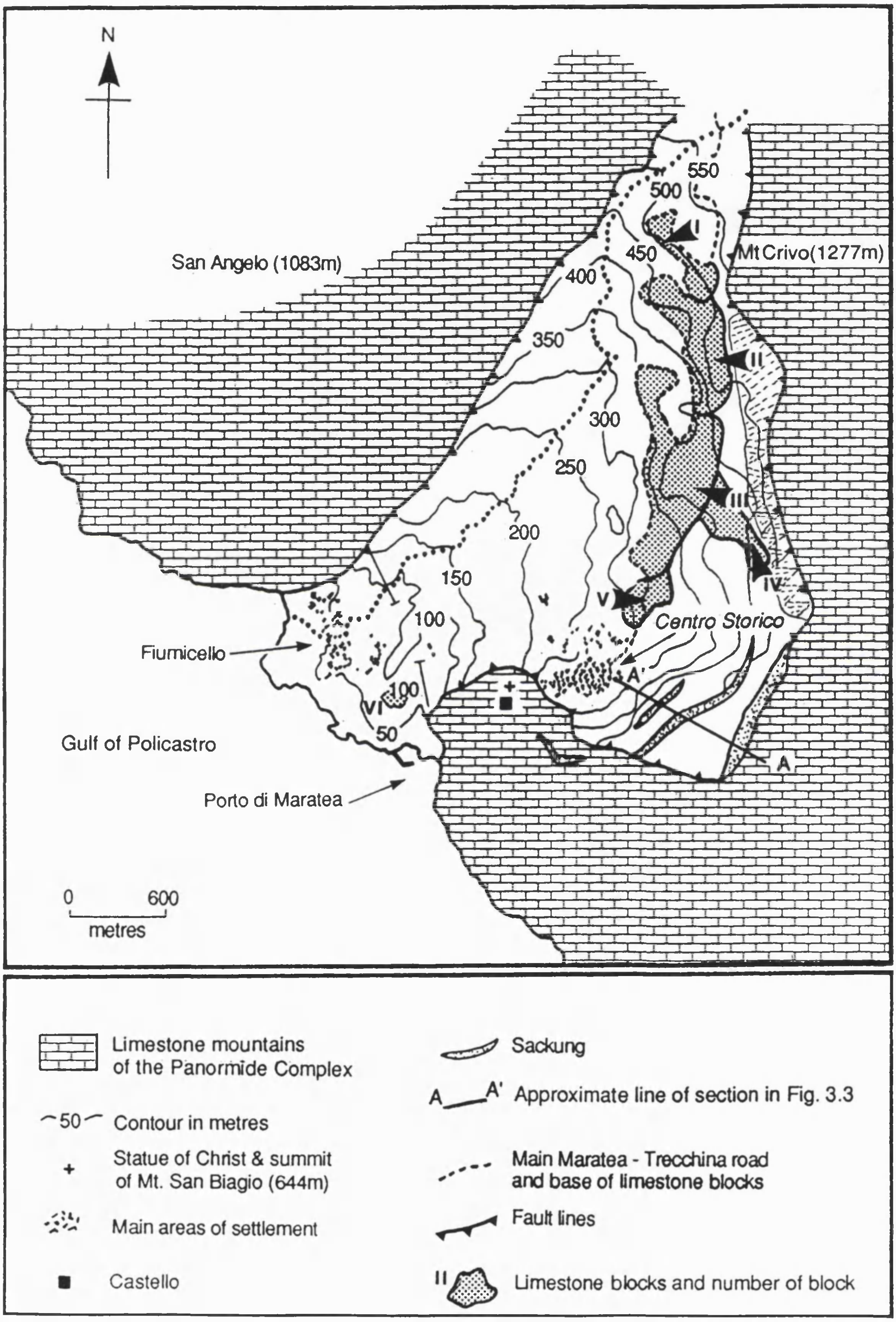


Fig. 7.2: General map of the position of the limestone blocks and other main structural features of the Maratea valley.

SLOPE PROFILES IN THE MARATEA VALLEY

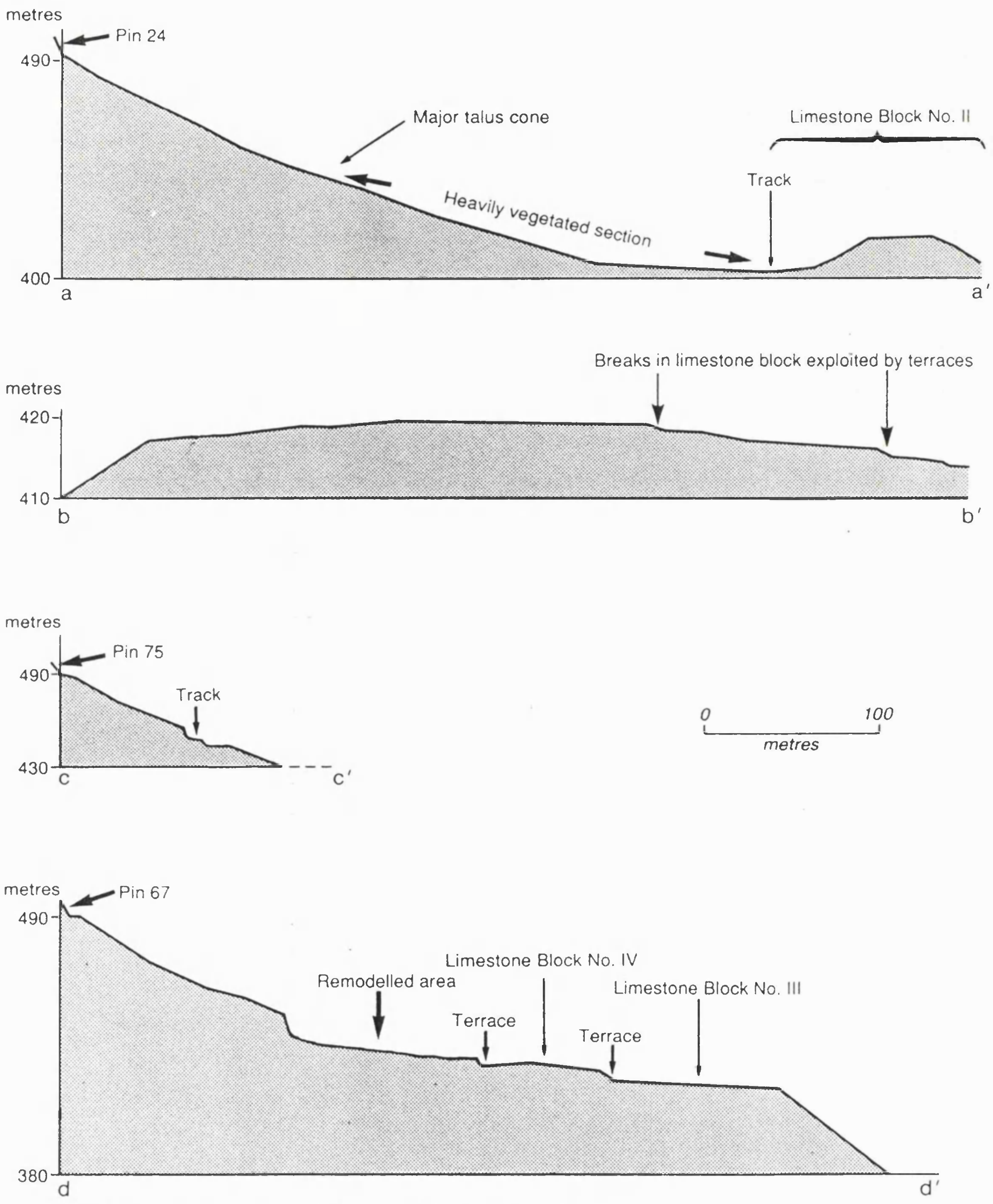


Fig. 7.3: Cross sections of the limestone blocks. See Fig. 7.1 for section locations.

The basal concavity marks the line along which the blocks appear to be breaking up; westward of this line are found smaller blocks which seem to have broken away from the parent block. This situation is particularly evident in the case of Block V (see Plates 7.1 and 7.2). The road runs along the basal concavity of block V but almost along the top of V_A. Air photographs show continuity of the block across the road suggesting that blocks V and V_A where once part of the same feature and that V_A has both split away from, and sunk, relative to the parent block.

The sizes of the blocks vary considerably. Block I is about 700m wide with a breadth of 200m and a depth from front scarp crest to base of about 120m. Block II is smaller, roughly 300m X 200m X 100m; block III, 450m X 500m X 90m; block IV, 150m X 100m with an uncertain depth because of large volumes of talus deposited around its flanks; block V, 450m X 500m X 80m and block VI about 150m X 150m X 100m. These values, which have been extracted from the air photographs, are necessarily approximate, particularly the depth which does not include the depth of buried block. Peels from both the blocks and the fault plane scarp show them to be composed of a dolomitic limestone.

Large areas of *blocchi carbonatici* (limestone blocks) were identified by Guerricchio and Melidoro (1981) in a geological sketch map of the Maratea valley (Guerricchio and Melidoro, 1981, p.257, Fig. 6). Their map, which was derived from an air-photograph interpretation, did not attempt to define individual blocks, rather it depicted a large area of *blocchi carbonatici*, extending from the approximate base of the talus to the Fiumicello river, in other words the whole of the valley floor. This map bears little resemblance to the morphology of the valley. The work of the author is, therefore, the first time that the limestone blocks in the Maratea valley have been accurately identified, surveyed and mapped.

7.2 Block Movements

7.2.1 Formation of the Blocks

As noted in Chapter Three, the presence of six limestone blocks below the fault plane scarp indicate that they may once have been part of the Monte Crivo massif and have since been transported downslope. Section 3.3.3 suggested various models of block break-up and concluded that a possible explanation of their formation may lie in the "Step Fault Model". In this instance the blocks are part of the fault hangingwall which has collapsed relative to the footwall; talus accumulations have brought about basal shear between two step faults which has formed the blocks and caused them to move downslope and rotate.

The four main blocks, I, II, III and V have all reached a similar position in the valley, as is evidenced by the Maratea - Trecchina road which runs due north from the *centro storico* along the base of the blocks. This observation lends further credence to the view that the blocks collapsed by a common mechanism and at the same time. Similarly, observations by the author of the slickenside striations on the fault plane scarp, (see section 4.2.2), suggest that the hangingwall of the fault has collapsed in 'segments'. Possibly the most northerly 'segment' moving south-east - north-west (represented by Block I), the most southerly segment moving either due west or north-east-south-west (Block V) and the others moving due west (Blocks II and III). This situation is illustrated in Fig. 7.4.

If the Step Fault Model is taken as a working hypothesis, then the Uranium date obtained from the fault plane may be the same as the date of block collapse, that is a maximum of c.46,000 years BP. However as the Uranium date is measuring the date of the last fault movement, for the dates to be coincident the blocks must have collapsed at the same time. Clearly if the fault has moved in two or more movements (see Fig. 3.14) then the blocks could have collapsed at any time between the first and last events.

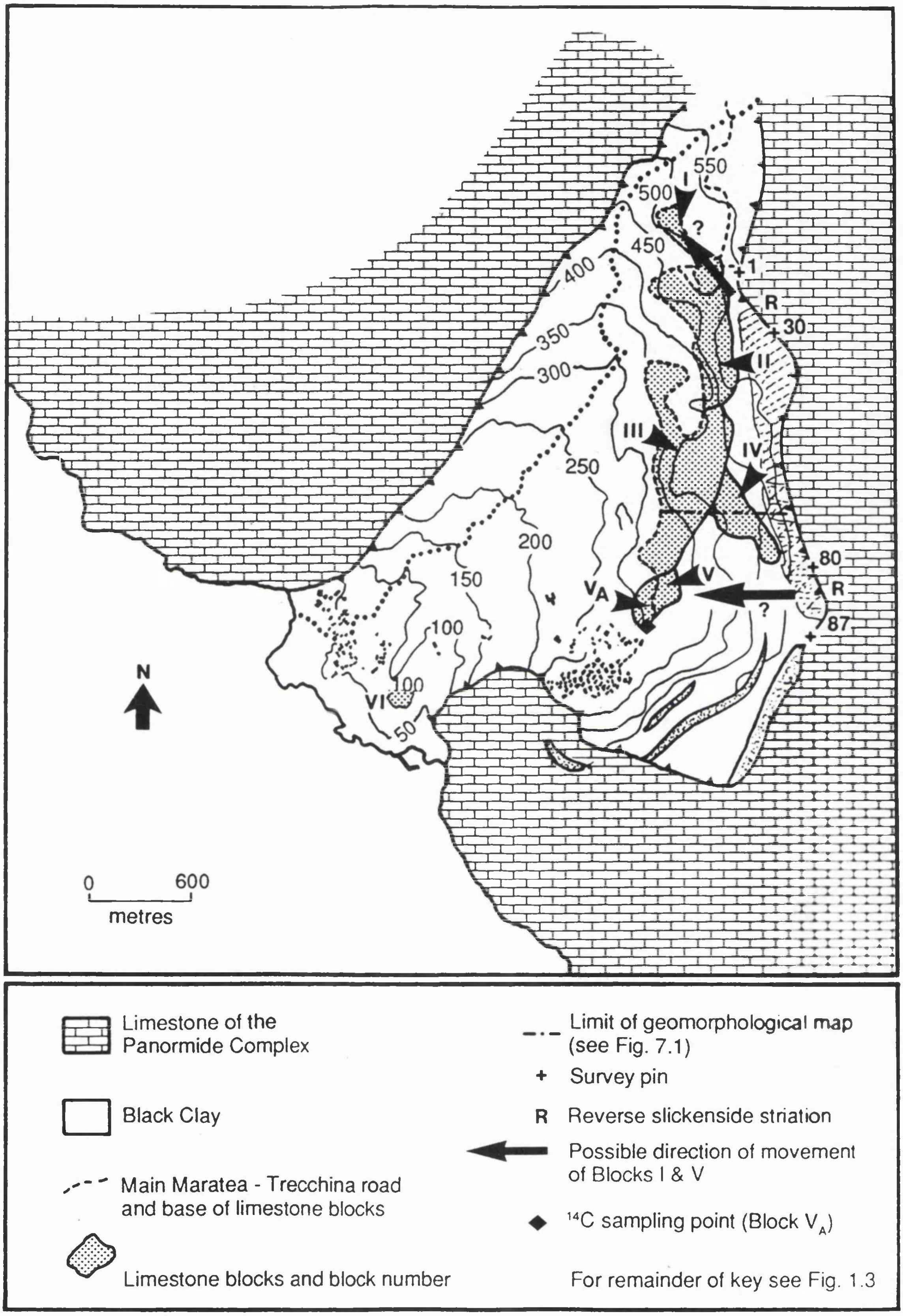


Fig. 7.4: Map of the possible movements of the limestone blocks. The 'reverse' slickenside striations seen on the north and south extremities of the fault plane scarp may explain the positions of blocks I and V.

This scenario is in broad agreement with the views of Guerricchio and Melidoro (1981) who have suggested that the blocks 'float' on the black clay layer. A step fault and basal shear mechanism which moved the blocks onto the black clay layer is a possibility with the "Step Fault Model" (see Fig. 3.19). Black clays under the blocks would not be expected if block movement has occurred along a listric fault plane. In this second case the blocks would have moved with a 'ploughing' action piling-up material, including black clay, in front of them as they moved. It should of course be noted that there is no subsurface information to support any of these views which must be regarded as hypotheses to be tested.

7.2.2 Recent Movements of the Blocks

It was suggested in Chapter One, that because of the lack of available building land in Maratea any new development would have to be in the area between the base of the talus accumulations and the leading edge or crest of the limestone blocks. It is clear, therefore, that a knowledge of recent block history is vital before any development takes place directly on them.

Guerricchio *et al* (1986b) established fixed survey points on Blocks I, II and V and recorded measurements between the blocks and the fault plane scarp during the month of July in the years 1983, 1984 and 1985. Their results (see Table 3.4) show that recorded differences in the surveyed measurements fall within the error limits of the instruments that were used (error limits are ±8mm at 100m and ±16mm at 1000m, see section 3.3.1 for a full discussion of the surveyed network). Consequently the authors argue that the blocks are not moving. Geomorphological mapping of the area below the fault plane scarp (see section 7.1 above) recorded no evidence for block movements in the area at the base of the talus deposition; tension cracks, for example, which might have been expected at the junction of the talus and the back of a block were not present. Below the blocks, the main Maratea - Trecchina road shows no sign of major distress due to block movement. The road displays some evidence of parallel cracking directly beneath Block III, although it is not certain whether this has been caused by block movement or movement of the macadam sub base.

Block V_A (see Fig 7.4 and Plates 7.1 and 7.2) is the only block to show clear signs of recent movement. In section 7.1 it was noted that V_A is probably a fragment of Block V, which has broken away from the parent block and sunk relative to it. A spring line at the base of Block V has caused a small stream to flow over the top of Block V_A, mobilised the calcium carbonate within the limestone and redeposited it as stalactitic tufa over the leading edge of Block V_A (Plate 7.3). Sections taken by the author through stalactites from Block V_A show several phases of stalactite growth around different growth axes indicating possible movements of the block during the growth of the stalactites. This observation indicates a basis for dating each of the growth phases and consequently charting the movement of the block.

As noted in section 4.4, calcite is amenable to absolute radiometric dating and so either U-series, ESR, ^{14}C or TL dating is applicable. All of these dating methods are, however, expensive and project funding limited the author to one radiometric date. As a consequence the available money was used where it was likely to be most effective, in this instance to obtain the U-series date for the fault plane scarp (see Chapter Four). This decision was taken because, as noted above, it is highly likely that Block V_A is only a fragment of Block V. An estimate of the date of recent movements will refer to the fragment and not to the main block; no general conclusions on block stability within the area will, therefore, emerge. In addition, sampling of Block V_A was difficult; obtaining a stalactite to date was a considerable task and only possible if the specimen was readily accessible. Larger stalactites exist on the block and would have yielded an older date. However to reach them would have required cranes or scaffolding which were not available to the author, and would have also resulted in the defacing of a local tourist attraction. A low-cost date for the stalactites from Block V_A was therefore desirable; fortunately

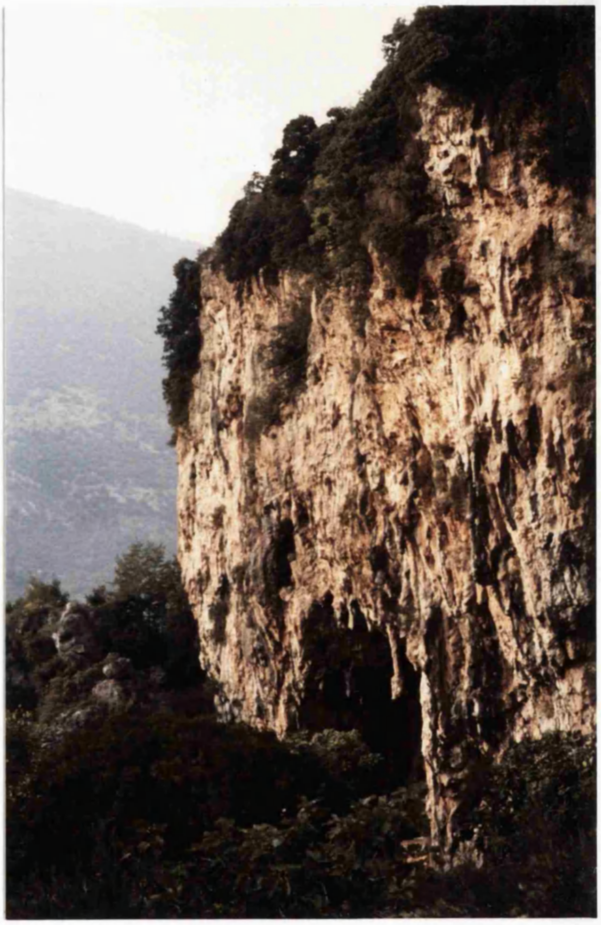


Plate 7.3: Block V_A showing the covering of tufa on the block.

this was available to the author in the form of a liquid scintillation method of ^{14}C dating at University College London.

Problems with the very high cost of conventional radiocarbon dating led Vita-Finzi (1983) to argue that 'in consequence the method tends to be used more sparingly and less effectively than it might'. In view of this, a technique of low cost radiocarbon dating has been developed by Eichinger and Rauert (1980, 1981) and extended by Vita-Finzi (1983). The technique is APPLICABLE to the dating of stalactitic calcite from Maratea and satisfies the requirements of being quick, low-cost and reliable.

7.2.2.1 First Order Radiocarbon Dating

Radiocarbon is produced by the bombardment of cosmic rays on nitrogen (^{14}N) in the upper atmosphere. The reaction produces a neutron (n) which results in the emission of a proton (p) and creates an atom of ^{14}C. Oxidisation then takes place and $^{14}CO_2$ (radioactive carbon dioxide) is produced. Radioactive carbon dioxide is distributed evenly throughout the atmosphere and assimilated by all living things. At death the assimilated ^{14}C begins to decay at a steady rate. Libby (1955) argued that if the half-life (effectively the rate of decay) of radiocarbon could be established then ^{14}C could be used as a dating technique. Dating relies on the assumption that the concentration of ^{14}C in the atmosphere (measured as the ratio between $^{14}C/^{12}C$) has been constant through time.

The technique has been widely applied in archaeological (see Renfrew, 1976) and geological problems. In work where there is a particular need for a very precise radiometric date (that is either reproducible or having a small standard deviation), careful sample preparation and long counting has led to a very high cost (see for example Gupta & Polach, 1985). Although generally applicable, this has particularly been the case with archaeological work. Vita-Finzi (1983) has, however, argued that 'there are problems in geology and archaeology whose investigation requires ages that need not be very precise provided they are reliable' (Vita-Finzi, 1983, p.389; see also Vita-Finzi, 1987).

The liquid scintillation counting method of radiocarbon dating using trapped $^{14}CO_2$ (see Eichinger and Rauert, 1980, 1981; Vita-Finzi, 1983) uses standard laboratory equipment and costs about £1.50/sample (at 1983 prices) compared with about £200/date from a specialist ^{14}C laboratory. Samples dated by this method at University College London have compared favourably with similar samples sent to specialist radiocarbon laboratories (Vita-Finzi, *pers. comm.*). The rig (see Fig. 7.5) consists of a glass jar containing the sample (minimum sample weight 25 grammes) set on a magnetic stirrer. The magnetic stirrer generates an electromagnetic field enabling the sample to be agitated. A 50% solution of hydrochloric acid (HCl) is dripped onto to the sample. The reaction produces $^{14}CO_2$ which is passed through silver nitrate to trap any HCl fumes and an empty glass vial which traps any accompanying froth. The gas is absorbed into Carbosorb and Permaflüor V which act as the trapping agent and scintillation mixture respectively. The whole rig is attached to a vial of sodalime which prevents CO_2 from the atmosphere polluting the system. Similarly, the system is first purged with nitrogen (N_2) to remove the air inside it. During a dating run, the only controls on the system are the drip rate of HCl and the rate of sample agitation.

Stalactitic tufa can be dated by measuring the amount of ^{14}C trapped since the sample was redeposited. Stalactitic tufa is $CaCO_3$. The carbon content (C) when mixed with HCl gives off CO_2. The CO_2 is trapped in Carbosorb (which probably has an ethanolamine base) to form a Carbamate. The scintillating agent - Permaflüor V - is added to the Carbamate and placed in the liquid scintillation counter. The counter measures the number of 'decay events' (expressed in counts per minute - cpm). The younger the sample the more decay events and the more counts per minute. The date of the sample is obtained by measuring the number of counts per minute over a background count of 7cpm. The result is read off from a calibration curve based on the half-

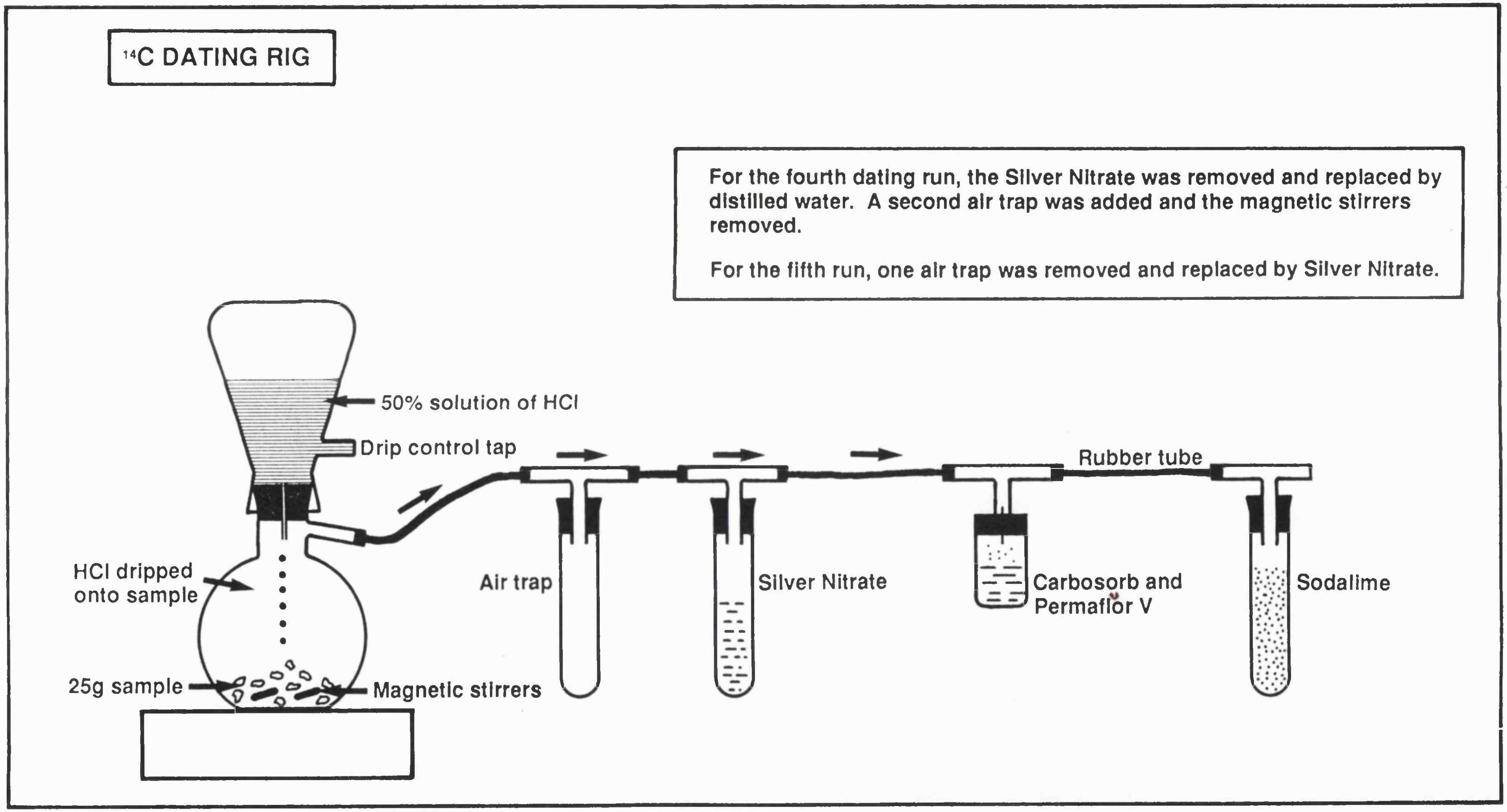


Fig. 7.5: ^{14}C test rig used at University College, London.

life of radiocarbon set at 5568 years. This curve is shown in Fig. 7.6.

7.2.2.2 Sampling of the Limestone Blocks

As noted in section 7.2.2, sampling of Block V_A was difficult due to the inaccessibility of large stalactites. Two stalactites which were accessible were detached from the block and sectioned. Both stalactites displayed a number of concentric rings or 'growth rings'. Each ring has grown around a different axis and represents a new phase in the growth of the stalactite. Thus, as Block V_A has shifted position, so a new growth phase or ring has begun. Stalactites grow by the accretion of calcium carbonate in layers around the outside of the formation. The innermost deposits will be the oldest and clearly, only a complete stalactite will be suitable for dating.

7.2.2.3 Sample Preparation

At least 25g of sample is required for ^{14}C dating and this should come from the innermost layers of the stalactite. It is also important to check the purity of the calcitic tufa and identify any evidence of recrystallisation. If there has been recrystallisation then the date obtained will reflect the date of recrystallisation rather than the formation initiation. Recrystallisation can be determined by taking a peel from the sample.

In preparation for peeling, both stalactites were sectioned and one half, which was to provide the sample, set aside. The other halves were ground with progressively finer grades of carborundum powder, in order to remove all evidence of saw cuts. The slabs were etched, to raise their relief, in a 10% solution of HCl for 20 seconds and then thoroughly washed with distilled water. To check the calcite content a staining solution was prepared, consisting of a 3:2 ratio of potassium ferricyanide and alizarin red-S. In this case, 2g of potassium ferricyanide mixed with

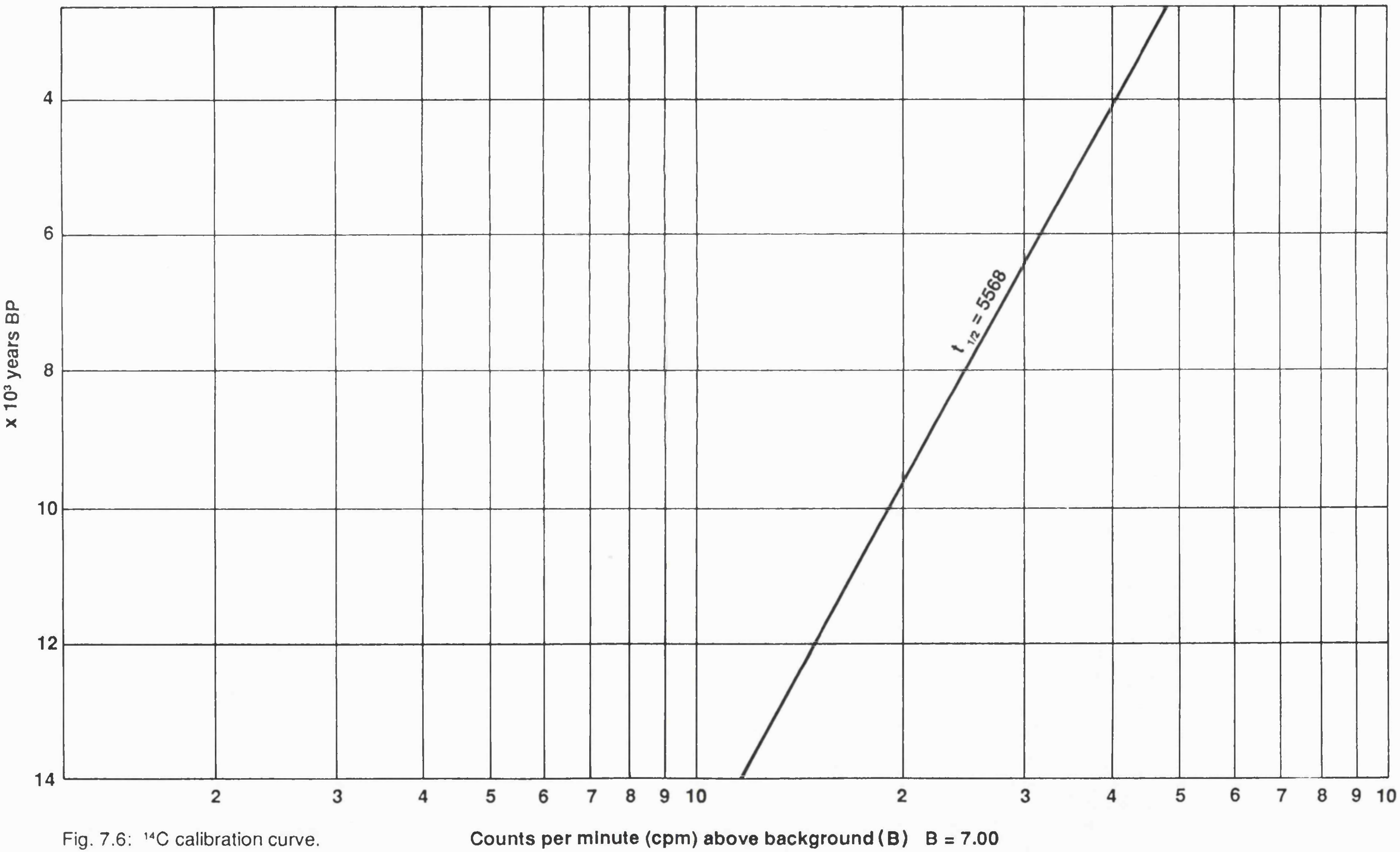


Fig. 7.6: ^{14}C calibration curve.

100ml of a 1.5% solution of HCl were combined with 0.3g of alizarin red-S mixed with 150ml of HCl. After immersion in the stain, the slabs were oven dried, placed in a sand bath for stability, and soaked in acetone. An acetate sheet placed on the surface of the slabs enabled a peel to be taken.

Staining revealed that both specimens were composed almost entirely of iron-free calcite. Small areas that remained unstained were of dolomite.

Under the microscope the peels showed no obvious evidence of recrystallisation. However both stalactites displayed evidence that block V_A had experienced several phases of movement.

Sample S1 has two clear sets of concentric growth circles about two different axes (Fig. 7.7). The innermost or first set of circles (S1/1/I) represent the earliest phase of deposition about a vertical axis that is now oriented 45° in an easterly direction. Thus, at some point the block has tilted by about 45° causing a change in the groundwater conditions and a shift in the growth axis of the stalactite (Phase S1/1/II).

Sample S2 displays a number of phases of deposition (Fig. 7.8 and Plate 7.4). Phase S2/1/I is the earliest depositional phase. The next phase S2/1/II is marked by a change in groundwater conditions and a westerly tilt of about 45°. There is then an easterly tilt of about 50° to phase S2/1/III. The next phase in the growth cycle is less clear but seem to be marked by a substantial westerly tilt of approximately 65° back to S2/1/IV. Present growth appears to be on ring S2/1/V, although the boundary between S2/1/IV and S2/1/V is not clear.

From the other (unstained) section of both stalactites, which had been set aside, 25g samples were taken for radiocarbon dating. Samples were taken from the inner core and the outer layer of S1, and from each of the depositional phases recognised in S2 (too little material was available from the present growth phase to enable it to be sampled). Care was taken to keep samples separate at all times in order to avoid the possibility of contamination.

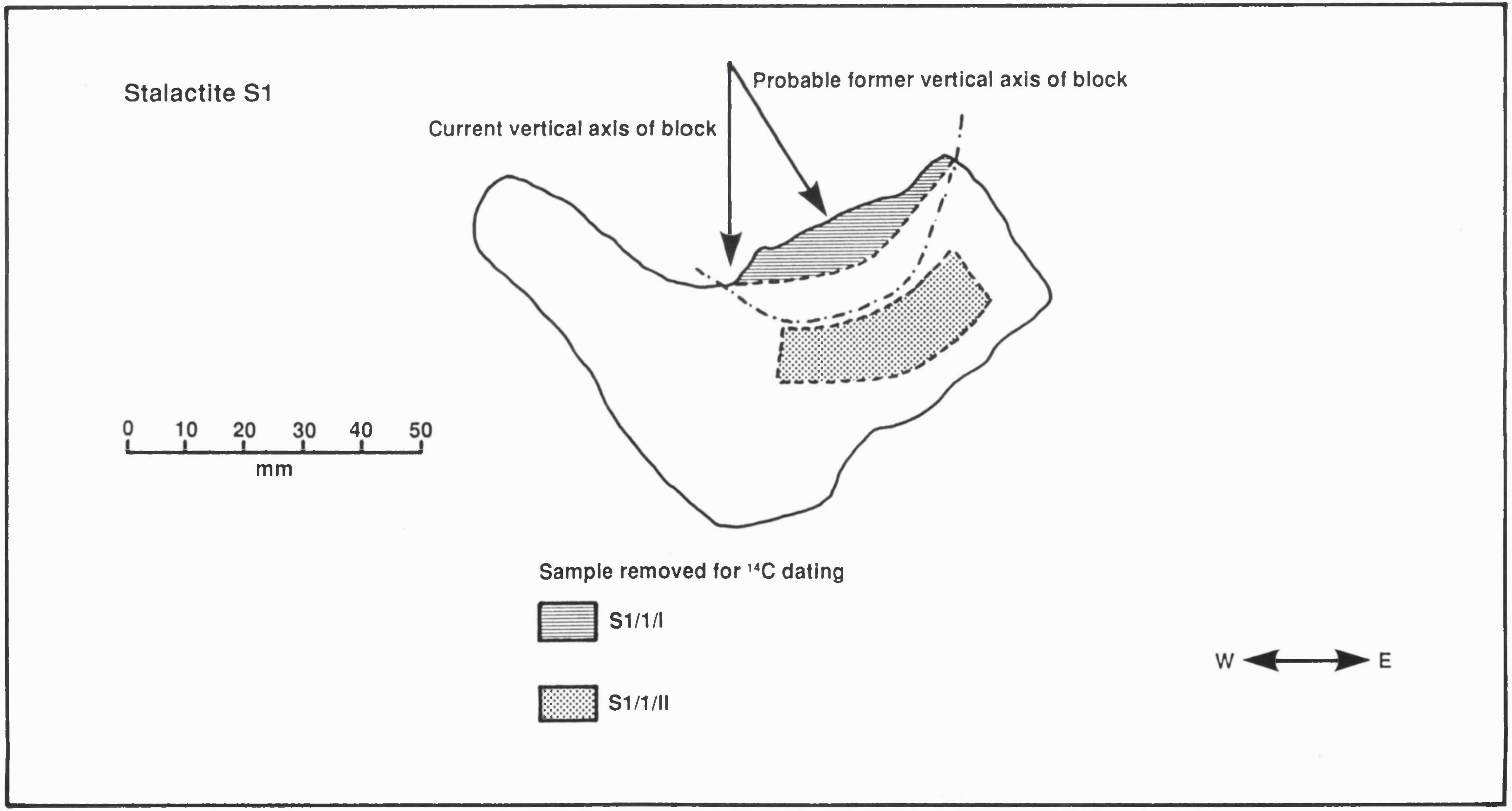


Fig. 7.7: Section of stalactite S1.

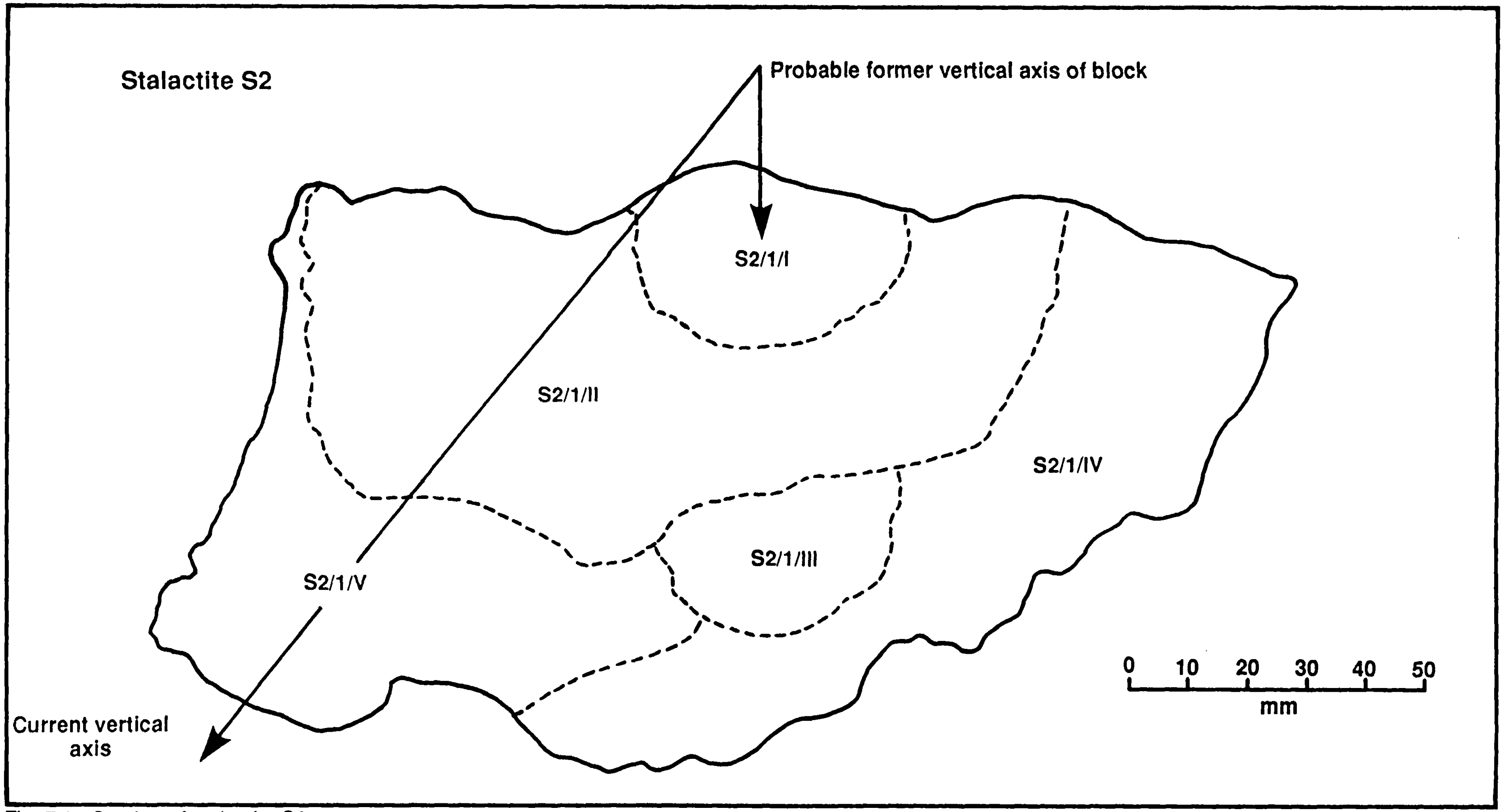


Fig. 7.8: Section of stalactite S2.

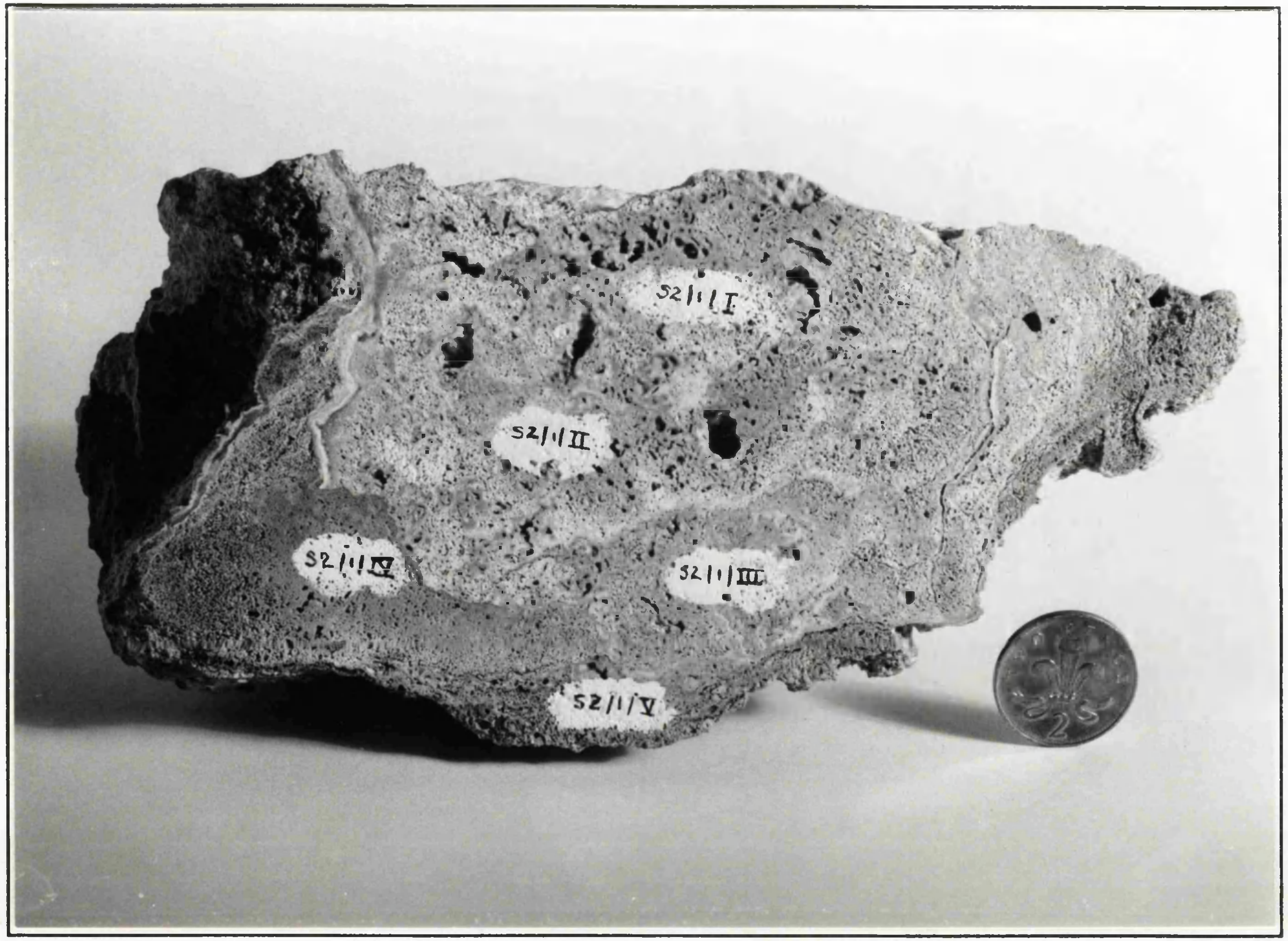


Plate 7.4: Stalactite S2 showing the phases in the deposition of the sample.

Before the dating runs the outermost samples from both stalactites (S1/1/II and S2/1/V were pretreated by soaking in sodium hypochlorite (NaCl) for one hour to remove any traces of organic material.

7.2.2.4 Results

Each dating run involved dripping a 50% solution of HCl onto the tufa until all the sample had been destroyed and no further bubbling could be seen in the trapping agent. Serious problems of excessive frothing were encountered during the first two dating runs (S1/1/I, S1/1/II) probably caused by dirt in the sample. The empty vial in the test rig rapidly filled with froth which could have contaminated the trapping agent. As a consequence, the empty vial had to be replaced during each dating run as soon as it became full. Although this caused difficulties, it is unlikely that any contaminating air came into the system because of the strong positive flow of $^{14}CO_2$ through it. In view of these problems a third date was run on stalactite S2, using a sample taken from the stained half of the slab. The slab was first washed to remove all traces of Alizarin red-S and potassium ferricyanide and a 25g sample taken, corresponding with sample S1/1/II from the other half of the slab. This sample was number S1/2/II.

To avoid the problem of excessive froth contaminating the trapping agent, the rig was changed for the fourth run. The Silver Nitrate trap was removed since it was only washing the HCL in the froth rather than trapping it. In its place a vial of distilled water was used to reduce the froth; two air traps were placed in parallel with the water to contain any froth that by-passed the water trap. In addition the sample was agitated manually, rather than mechanically. The water trap worked so well that on the fifth run it was felt unnecessary to have two air traps and in place of one, the Silver Nitrate trap was restored, although the mechanical agitation of the sample continued.

During the third run (sample S1/2/I) the sample was completely dissolved by HCl before the Carbosorb trapping agent had become fully saturated. As such it is apparent that tufa reacts violently with HCl and dating requires a larger sample than the 25g normal with shelly material (the samples most commonly dated by this method of radiocarbon dating). This is shown in Fig. 7.9 which is a graph of the energy spectrum of sample S1/2/I and provides a measure of the sample quality. The graph, which should be a smooth curve, is slightly irregular and shows that the sample was undersaturated. As such S1/2/I provides a maximum age only, that is the sample could be younger than the calculated date of 3100 ± 200 years BP.

Two other dating runs were carried out and in both cases samples were combined to avoid the problem of undersaturation. Thus S2/1/I and S2/1/II were combined as well as S2/1/III and S2/1/IV. Although this process is not satisfactory, it was felt that slight accuracy could be sacrificed in order not to suffer a much larger inaccuracy inherent in an undersaturated sample. Fig. 7.10 is the energy spectrum of combined sample S2/1/II and S2/1/I and displays a much smoother curve than Fig. 7.9, indicating a fully saturated sample.

After counting overnight, the results obtained (Table 7.1) indicate that the limestone block V_A experienced a major movement or disruption about 2400 ± 300 years BP. The date agrees well with S1/2/I given as <3100 ± 200 years BP; this was the undersaturated sample which it was noted could be younger than the calculated date. These dates may mark the point at which Block V_A became detached from Block V, although as was discussed in section 7.2.2, larger stalactites on Block V_A could well yield significantly older dates.

The date of 'modern' for samples S1/1/II, S2/1/I & II and S2/1/III & IV indicates that the concentration of ^{14}C in the samples is not significantly different from that found in a present day specimen. In other words, the growth of the outer layer of stalactite S1 and the entire growth of S2 is modern, probably within the last 300 - 400 years. More reliance can be

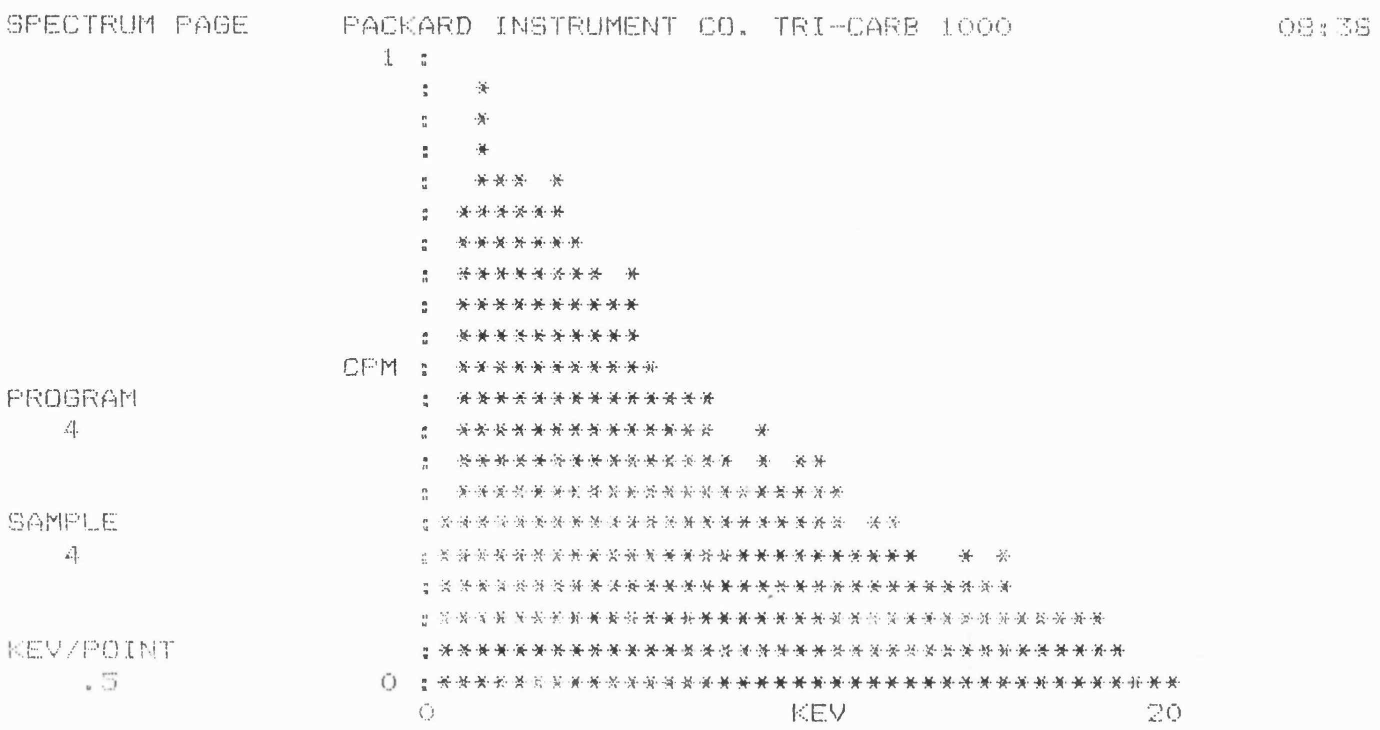


Fig. 7.9: Energy spectrum of sample S1/2/I. Note the irregular curve of the graph and compare with Fig. 7.10.

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Fig. 7.10: Energy spectrum of combined sample S2/1/II and S2/1/I. Note the smoother curve of the graph compared with Fig. 7.9.

SAMPLE	LOCATION	AGE (Years BP)	LAB.NO.
S1/1/I	Inner core	2400 ± 300	UCL/84
S1/1/I	Outer layer	'Modern'	UCL/85
S1/2/II	Inner core (stained section)	<3100 ± 200	UCL/138
S2/1/I & II	Inner core (combined sample)	'Modern' 0 ± 400	UCl/139
S/2/III & IV	Combined sample	'Modern' 0 ± 300	UCL/140

TABLE 7.1: Radiocarbon dates for the Maratea tufa.

placed on the result of S1/1/II than on those from S2. As has been discussed above, problems with undersaturation required combined samples for S2; this was not a satisfactory process and may well have resulted in an analysis error. It seems unlikely that the inner portions of two nearby stalactites could be of such different ages. In short it would seem probable that movements in historical time, may have affected Block V_A as is evidenced by the radiocarbon date from S1/1/II, although this would need to be confirmed by further dates from other stalactites.

The results of the radiocarbon dating runs on Block V_A are not, in themselves, enough to draw general conclusions about instability implications for the valley as a whole. This is an area which would benefit from a great deal more research work than was possible within the confines of this thesis. Forti and Postpischl (1986), for example, established that the growth axis of stalagmites in caves near Bologna corresponded to historical earthquakes in the region. Their assertions were based on the recognition of a major earthquake in 1117, which substantially changed the growth axis of the stalagmite. It is possible that the observed changes in growth of the Maratea stalactites may, similarly, be due to movements, or more likely differential tilt, caused by seismic shaking. It is certainly an area of study which should be extended.

CHAPTER EIGHT

THE EVOLUTION OF THE MARATEA VALLEY

8.1 Introduction

This thesis has so far examined the genesis of the Maratea valley, from the first stages of continental rifting in the early Triassic about 250 million years ago, to the widespread landslide movements occurring along the fault plane scarp in the last ten years.

In the next chapter, the focus of the thesis will shift to the affect of landslide movements and seismic shaking on the buildings of Maratea. Before this, however, it is worthwhile to summarise the knowledge of the evolution of the valley so that the work of the author, contained in the last four chapters, can be evaluated. In doing this it is possible to show how this work has added to an understanding of the area's evolution.

8.2 The Formation of the Maratea Valley

In Chapter Two it was seen that the rocks surrounding the Maratea valley are derived from a limestone platform (the Latium-Campania-Lucania Carbonate Platform), formed during a period of continental rifting in the late Triassic. This platform was deformed and incorporated into the Southern Apennines thrust belt during a phase of compressive continental margin deformation which began in the early Miocene.

About 5 million years ago the compressive tectonic movements, which formed the Apennine mountain chain, began to subside and were completely replaced by vertical (neotectonic) movements from 3 million years ago. The Maratea valley which, it was seen in Chapters One and Three, is a graben-like trench bounded by two converging normal faults, is a result of these neotectonic movements. Studies of the neotectonic evolution of southern Italy (Ciaranfi *et al*, 1983), have concluded that the faults of the Maratea valley were probably formed during Phase IIIb of the neotectonic evolution of southern Italy (2.0 - 0.7 MY BP). Thus, by 700,000 years BP, the general form of the Maratea valley had probably been established, with normal faulting leading to the collapse of the central portion of the valley.

8.3 The 'Second' Neotectonic Episode

The presently visible fault plane scarp is considered to represent the last movement of the Maratea fault. In Chapter Three it was noted that there exists a very distinct break of slope on profiles of Monte Crivo. This it was argued, could only have been created by at least two distinct, separate movements of the Maratea fault (see Fig. 3.14). Thus, the visible fault plane scarp is the most recently exposed element of a larger scarp which once extended to an elevation equivalent to the break of slope seen on the profiles.

U-series dating of a thick calcite layer on the fault plane scarp, has indicated that the deposit is around 46,000 years old. Chapter Four argued that this layer could have been formed at the same time as the last movement of the fault by a process known as seismic pumping. Problems in determining precisely how the calcite layer was formed, and possible inaccuracies in the date due to the presence of detrital thorium, cast some doubt on the accuracy of the date. Nonetheless, it is clear that the date is so much younger than the age of valley formation postulated by Ciaranfi *et al*, (1983) as to suggest that either a subsequent round (or rounds) of neotectonic activity, have affected the Maratea valley or that one of the dates is wholly incorrect, It is, therefore, the view of the present author, based on the work presented in Chapters Three and Four, that at least two periods of neotectonic activity have led to the formation of the Maratea valley; the first of these created the graben, between a maximum of 2.0 MY BP and a minimum of 700,000 years BP, and the last (possibly the second) accentuated the valley form at around 46,000 years BP.

8.4 The Exposure of the Fault Plane Scarp

In Chapter Four it was argued, on the basis of historical records of earthquake activity in the region, that either active faulting in the Maratea valley has ceased, or that there is an extremely long return period between shocks either produced by fault movement or capable of moving the fault. On the basis of the possible dates of neotectonic activity described in section 8.3, a long return period appears to be a more plausible explanation. The evidence of the U-series dating indicates a return period of at least 46,000 years.

There are, however, clear signs that the presently visible fault plane scarp has been exposed for a much shorter time than is suggested by either the seismic record or the U-series date. The pale colour of the exposed fault plane scarp and its smooth surface with limited weathering etching, suggest relatively recent exposure from beneath covering deposits.

Lichenometry, applied for the first time in the Mediterranean, was used to establish the age of exposure of the fault plane scarp. From this work it was calculated that around 15 metres of fault plane scarp surface has been exposed in the last 300 - 600 years. In addition, a detailed survey of the fault plane scarp has revealed that while the feature appears from a distance to be an unbroken shear plane of even height, in reality it is of irregular height and very broken-up. It can, therefore, be envisaged that there is a continual process of erosion taking place along the fault plane scarp, with weathering destroying the scarp. The material derived from the eroded fault plane scarp forms the coalescent debris cones below the scarp.

A geomorphological map of the largest of these cones established that they are constantly growing with the addition of new material from either the fault plane scarp or by free-fall debris from the higher slopes of Monte Crivo. All of this material is being transported downslope in the debris channels illustrated on the geomorphological map. These processes suggest that part of the exposed fault plane scarp should be destroyed over time and the debris produced should conceal the lower portions. The fact that 15 metres has been exposed in the last 300 - 600 years indicates that new or 'fresh' portions of fault plane scarp surface are being exposed by the processes of mass movement. The lichenometric date, therefore, represents the last 300 - 600 years of a process of erosion and mass movement that began approximately 46,000 years ago.

The work of the author has further established that these mass movement processes periodically experience a distinct acceleration. As discussed in Chapter Six, a band of very pale grey colouration, which is often seen at the base of the fault plane scarp, termed the 'white line', indicates a zone of minimal weathering and hence very recent exposure. In many areas, particularly along the crest of the large debris cone, a number of discrete colour bands can be observed, indicating at least four phases of movement.

No lichens were found on any of the colour bands. Absolute radiometric techniques were also unsuitable due to a lack of datable material, such as calcite, and the fact that the colour banding was probably too recent for them to be applicable. Thus, the author was required to rely on a colour dating technique to establish the age of the 'white line'. The technique relied on a comparison between the colour of the band and the colour of a surface of 'known age', DEFINED by Munsell Soil Colour Charts.

Colour dating produced ages which were close to the three most recent earthquakes to have occurred within a 50km radius of Maratea, that is 1934, 1955 and 1982, indicating that the acceleration of mass movement processes along the fault plane scarp is caused by seismic shaking. These mass movements may be related to a movement of talus on an underlying slip surface or surfaces, or to a settling of loosely consolidated deposits.

8.5 The Limestone Blocks

Previous authors (Guerricchio and Melidoro, 1979; Guerricchio *et al*, 1986b, 1987) indicated the presence of large blocks of limestone - *blocchi carbonatici* - in the Maratea valley. The work of the present author, using the techniques of air photograph interpretation and geomorphological mapping, has been the first to map the blocks in detail. Six limestone blocks are now known to exist in the valley; five of these are major features adjacent to the talus deposits of the fault plane scarp and the sixth a much smaller feature near to the coast.

Chapter Three discussed the formation of the limestone blocks and concluded that a step fault mechanism is the most likely explanation for them. Such a mechanism would produce the characteristic block form and rotation which is particularly evident with blocks I - V. The timing of block formation is much more problematic and few clues point to a date. If a two phase model of Maratea fault movement is accepted, then block collapse could have occurred anywhere between 2.0 MY BP and the last movement of the fault at around 46,000 years BP, clearly a very wide spread indeed.

More recent movements of the limestone blocks are somewhat easier to establish. Detailed geomorphological mapping by the author, of the limestone blocks adjacent to the fault plane scarp, could not establish any surface features, such as tension cracks, which would have been caused by the accumulating talus exerting pressure on the blocks and hence moving them. Similarly, the Maratea - Trecchina road which, over much of its length, is incised into the basal concavity of the blocks, shows no sign of distress due to block movement. It can, therefore, be stated with some certainty that at present the limestone blocks are stable features. Uncertainty remains as to if and when the talus deposits presently accumulating behind the blocks will cause displacement.

The only limestone block which displays any evidence of movement is Block V. It was established by the author, from an air photograph analysis of the valley, that this block is in two portions. The smaller of the two portions (Block V_A), has a number of stalactites growing on its leading, or westerly, edge. Sample stalactites revealed, in section, that they are formed from a number of growth rings about different axes. It was concluded in Chapter Seven that these rings represented changes of tilt to Block V_A. A technique of liquid scintillation ^{14}C dating, applied to samples from the growth rings of two stalactites, dated the innermost cores to 2400 and 3100 years BP; other growth rings were dated as modern. Unfortunately there were four problems with this analysis;

(i) stalactitic tufa appears to react violently with HCl; the 25g sample, normal for dating Holocene molluscs was, therefore, too small in many cases, with the result that the sample was exhausted before the trapping agent was fully saturated;

(ii) the liquid scintillation technique is probably not precise enough to date growth rings which are so close in age;

(iii) the largest stalactites on Block V_A were inaccessible and could not, therefore, be sampled; and

(iv) the analysis related to Block V_A only.

^{14}C dating was, therefore, not helpful in drawing general conclusions on block stability as a whole. The main argument for the stability of the limestone blocks must, therefore, rest with the geomorphological map. This, as noted above, does not reveal any ground evidence to suggest that the limestone blocks have experienced recent movement.

8.6 The Maratea Valley - A New View

The work of the author has added considerably to the understanding of the Maratea valley, such that a new view of its evolution and recent history can now be taken.

Of its evolution, it can now be stated with some certainty that the present form of the Maratea valley is the result of two periods of neotectonic activity; the first of these formed the valley and the last deepened it. Since the final neotectonic episode at around 46,000 years BP, the fault plane has experienced a slow exhumation from beneath covering deposits. The presently visible fault plane scarp represents the last 300 - 600 years of this process.

In terms of its recent history, the coalescent debris cones at the base of the fault plane scarp are seen to be areas of marginal stability, constantly being added to, constantly moving and periodically experiencing accelerated movement due to seismic shaking. This whole area, therefore, is a zone of slow but widespread slope instability. These movements do not, as yet, appear to have had any effect on the limestone blocks, which are regarded as stable features.

These conclusions represent an advance on the understanding of the area which existed prior to this thesis. At that time most of the previous work in the Maratea valley had been concentrated in the sackung area. No work had been carried out on the fault plane scarp; indeed the Regional Geological Office regarded the feature as a relic along which no neotectonic or mass movement had occurred since the Pleistocene. Moreover, the limestone blocks had never been accurately mapped and no rigorous study of any kind had been carried out to determine their stability.

The work presented in this thesis therefore provides a useful basis on which to look at other problems in the Maratea valley. Foremost is the condition of the buildings in the valley, the majority of which have suffered considerable damage due to either mass movement, seismic shaking or a combination of the two. It is to this problem that the thesis will now turn.

CHAPTER NINE

SLOPE STABILITY AND BUILDING DAMAGE

9.1 Introduction

Chapter Eight concluded that marked slope movements were evident in the Maratea valley. Lichenometric dating has argued for the exposure of about 15m of the fault plane scarp in the last 300 - 600 years, that is well within the time span of urban settlement in Maratea. When coupled with the work of Guerricchio *et al* (1986b) on the *sackung*, which was discussed in Chapter Three, these results are clear evidence for the widespread occurrence of unstable slope zones in the Maratea valley.

Apart from the investigations carried out by Guerricchio *et al*, of which Chapter Three was highly critical, no work has been undertaken on the effects of slope movements on the buildings of Maratea. Such a study is crucial to future planning, helping not only to identify areas of differential movement, but also to evaluate the suitability of vernacular architecture and building techniques in unstable ground and to modify design accordingly. It is another failure of the 1978 Structure Plan that a survey of this nature was not commissioned.

This chapter seeks to address the problems of building damage in Maratea and to answer the following questions:

(i) Have the slope movements, recognised in the preceding chapters, had any effect on the buildings of the Maratea valley?

(ii) What are the effects of earthquake shaking on the buildings? Can seismic damage be divorced from damage caused by slope movements?

(iii) Is the construction and design of buildings adequate to withstand the effects of unstable slopes and seismic shaking?

(iv) What remedial measures have been undertaken? Are they adequate?

The data necessary to resolve these issues was collected by the author during an extensive, two month long, field survey in the summer of 1987 and from research and discussions undertaken by the author in the *Comune* offices and Maratea library. All information on building damage data presented in this chapter is from these sources.

9.2 Building Use, Distribution and Type

There are 1008 buildings in Maratea, of which 547 are in multiple occupation, that is flats or divided houses; the figure of 1008 therefore relates to the number of building **structures**, rather than referring to dwelling or trading **units**. Of these, 813 are in residential occupation and 93 in commercial use (this includes restaurants, bars, tourist hotels and pensiones). The next largest group ('other') of 81 buildings, comprises churches, chapels, hospitals, *Comune* and government buildings such as the *Guardia di Finanza* (Customs and Excise) and *Carabinieri*. Fourteen buildings have been classified as industrial, although most of these are small concerns such as workshops and potteries; only one - the Intessa textile factory in Fiumicello, is of any significance.

A reconnaissance of the area revealed that building age, type and location were correlated both spatially and temporally. Virtually all the pre-war buildings in Maratea are located in and around the *centro storico*, and are either constructed of rubble core walls, faced on both sides by dressed blocks of local limestone, a building technique known as ashlaring or ashlar veneer or rubble core walls with a plaster coat (Plate 9.1). Post-war building has been concentrated in the Fiumicello area and is of a quite different construction; generally, a reinforced concrete 'cage' structure, infilled with pre-cast concrete building blocks. Construction type and age will be more fully discussed in section 9.3.

Plate 9.1: Collapsed building in Maratea showing rubble wall construction.

Pantile roofs are favoured in Maratea, 982 of the 1008 structures having them, as is a stucco plaster coat to the outside of structures (949); these features tend to occur regardless of the age of the building.

In contrast to other towns in Basilicata, condominiums are not popular; of the 547 houses in multiple occupation only 215 have more than two storeys and only 2 more than three storeys.

All the 1008 structures in Maratea were found on the five 1:2000 scale topographic map sheets of the area, obtained from the *Comune*. It was noted in Chapter Two, that three distinct poles dominate the settlement of Maratea - the *centro storico,* Fiumicello and the Porto di Maratea. An impression of this dominance can be gained from the five map sheets placed in the back pocket of this thesis. Map sheet FG3 covers the *centro storico* and FF2 the Fiumicello and Porto di Maratea areas. Together these two sheets contain 719 structures, or 71% of the total buildings in Maratea (351 in the *centro storico,* 368 in Fiumicello and the Porto di Maratea.

9.3 Vernacular Architecture

As a precursor to an extensive survey of building damage in the Maratea area, an assessment of vernacular architecture was undertaken. The assessment drew on both a field survey and discussions with the *Comune*.

The vernacular architecture of Maratea closely reflects changing tastes and improving construction techniques. Unlike the United Kingdom, brick is very rarely used in building construction, indeed only 8 buildings in Maratea contain any appreciable quantity. The size of standard building bricks and the subsequent necessity for close interlocking, mean that brick built structures achieve a substantial rigidity and do not require a frame, except in the case of more modern UK houses which have a timber frame with brick cladding. In contrast, frame structures are very common throughout southern Italy. Timber is the traditional frame material although since 1945 it has largely given way to steel reinforced concrete.

The materials used in the vertical construction of buildings are complemented by those used in the horizontal construction, that is the building walls. Again, in Maratea ashlar was the pre-war material; this has been replaced in the post-war period by pre-cast concrete building blocks or breeze blocks (pre-cast building blocks of clinker concrete). Whether the building is constructed of pre-cast blocks or ashlar, it is common in Maratea, and southern Italy in general, to cover the wall material with a skim coat of plaster, which is then painted.

9.3.1 Pre-War Construction

Pre-war construction in Maratea, consisted of timber framing with a rubble wall and ashlar veneer. Of the 421 houses constructed prior to 1940, 389 were timber framed (Tables 9.1 and 9.2). The construction of this type of house begins with the erection of the wooden frame which is fastened with steel pinned mortice and tenon joints at each corner (Fig. 9.1). Variations in the construction of the timber frame are found only at the joints, where timber pins sometimes replace steel pins in the older structures. The frame is sunk into pre-dug footings, which in Maratea tend not to be very deep, generally about 0.5 - 0.75 metres.

Floor joists employ pinned mortice and tenon joints to bond them to the main frame structure. Access to the second floor is usually from outside and by internal wooden stairs from the second floor to the loft. The ashlar veneer is built-up around the wooden frame and rubble wall; in Maratea, the blocks which form the veneer are, almost entirely, of dressed blocks of local limestone. Each block is small, roughly about double the size of a conventional house brick but with half the thickness. It is cemented to its neighbour by weakly bonded lime mortar. The

VERTICAL CONSTRUCTION BY AGE OF BUILDING (Total Survey)										
	Pre 1900	1901-1910	1911-1920	1921-1930	1931-1940	1941-1950	1951-1960	1961-1970	1971-1980	1981-
Timber Frame	224	8	9	147	1	3	1	0	0	0
Pre-Stressed Concrete	0	0	0	24	2	118	227	201	17	20
Steel Girder	0	0	2	0	0	0	0	0	0	0
None	2	0	2	0	0	0	0	0	0	0

Table 9.1

HORIZONTAL CONSTRUCTION BY AGE OF BUILDING (Total Survey)										
	Pre 1900	1901-1910	1911-1920	1921-1930	1931-1940	1941-1950	1951-1960	1961-1970	1971-1980	1981-
Ashlar Masonry	226	8	11	158	0	10	2	2	1	0
Building Blocks	0	0	2	13	3	111	226	199	16	20

Table 9.2

Source: Author Survey

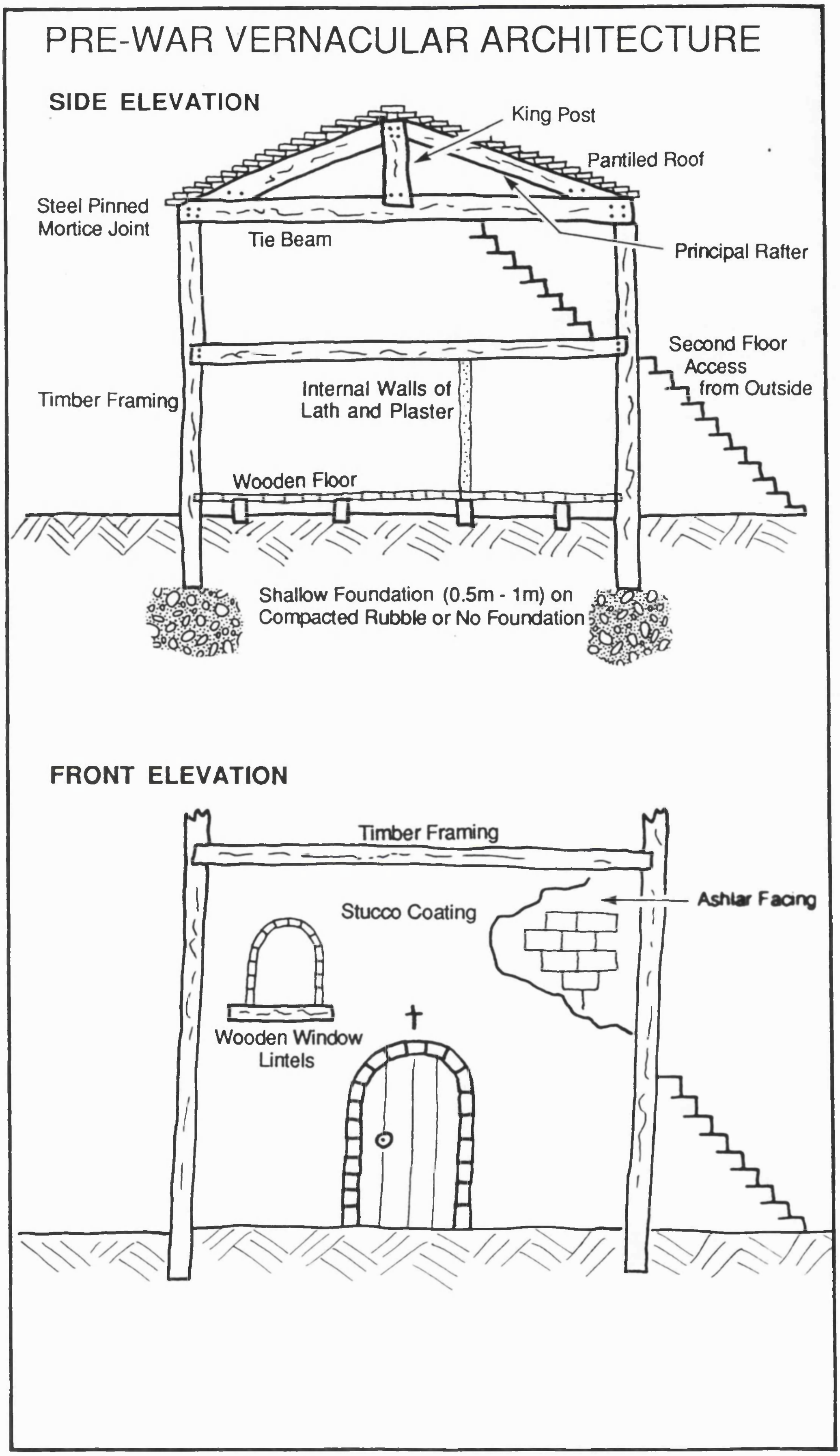


Fig. 9.1: Pre-war vernacular architecture.

ashlar veneer is built-up in two parallel walls and the cavity filled with an unbonded rubble infill (Fig. 9.1).

A stucco coating is applied to the ashlar veneer and painted. Window sills and lintels are of wood and, in Maratea, window and door arches are predominantly round, reflecting a very strong Moorish influence. Internal walls are of lath and plaster construction. In Maratea, the roof structure is gabled, generally with a king post, standing on a tie beam, rising to the apex where it supports the ridge.

This type of construction is very common in southern Italy and has parallels in the buildings of medieval England and northern France. The Norman manor house of Boothby Pagnell in Lincolnshire, for example, is similar in construction to many of the larger, pre-1900, houses in Maratea although lacking the king post roof and having in its place a trussed rafter construction (see Fletcher, 1967). The essential difference, however, is the use of space; in the manor houses of Norman England the domestic living area is on the second floor above the undercroft, whereas in Maratea both areas are used as living quarters, often divided amongst two families.

In southern Italy the use of rubble infill, ashlar veneer masonry and stucco coating, gave very thick walled houses which were cool in summer yet retained their warmth during the winter. It was not until after the Second World War, with improved road links allowing building materials to be brought in, and the advent of concrete, that the construction of timber framed houses died out.

Often with the houses of many poorer families, the ashlar veneer is missing and the walls made of weekly bonded rubble with a stucco coating. Unless the stucco is damaged and the wall can be seen in cross section, it is difficult to determine the construction method as both have a very similar appearance. Regrettably the *Comune* have no record either.

9.3.2 Post-War Construction

Post-war construction in southern Italy, relied on broadly similar building techniques to those used in the pre-war period, but very different materials (Fig. 9.2). Timber framing gave way to a frame of steel reinforced concrete; of the 587 buildings erected after 1940, 583 (99%), have a reinforced concrete frame (Tables 9.1 and 9.2). It is, however, below ground that the greatest differences exist between the two construction types. As noted above, timber framed buildings have little in the way of foundations; the timber posts merely being sunk into the ground to provide support. In contrast, reinforced concrete frame buildings have either of two types of foundation. A strip foundation consists of a strip of concrete set in a trench on the top of which sits the frame structure of the building. Alternatively, a solid reinforced concrete base or 'raft' can be constructed on top of which the building is placed. In Maratea, it was not possible to determine which buildings were constructed on which type of foundation. This would have required a full structural survey of each building including the excavation of a trench next to it. Such a survey was beyond the time limits of this thesis.

Post-war buildings have solid ground floors and internal walls are made of a wooden stud construction covered with gypsum plaster board. Horizontal construction consists of breeze blocks or concrete building blocks bonded with a lime mortar. Walls are generally single skinned rather than of a cavity construction and finished inside and outside with a plaster coat. This technique produces a much thinner wall than timber framing, allowed for by the introduction of modern heating and air conditioning systems.

Roofs are a mixture of flat and gabled with pantiles hung on a frame of wooden rafters.

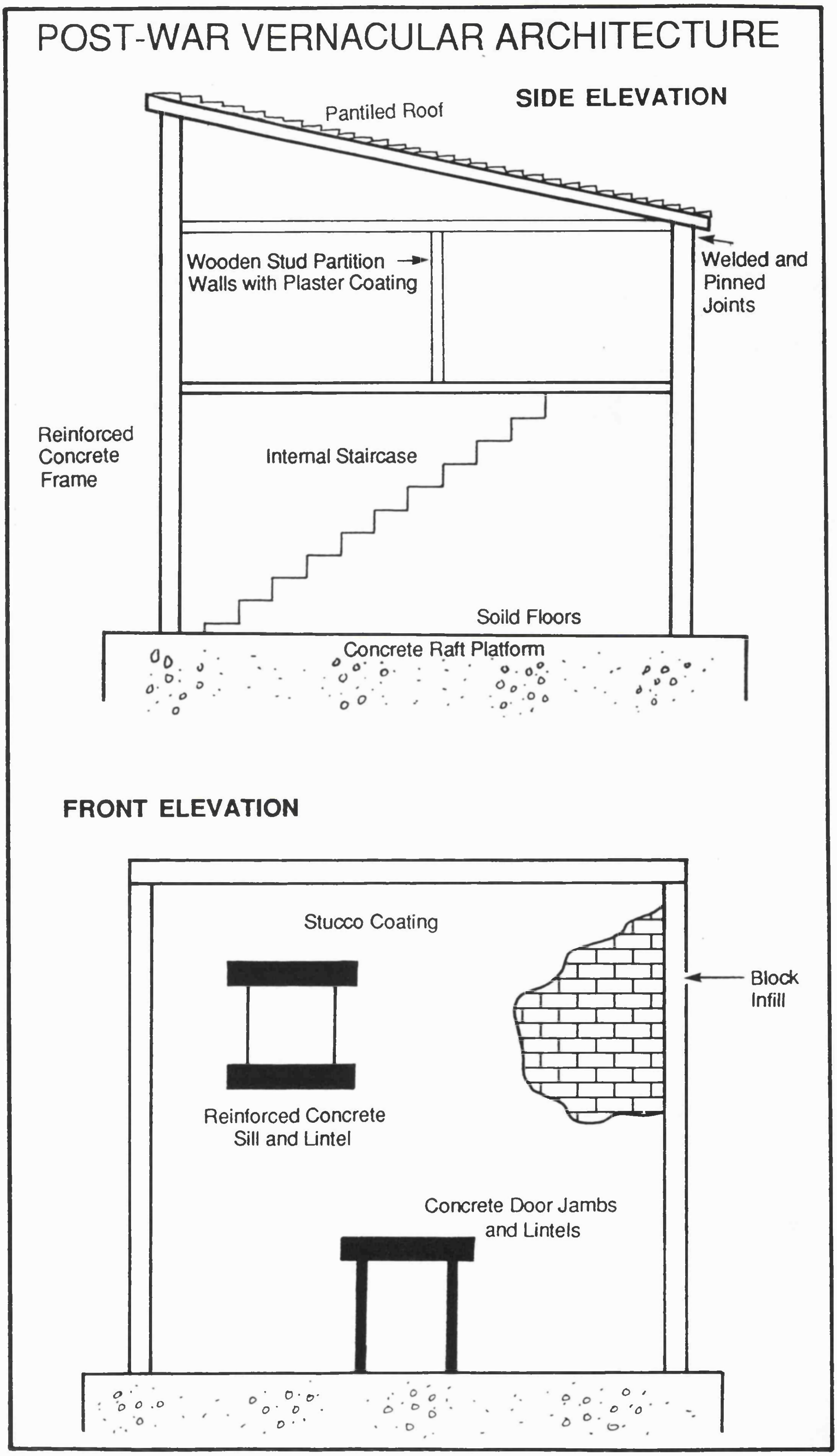


Fig. 9.2: Post-war vernacular architecture.

9.4 Distribution of Building Types

The distribution of pre-war and post-war building in Maratea closely reflects the growth of the town during the last century. Prior to 1939, virtually all building was in and around the *centro storico* (see map sheet FG3), and almost exclusively timber framed. Of the 351 buildings in the *centro storico*, 208 (59%) are timber framed and of these 162 (78%) were built prior to 1900 (Tables 9.3 and 9.4). Reinforced concrete structures number 136, 128 (94%) of which are post-war in age.

In contrast, 302 of the 368 buildings in the Fiumicello - Porto di Maratea area (82%; map sheet FF2) have a reinforced concrete frame and all but 1 are post-war built (Tables 9.5 and 9.6). New housing has developed in the Fiumicello area; these are largely (approximately 60%), privately owned weekend and holiday homes built in response to the post-war tourist boom (see Chapter Two).

The remaining timber framed and reinforced concrete frame structures tend to be more evenly distributed throughout the valley with no particular pole of concentration evident.

9.5 Damage Survey Methodology

Only two surveys of building damage have been carried out in Maratea and both have concentrated on the *centro storico*. The surveys (now forming appendices to the 1978 Structure Plan - Fiore and Brando, 1978, Tables 3 and 3^B) detail damage caused by the 1980 and 1982 earthquakes. The two surveys thus update the Plan, hence causing a discrepancy with the dates. Both surveys are dated January 1985 and have been prepared by the *Comune* on the basis of claims for compensation submitted to them by householders. It should be noted that the *Comune* strongly supported claims for earthquake compensation and in 1985 were actively searching for funds in order to develop the Structure Plan.

With this in mind, the survey undertaken by the author and presented here, began with the supposition that no objective

VERTICAL CONSTRUCTION BY AGE OF BUILDING *(Centro Storico)*										
	Pre 1900	1901-1910	1911-1920	1921-1930	1931-1940	1941-1950	1951-1960	1961-1970	1971-1980	1981-
Timber Frame	162	7	8	30	1		0	0	0	0
Pre-Stressed Concrete	0	0	0	7	1		56	38	7	9
Steel Girder	0	0	0	0	0		1	0	0	0
None	2	0	4	0	0		0	0	0	0

Table 9.3

HORIZONTAL CONSTRUCTION BY AGE OF BUILDING *(Centro Storico)*										
	Pre 1900	1901-1910	1911-1920	1921-1930	1931-1940	1941-1950	1951-1960	1961-1970	1971-1980	1981-
Ashlar Masonry	164	7	10	32	0	2	1	0	0	0
Building Blocks	0	0	2	5	2	16	56	38	7	9

Table 9.4

Source: Author Survey

VERTICAL CONSTRUCTION BY AGE (Fiumicello)										
	Pre 1900	1901-1910	1911-1920	1921-1930	1931-1940	1941-1950	1951-1960	1961-1970	1971-1980	1981-
Timber Frame				59		1	0	0	0	
Pre-Stressed Concrete				1		81	136	83	1	
Steel Girder				0		2	3	2	1	
None				0		0	0	0	0	

Table 9.5

HORIZONTAL CONSTRUCTION BY AGE (Fiumicello)										
	Pre 1900	1901-1910	1911-1920	1921-1930	1931-1940	1941-1950	1951-1960	1961-1970	1971-1980	1981-
Ashlar Masonry				58		1	1	0	0	
Building Blocks				2		81	138	85	2	

Table 9.6

Source: Author Survey

assessment of building damage had been carried out in the area. The survey was based around the check-list approach employed by Alexander (1984b) for the Ancona landslide and by Lagorio and Mader (1981) for the earthquake of 23 November 1980 in Campania and Basilicata (see Table 9.7). The rationale behind such an approach is that it allows different studies to be directly comparable and lends itself to the formulation of a regional and national data base of urban damage (cf. Rendell, 1985). The survey check-list differed from that of Alexander (1984b) in that the 'negligible damage' (Alexander's Grade 1) category was removed, it being very difficult in practice to separate it from the 'light damage' category (Grade 2). Similarly Alexander's 'total collapse' category (Grade 7) was excluded; Alexander included it in his check-list because he was undertaking a survey immediately after a major landslide (the 1982 Ancona landslide), where buildings had collapsed and the site needed to be cleared. In contrast, Maratea had not experienced a major damage-inducing event since the 1982 earthquake and no buildings came into this category. The only other addition to the Maratea survey was a category of 'remedial work'. In Alexander's study such a category was not relevant as he was dealing with the immediate after effects of a catastrophic landslide; in the the Maratea case, identifying the extent of remedial repairs five years after the last damage-inducing earthquake, helped to determine the effects of the event where damage to a building was not apparent because of the repairs.

The full proforma used in the damage survey is reproduced in Table 9.7; the proforma is the authors', adapted from Alexander (1984b). For each building a proforma was completed by scoring a line through the relevant category. Each building was accorded a unique number based on the 1:2000 scale map sheet it appeared on and its number on that sheet, determined simply by the order in which the buildings were surveyed. For example, FG3/125 is building number 125 (or the 125th building surveyed) on sheet FG3.

The age of each building was arrived at by discussions with the *Comune* and by noting certain architectural features. So, to take

BUILDING

- Map Sheet Number
- Building Number
- Use
  - Commercial
  - Industrial
  - Residential
  - Sporting/Leisure
  - Other (Specify)
- Approximate Age: Pre 1900, 1901-1910, 1911-1920, 1921-1930, 1931-1940, 1941-1950, 1951-1960, 1961-1970, 1971-1980, 1981-
- Vertical Construction
  - Timber Frame
  - Re-inforced Concrete
  - Steel Girder Frame
  - None
- Horizontal Construction
  - Ashlar Masonry
  - Concrete Block
  - Brick
- Roof
  - Pantile
  - Slate
  - Other

DAMAGE

- Grade 1: None
- Grade 2: Light; Small cracks in the plaster work, building has maintained its shape. No damage to sills, lintels or roof.
- Grade 3: Moderate; Cracks >5mm, inclinometer shows walls out by 1° - 2 °. Windows and door frames distorted.
- Grade 4: Serious; Very large cracks (>10mm). Walls out by 2° - 5°. Window sills and lintels are broken.
- Grade 5: Very Serious; Walls breaking apart at the corners of the building. Sills and lintels broken and displaced. Floors cracked. Walls out by >5°. Building is beyond repair.
- Grade 6: Partial Collapse
- Building Abandoned but not Collapsed or Very Seriously Damaged
- Type of Damage
  - Horizontal Cracks
  - Vertical Cracks
  - X Cracks
  - Diagonal Cracks
  - Wall Burst
  - Jamb Burst
  - Sill Shear
  - Dendritic Cracks
- Position of Damage
  - Base of Building
  - Middle
  - Top
- Remedial Work
  - Repair of Cracks
  - Partial Re-building
  - Shoring-up
  - None

Table 9.7: Damage survey checklist. Source author and Alexander (1984).

a simple example, the *Comune* were able to say that buildings FG4/159 - FG4/169 were constructed in 1984 in order to house victims of the 1982 earthquake. Similarly they knew that all the timber framed buildings were pre-war in age and tended to have rounded window and door arches. Reinforced concrete frame buildings in the immediate post-war period, carried on the round arch tradition, although it soon died out due to the unsuitability of the construction technique to this type of architectural detail. Other indicators also emerged; flat roofs were indicative of 1960s construction, gabled roofs reflected construction in the 1970s and 1980s. With these details in mind and broad outlines from the *Comune* about what was built where and when, it was possible to generally date each building. This technique is not without its problems and errors, but it is likely that very few buildings have been assigned to the wrong date category, and if they have there will only be an error of ± 10 years.

Vertical and horizontal construction techniques can be largely determined by the age of the structure. Problems arise when old timber framed buildings have been partially reconstructed using more modern techniques. In such a case the older technique was recorded with a note made of the newer re-building.

Care must be taken too, in assigning a meaningful damage grade. The inclination (departure from the vertical) of the walls of a structure, is not an adequate measure of building damage. Walls may incline by a degree or so because of errors during construction; similar inclined walls may be found in UK buildings, including many new housing developments but are clearly not indicative of earthquake or landslide damage. If wall inclination is to be used, supporting evidence such as door and window frame distortion must also be collected. Similarly, building damage should not be noted by reference to the external fabric of a building alone. In Maratea, many examples were found of buildings which looked to have very light or no damage (Grade 1 or 2) and yet reference to their internal structure placed them in a much higher category. Building FG3/127 is a case in point; although having little external sign of distress the owner pointed out an internal vertical rift in the floor, thus displacing one half of the floor so that it was 0.2m higher than the other.

Cracks in the main building structure, as distinct from superficial cracks in the stucco coating, were determined by examining the depth of the crack with a pocket knife.

It was also necessary to filter out those buildings which had been abandoned but which had no serious structural problems at the time of their abandonment. Specifically, this meant obtaining details from the *Comune* of houses abandoned during the major phase of migration to Venezuela in the early part of the century.

Although the central theme of this thesis has been the establishment of slope movement rates in the area of the fault plane scarp and limestone blocks - that is the south-eastern half of the Maratea valley - the damage survey was extended to cover the entire area of the Comune di Maratea. This was done because to exclude the sackung/*centro storico* area would have introduced an unnecessary bias into the sampling procedure. Although its inclusion is not a requirement for the assessment of building damage caused by slope movements along the fault plane scarp, it is essential in order to examine the questions of building design and construction, given that one third of all the buildings in the Comune di Maratea, are in the *centro storico*.

9.6 Results

9.6.1 Introduction

The data from each pro-forma was entered into a VAX/VMS (Version 4.4) data file using a binary code, where 1 signified the presence of a particular attribute and 0 its absence; building number and age were given real numbers. The data was entered by map sheet in building number order, so that each map had its own file. A copy of each file was written out to a single concatenated file; in other words, six files were created, one for each map sheet and one concatenated. This enabled the data to be analysed as a whole and allowed the data from map sheets FF2 and FG3 (Fiumicello and *centro storico* respectively) to be looked at separately. The rationale behind this approach is that these two sheets contain no less than 71% of all buildings and yet are characterised by very different construction types, therefore a comparison between them is desirable.

9.6.2 Building Damage: Total Population

Table 9.8 details the building damage for the Comune di Maratea as a whole. Of the 1008 buildings 434 (43.1%) have no damage, 50 (5%) light damage, 96 (9.5%) moderate damage, 82 (8.1%) serious damage, 234 (23.3%) very serious damage and 12 ((1%) have collapsed. One hundred buildings (10%) were noted as being abandoned with no structural collapse prior to their abandonment.

When tabulated against age the data shows that of the 434 buildings with no damage, 398 (92%) are post-war constructions. In contrast of the 234 very seriously damaged 198 (85%) are pre-war vintage. Similarly, all 12 collapsed buildings are pre-war in age, as are all but 4 of the abandoned houses. Direct comparison of these figures is valid as the total population consists of roughly equal proportions of post-war and pre-war buildings (42% and 58% respectively). Building damage, tabulated against type of construction reveals that of the 434 buildings

DEGREE OF DAMAGE BY AGE OF STRUCTURE (Total Survey)	Pre 1900	1901-1910	1911-1920	1921-1930	1931-1940	1941-1950	1951-1960	1961-1970	1971-1980	1981-
None 1	11	2	1	21	1	47	139	175	17	20
Light 2	5	0	0	6	0	8	28	3	0	0
Moderate 3	6	1	3	19	1	22	28	16	0	0
Severe 4	4	0	1	33	0	18	24	2	0	0
Very Severe 5	119	4	5	69	1	23	8	5	0	0
Collapse 6	8	1	1	2	0	0	0	0	0	0
Aban. no coll.	73	0	2	21	0	3	1	0	0	0

Table 9.8

Source: Author Survey

recorded as having no damage, 403 (93%) have a reinforced concrete frame. At the other end of the spectrum, 234 buildings were noted as having suffered very severe damage and of these 181 (77%) have a timber frame (see Tables 9.9 and 9.10). It is clear, therefore that susceptibility to damage in part reflect type of construction.

9.6.3 Building Damage: *Centro Storico*

The figures for building damage in the historic centre of Maratea bear a close resemblance to the data from the whole *Comune*. The main feature is a concentration of building damage amongst the pre-war structures. There are 222 pre-war buildings and of these 122 (55%) have very serious damage (Grade 5 - see Plate. 9.2). Taken as a whole 68% of all the buildings in the *centro storico* have either serious (Grade 4), very serious (Grade 5) damage, or have collapsed (Grade 6; Table 9.11).

In contrast, 89 out of a total 108 buildings with no damage (82%) are of post-war construction, representing 69% of all post-war buildings within the *Comune*. When the Grade 2 (light damage) category is included, 85% of all post-war buildings in the *centro storico* are seen to have either light or no damage.

Similarly, construction and damage are closely related. Of the 126 very seriously damaged properties 115 (91%) are timber framed, contrasting with the 108 undamaged buildings, 100 of which (93%) have a reinforced concrete frame (Tables 9.12 and 9.13).

BUILDING DAMAGE BY HORIZONTAL CONSTRUCTION (Total Survey)						
	1 None	2 Light	3 Moderate	4 Severe	5 Very Severe	6 Collapse
Ashlar/Brick	40	10	27	36	193	12
Building Blocks	394	40	69	46	41	0

Table 9.9

Source: Author Survey

BUILDING DAMAGE BY VERTICAL CONSTRUCTION (Total Survey)						
	1 None	2 Light	3 Moderate	4 Severe	5 Very Severe	6 Collapse
Timber Frame	31	9	24	36	181	12
Pre-Stressed Concrete/Other	403	41	72	46	53	0

Table 9.10

Source: Author Survey

Plate 9.2: Building FG3/163 at the top of the Via Pendinata in the *centro storico*. The building is seriously damaged (Grade 5), with timber props supporting the balcony arches, yet is still inhabited.

DAMAGE BY AGE OF CONSTRUCTION *(Centro Storico)*										
	Pre 1900	1901-1910	1911-1920	1921-1930	1931-1940	1941-1950	1951-1960	1961-1970	1971-1980	1981-
None 1	4	2	1	2	1	8	38	36	7	9
Light 2	5	0	0	1	0	1	11	1	0	0
Moderate 3	5	1	3	7	1	2	0	0	0	0
Severe 4	4	0	1	14	0	4	5	1	0	0
Very Severe 5	104	4	5	9	0	2	2	0	0	0
Collapse 6	6	0	1	2	0	0	0	0	0	0
Aban. no coll.	36	0	1	2	0	1	1	0	0	0

Table 9.11

Source: Author Survey

BUILDING DAMAGE BY HORIZONTAL CONSTRUCTION *(Centro Storico)*						
	1 None	2 Light	3 Moderate	4 Severe	5 Very Severe	6 Collapse
Ashlar/Brick	9	6	13	18	120	9
Building Blocks	99	13	6	11	6	0

Table 9.12

Source: Author Survey

BUILDING DAMAGE BY VERTICAL CONSTRUCTION *(Centro Storico)*						
	1 None	2 Light	3 Moderate	4 Severe	5 Very Severe	6 Collapse
Timber Frame	8	5	12	19	115	8
Pre-Stressed Concrete/Other	100	14	7	10	11	1

Table 9.13

Source: Author Survey

9.6.4 Building Damage: Fiumicello & Porto di Maratea

In the Fiumicello/Porto area, buildings dating from the periods pre-1900 / 1901-1910 / 1911-1920 and 1931-1940 are absent. Building during the years 1921-1930 reflects a period of development in the area of the Porto. There are 368 buildings of which 308 (83%) are post-war. Of these 182 (59%) are undamaged and 64% either undamaged or only lightly damaged. Although there are only 60 buildings dating from the pre-war period, 50% of these have very serious damage (Table 9.14).

The pre-war buildings are all timber framed and the post-war have a reinforced concrete frame. A cross tabulation of building damage against construction techniques, shows that of the 186 undamaged buildings 182 (98%) are concrete framed (Tables 9.15 and 9.16). In contrast to the *Comune* as a whole and the *centro storico* in particular, there is a more even division amongst damage to pre-war and post-war properties; for example, of the 50 buildings in the very seriously damaged category (Grade 5), 60% are pre-war timber framed and 40% post-war concrete framed. However, in terms of their population size, the tendency for pre-war buildings to display signs of more serious damage is marked; the 30 pre-war buildings in the very serious damage category (Grade 5), represent 50% of the total pre-war population, while the 20 post-war concrete frame buildings in the same category are only an insignificant 5.5% of the post-war population.

9.7 Type of Building Damage

For each damaged building the type of damage and its position was noted as detailed in Table 9.7. Cracks in the main structure could be categorised under more than one heading, for example, a building could have a combination of both horizontal and diagonal cracks. Where this was the case the dominant type of cracking was recorded.

DAMAGE BY AGE OF STRUCTURE (Flumicello)										
	Pre 1900	1901-1910	1911-1920	1921-1930	1931-1940	1941-1950	1951-1960	1961-1970	1971-1980	1981-
None 1				4		25	86	69	2	
Light 2				4		7	7	0	0	
Moderate 3				3		20	27	15	0	
Severe 4				9		13	16	1	0	
Very Severe 5				30		17	3	0	0	
Collapse 6				0		0	0	0	0	
Aban. no coll.				10		0	0	0	0	

Table 9.14

Source: Author Survey

DAMAGE BY HORIZONTAL CONSTRUCTION *(Fiumicello)*						
	1 None	2 Light	3 Moderate	4 Severe	5 Very Severe	6 Collapse
Ashlar/Brick	15	2	4	9	30	0
Building Blocks	181	16	61	30	20	0

Table 9.15

DAMAGE BY VERTICAL CONSTRUCTION *(Fiumicello)*						
	1 None	2 Light	3 Moderate	4 Severe	5 Very Severe	6 Collapse
Timber Frame	4	3	4	9	30	0
Pre-Stressed Concrete/Other	182	15	61	30	20	0

Table 9.16

Source: Author Survey

No horizontal cracks were found in any buildings, except for a garage in the *centro storico* where the roof had been displaced horizontally (Plate 9.2). Wall bursts, jamb bursts, lintel and sill shears were common in all damaged houses regardless of construction type. Small dendritic and diagonal cracks were common in timber framed houses but were always subordinate to the dominant 'X'-shaped cracking.

In Maratea, diagonal cracking or 'X'-cracking (Fig. 9.3) seems to be more characteristic of timber framed buildings. Of a total of 393 timber framed buildings, 254 (64%) have dominant diagonal cracking or 'X'-cracking (Table 9.17). The figures are complicated by spatial variations in the pattern of damage. For example, the *centro storico* has the highest concentration of timber framed buildings but here only 89 (43%) of buildings have diagonal or 'X'-cracks and 57% have dominant vertical cracking (Fig. 9.3). On map sheet FF1, there are 33 timber framed houses and 35 concrete framed houses: of these 26 have some form of damage split evenly between the two construction types; all timber framed buildings have 'X'-cracks and concrete framed buildings vertical cracks. Similarly, on sheet FE3, 27 buildings are timber framed and 18 concrete framed. Of these 17 are damaged (38%), 14 timber framed (52% of timber framed) and 3 concrete framed (17% of concrete framed). The concrete framed buildings all have vertical cracks whereas 2 timber framed houses have vertical cracks and 12 'X'-cracks. The pattern is repeated in the Fiumicello/Porto area (sheet FF2). Here 33 of the 45 damaged timber framed buildings have 'X'-cracks (73% of the total damaged timber framed buildings), and 88 of the 127 concrete framed buildings (69%) have vertical cracks. Again on sheet FG4, 37 of the 52 damaged timber framed buildings have 'X'-cracks (71%) and 19 of the 28 reinforced concrete houses (68%) have vertical cracks.

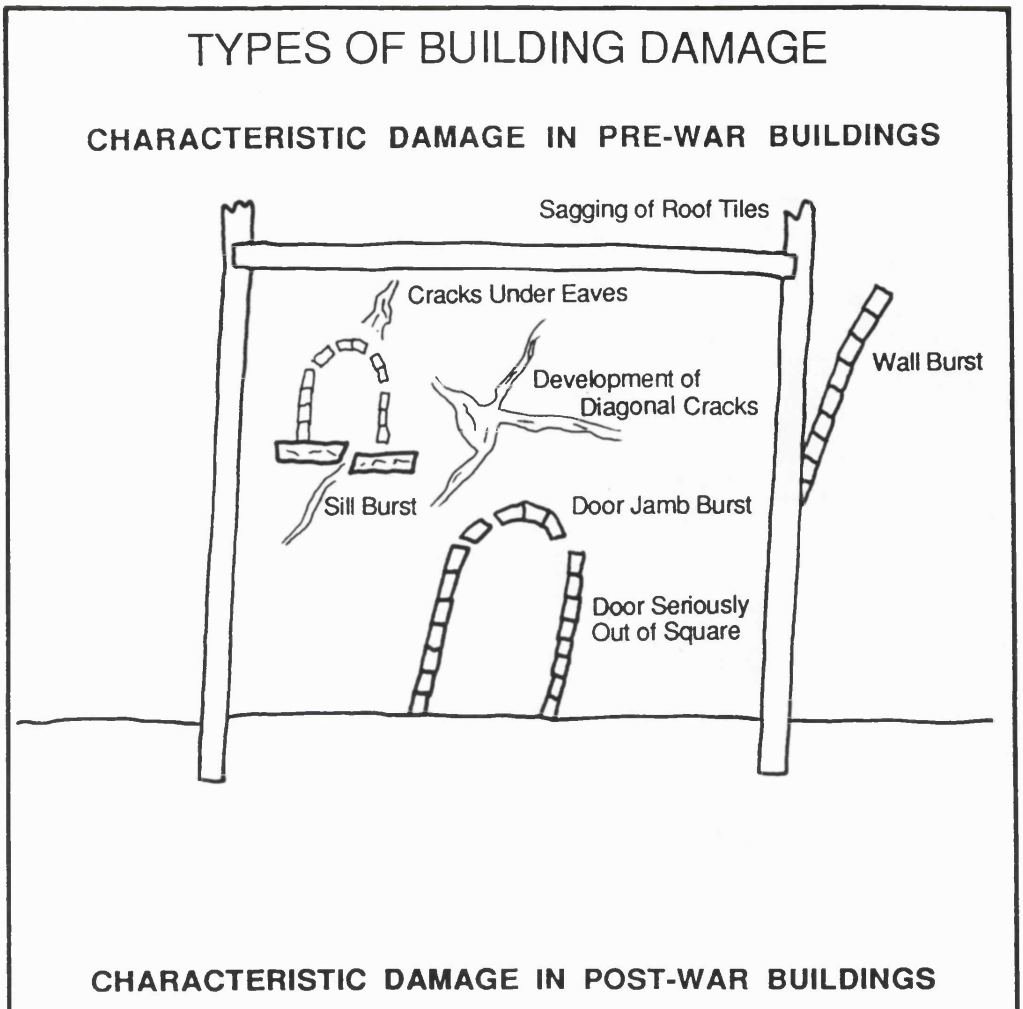


Fig. 9.3: Types of building damage seen in Maratea.

TYPE OF DAMAGE BY AREA AND CONSTRUCTION							
		TIMBER			CONCRETE		
Sheet N°	N° Damaged	N° Damaged	X Cracks	Vert. Cracks	N° Damaged	X Cracks	Vert. Cracks
FF1	26	13	13	0	13	0	13
FE3	17	14	12	2	3	0	3
FF2	172	45	33	12	127	39	88
FG3	202	166	89	77	36	8	28
FG4	80	52	37	15	28	9	19

Table 9.17

Source: Author Survey

9.8 Distribution of Building Damage

The reader is asked to refer to map sheets FG3, FG4, FF1, FF2 and FE3 and the accompanying index map which are placed in the back pocket of this thesis.

- **Sheet FG3**

The very high density of building and concentration/degree of damage in the *centro storico* is well illustrated on sheet FG3, as is its position directly beneath the major breaks of the sackung. Very serious building damage (Grade 5) can be observed in all parts of the *centro storico* with no one area being highlighted. The exceptions are two areas of collapsed housing. The first of these has not been included in the building damage data base as it was awaiting demolition at the time of the survey and had restricted access. The area can be seen due south of buildings FG3/274 and FG3/272. Discussions with the *Comune* reveal that building collapse here relates entirely to a long-standing process of decay affecting a number of timber framed buildings, seriously damaged even further by the 1982 earthquake, and now partially collapsed. The area is immediately adjacent to the very seriously damaged Chiesa di San Vito. Guerricchio *et al* (1987) report very serious damage to this building associated, they argue, with movements of a sackung tear (Guerricchio *et al*, 1986b). Access to this building was also restricted at the time of the survey, hence its exclusion from the data base, although it has been categorised on sheet FG3 as very seriously damaged after the report of Guerricchio *et al* (1986b).

The other area of structural collapse is in the western sector of the town where 7 timber framed buildings are involved. As with the first collapsed area, all these buildings were very seriously damaged during the 1982 earthquake and have since partially collapsed. However, the situation here is less serious and none of the houses involved is in immediate danger of total collapse although they remain uninhabitable because of structural distortion and roof and floor collapse. Buildings FG3/331 - FG3/339 were built shortly after the 1982 earthquake to house families from these two collapsed areas.

There are 41 building in the *centro storico* which have been described as abandoned with no structural collapse. All of these have now suffered very serious structural damage and/or collapse. The rationale behind their inclusion in a separate category is simply to illustrate that these buildings were not abandoned because of their state of repair. This has come about since their abandonment and may in part be related to a lack of maintenance.

All the major *Comune* buildings have either very serious or serious damage - the monastery of Cappuccini (FG3/120), Istituto di Pino - a girl's college (FG3/1) - the *Comune* buildings (FG3/8) and hospice of San Francesco (FG3/46). The hospice is the main very seriously damaged building in a predominantly undamaged area. The Chiesa Santa Maria Maggiore was under repair at the time of the survey. Section 3.3.1 noted that historical records indicate that the church has suffered throughout its history from movements thought to be associated with the sackung. The foundations of the church (Plate 9.3), show it to be precariously sited.

The final point to note regarding the building damage displayed in sheet FG3 is the presence in the area of the *centro storico* of a high water table. The owners of buildings FG3/129 and FG3/131 - FG3/135 all report that during rainstorms the basements of their buildings flood. A high water table was noted in all other areas of the *centro storico* evidenced by the growth of mould at the base of buildings, along steps and in little used passages and alleyways. The situation is not improved by ancient surface drainage channels which often overflow.

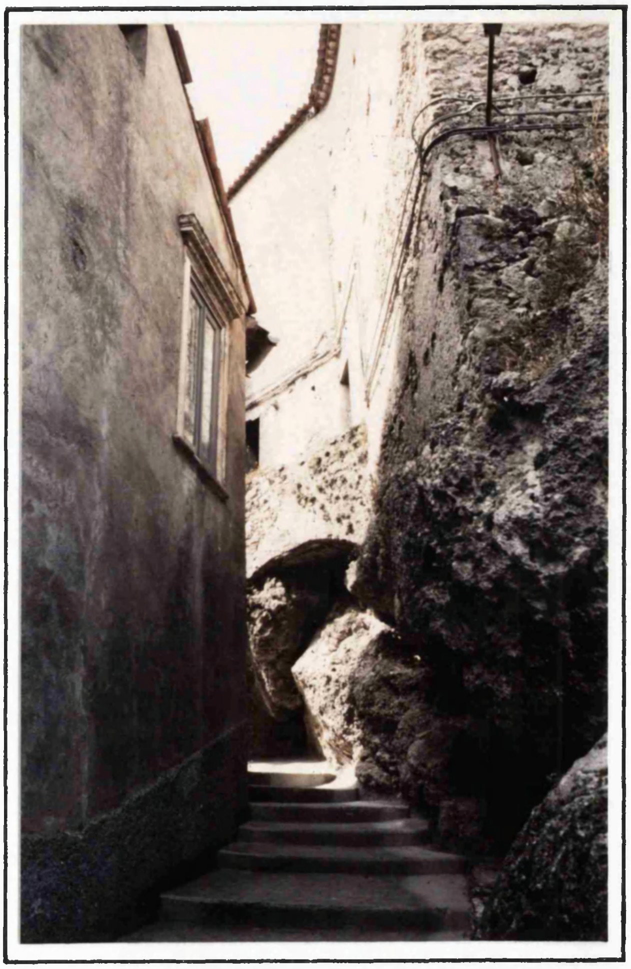


Plate 9.3: The foundations of the Chiesa Santa Maria Maggiore.

• **Sheet FF2**

The location of buildings on sheet FF2, displays a much more even distribution than is apparent in the *centro storico*. As noted in Chapter One, there are two main poles of population concentration. Fiumicello encompasses an area which runs north from the Intessa textile factory (the large very seriously damaged building in the centre of sheet FF2 - building FF2/188) to the seriously damaged Collegio Scuola (FF2/367). The Porto di Maratea is an inverted 'Y' shaped area, south of Fiumicello, lying between the base of Monte Crivo and the sixth displaced block of limestone, known locally as Capo la Timpa.

There is a smaller concentration of population in the *rione* Ondavo area with new (post 1972) housing immediately to the north. New housing construction can also be noted to the north-west, north, and north-east of the Intessa textile factory; most of this is private holiday development. New housing (FF2/229 - FF2/234) has also been located near the Stazione Centrale (FF2/215) although, in contrast, this is a *Comune* rather than a private development. It should be noted that most of the lower lying sections of this area have been taken-up with housing building.

Turning to the distribution of building damage, 19 of the 34 buildings (56%) in the Porto area have either Grade 3 (serious) or Grade 4 (very serious) damage, with no particular concentration evident. There is a greater clustering of building damage in the Fiumicello area. For example, the Intessa textile factory (FF2/188) has been assigned a Grade 4 (very serious) damage category, yet is surrounded by largely undamaged buildings. Buildings FF2/317, FF2/319 - FF2/322 and FF2/328 - FF2 332 represent a further cluster of damaged buildings, as do buildings FF2/138 - FF2 143. Similarly, there is a small group of buildings in the *rione* Ondavo FF2/38 - FF2/39 and FF2/41 - FF2/43, which have Grade 3 or Grade 4 damage. These buildings seem to be part of an arc of building damage which stretches from the Porto di Maratea around the base of Monte Crivo and up to the *centro storico.* This pattern can be seen very clearly if sheets FF2 and FG3 are placed side by side.

- **Sheet FG4**

This sheet illustrates the difference between the concentration of inhabited buildings above and below the line of the displaced limestone blocks. This line can be delimited by the main Maratea - Trecchina road which divides the map in half. The road, seen immediately to the east of the cemetery, is cut into the basal concavity of the limestone blocks. To the west of the road there is a line of low hills which may represent former portions of the main blocks, broken or 'calved' from them. The western boundary of these hills marks the divide between the upland area of Maratea and the valley floor proper which contains the main concentration of inhabited buildings.

In the area of talus deposition above and to the east of the limestone blocks are found the majority of buildings abandoned at the time of the Venezuelan migration. As with similar buildings in the *centro storico*, most of these buildings are now experiencing very serious structural problems, although again, there is nothing to suggest that this has come about due to anything other than neglect. In this area too, is a development of new weekend houses (FG4/159 - FG4/169), all privately owned and built. Immediately to the west of this development is a clearly marked track, presently being upgraded to a single carriageway tarmacadam road aimed at providing an alternative route in the *centro storico* and to the Pianeta Maratea.

The main zones of building damage on sheet FG4 can be seen running in a north - south direction, along the boundary between the base of the limestone block field and the valley floor. A number of Grade 3 and 4 clusters may be noted here; at the southern extremity of the sheet, buildings FG4/119 - FG4/121 (a 1970s housing development of two storey buildings) have suffered very serious structural damage. These buildings have been saved from demolition by a lengthy, and very costly, programme of remedial work, involving extensive underpining of the foundations (Plate 9.4). Buildings FG4/127 - FG4/129 are all of the same age and FG4/126 about 10 years older, yet none of these buildings in the same locality have suffered any damage at all. East of these buildings Grade 4 damage has been recorded to buildings FG4/84 - FG4/86, FG4/90, FG4/96 - FG4/97 and FG4/99 - FG4/100. Moving due north a cluster of Grade 4 damage can be seen involving buildings FG4/12 - FG4/16 and Grade 3 (FG4/16). North-east of these FG4/42 and FG4/44 - FG4/47 form another cluster of Grade 4 damage.

- **Sheets FE3 and FF1**

Both of these map sheets encompass areas of low density housing (46 houses on FE3 and 68 on FF1).

No particular concentration of building damage is evident although there is a small area of Grade 4 in the south-east corner of FF1 (buildings FF1/35 - FF1/36, FF1/38 and FF/44). Sheet FE3 displays the same general tendency, noted on sheet FG4 with damage concentrated at the base of the displaced limestone blocks. FE3/23 - FE3/24, FE3/28 and FE3/33 are all along the basal concavity of block I, although clearly there are a number of undamaged buildings in the same area.

9.8.1 Patterns of Building Damage

Having looked at the distribution of building damage by individual map sheets, it is instructive to obtain an overview of the whole area and to attempt to discern patterns of building damage across the valley.

As noted above, if map sheets FF2 and FG3 are placed side by side, an arc of building damage can be identified, running from the Porto di Maratea northwards between the base of Capo la Timpa and Monte San Biagio through the *rione* Ondavo and up towards the *centro storico*. North-east of the *rione* Ondavo in the south-west (bottom right) corner of sheet FG4, the line of damage forks

Plate 9.4: Buildings FG4/119 - FG4/121. Constructed in the 1970's, only extensive underpining has saved these buildings from demolition.

north onto sheet FG4 and, as previously discussed, follows the base of the displaced limestone blocks. Similarly on sheet FF2, a broad band of building damage can be identified running from the north-west (top left) corner of the sheet to the Porto di Maratea. In short, apart from the *centro storico*, which, largely because of the concentration of building, has the highest number of damaged buildings in the area, building damage seems to be occurring in belts across the valley. Broadly speaking the greatest concentration of damage is at the base of displaced limestone blocks. Even in Fiumicello building damage is located in a narrow belt running from building number FF2/317 to FF2/367; most buildings here are either at the base of slopes or in the immediate area of the Torrente Fiumicello.

In addition, areas of building damage are often coincident with spring lines or surface water flow (the Torrente Fiumicello or its tributaries). As noted in the last paragraph, building damage in Fiumicello tends to be concentrated around the river. Similarly a tributary of the Torrente Fiumicello can be seen in the Porto area running from building FF2/250 to the coast and partly canalised for about 60m from building FF2/262 to FF2/285.

9.9 Discussion

9.9.1 Causes of Building Damage

The main aim of the building damage survey of Maratea was to identify the effects of slope movement on the urban fabric of the area. Unfortunately this proved to be difficult for, as noted in Chapter Three, Maratea suffers from the twin problems of earthquake shaking and slope instability. As Alexander (1984b) was forced to point out at the end of a description of building damage by landslide in Ancona, 'many of the above observations [of landslide damage] are also true of earthquake damage' (Alexander, 1984b, p.460). Alexander continues, however, by arguing that 'there are fundamental reasons why landslide damage is different' (p.460). He notes that while both landsliding and earthquake shaking concentrate forces at the base of a building, landsliding is unidimensional whereas during an earthquake event a combination of horizontal and vertical forces is experienced. Alexander goes on to contend that the alternation of forces during an earthquake tends to produce 'X'-pattern cracks, while landsliding causes more vertical and sub-vertical fractures.

Regrettably, while Alexander's general argument is correct, his conclusions are too simplistic and tend to ignore the influences of sub-surface conditions and differences in building design and construction. This last point is the most crucial, because whatever the forces acting on a building it will always fracture along the line (or lines) of greatest weakness. These will vary from one construction type and one building to another. It is fundamentally very difficult to identify the difference between landslide and seismic damage; the pattern of cracking is not a foolproof guide. Building damage in Maratea probably reflects the complex interaction of several sets of factors which vary in space and time. These factors include:

- earthquake shaking;
- landslide activity;
- type of building design and construction;
- building decay with age;
- quality of construction; and
- sub-surface conditions, that is the position of the building in the valley particularly with regard to surficial deposits, foundation conditions and groundwater conditions.

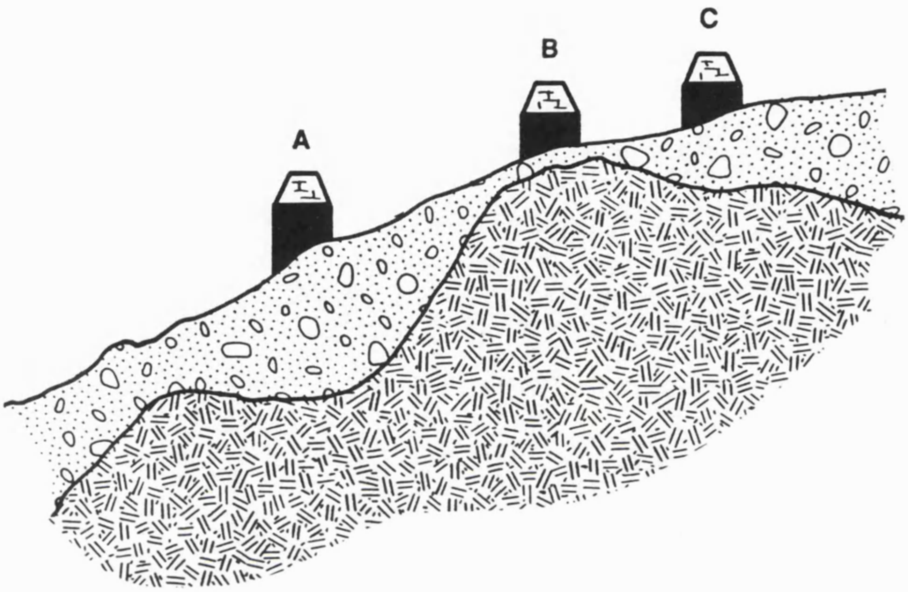
The high spatial variability of building construction, building age and sub-surface geology, render it difficult to draw immediate general conclusions from the building damage data base. Rather, it is more sensible to look at building damage on the smaller scale, that is on a map sheet basis, and then to draw the sheets together and look at patterns across the valley.

- **Sheet FG3**

De Stefano (1978) attempted to relate the very high degree of building damage apparent in the *centro storico* to the variability in the sub-surface geology of its site. De Stefano argued that the problem lay in the variable depth of the material which mantles the underlying clay layer; where the detritus is very thick (De Stefano argues greater than 10m, although he presents no reasons for selecting this value) it acts as a 'plate' or 'raft' which spreads the building load over a large area. Conversely, a thin detrital layer imposes a much heavier building load on the black clay layer beneath (see Fig. 9.4).

De Stefano envisaged that during an earthquake the black clays experienced severe shaking, which he imagined to be similar to a jelly on a plate. Buildings constructed on a very thick detrital layer experienced less intense shaking because the detritus both absorbed a proportion of seismic wave energy and acted as a raft for the building. Conversely, building foundations which penetrate the clay layer are likely to experience severe damage due to the clay magnifying the seismic wave energy.

De Stefano's hypothesis can be tested by examining the building damage survey in conjunction with the borehole data of Regione Basilicata (1978). The location of each borehole with reference to the building damage survey is displayed in Table 9.18 (see also Fig. 3.2a - 1). As noted in Chapter Three, black clays are found in five boreholes in the *centro storico*. Boreholes S4, S5 and S6 sunk along the Via Manderino are located in an area of very serious building damage, immediately outside buildings FG3/132, FG3/128 and FG3/129 respectively. Along this section, the upper boundary of the clay layer lies at a very variable depth, being closest to the surface (8.8m) in borehole S5 (immediately adjacent to FG3/128). The clay layer is again very close to the surface in borholes S8 (5.5m) and S12 (5m). Both



Detritus

Clay

Sketch to show the effect of the variability in the thickness of detrital material. In A and C the weight of the building is spread over the detritus which acts as a 'raft'. In B earthquake shaking and hence building damage, is magnified because the building is resting directly on the clay layer.

Fig. 9.4: The variability of the detrital layer and its possible effect on building damage.

BOREHOLE SURVEY LOCATION			
	Next to Building N°	Depth to Black Clay (m)	Depth to other clay (m)
S1	FG3/300	No Clay	0.8
S2	FG3/307	No Clay	1.5
S3	FG3/308	No Clay	6.4
S4	FG3/132	20	2.2
S5	FG3/128	6.8	1.5
S6	FG3/129	16.3	2.0
S7	FG3/301	No Clay	No Clay
S8	FG3/102	5.5	1.6
S9	FG3/1	No Clay	0.5
S10	FG3/46	No Clay	1.5
S11	FG3/17	No Clay	1.0
S12	FG3/98	5	0.5

Table 9.18

See Fig 3.2a - I for borehole stratigraphy these boreholes are adjacent to serious (Grade 3) damaged buildings (FG3/109 and FG3/98 respectively), although S8 is midway between the Grade 3 building FG3/109 and the undamaged hospital (FG3/102).

No black clays were found in boreholes S1 - S3, S7 and S9 - S11, although terra rossa was discovered in S2 - S3 and S9 - S11. A reddish-yellow clay was found in S1 and no clay of any sort in S7. In all these boreholes (except S7) clay was very close to the surface; 0.8m in S1, 1.5m in S2, 8.4m in S3, 3.3m in S9, 1.5m in S10 and 1m in S11. Indeed, Table 9.18 shows that in all boreholes except S7, a clay layer was encountered very close to the surface. The depth to the clay layer makes it likely that the foundations of buildings adjacent to these boreholes, particularly S1, S2, S10 and S11, have penetrated the clay. In short, the hypothesis of De Stefano (1978) cannot be refuted on the basis of the borehole evidence. Likewise it cannot be confirmed either, as no borehole evidence exists for other parts of the *centro storico* which have not experienced building damage. However, in these other areas evidence points to the existence of an underlying clay substratum. As noted in section 9.8, a high water table is found in all parts of the *centro storico* which have experienced building damage. The water table suggests the presence of impermeable (clay) layers close to the surface.

As noted in Chapter Three, Guerricchio *et al* (1986b), argue for creep type landslide movements affecting the *centro storico*. At intervals, for example during an earthquake, this movement is envisaged to be accelerated and may become a slide. In consequence, the authors ascribe building damage to this creep/slide mechanism. As mentioned above, Alexander (1984) regards vertical and sub-vertical building cracks as characteristic of landslide damage to buildings. In this instance it should be possible to identify vertical and sub-vertical cracking in the buildings of the *centro storico* if landsliding is the primary cause of damage. It can be seen, with reference to Table 9.17, that of the 166 damaged buildings in the *centro storico*, roughly half have 'X'-cracks and half vertical cracks. Indeed the data displayed in Table 9.17 indicates that 'X'-cracking is a feature of timber framed buildings.

On the basis of the available data, it is difficult to ascribe building damage in the *centro storico* to any one particular causal mechanism. Earthquake shaking is clearly a recurring problem in the area and slope instability phenomena are likely to be occurring. Sub-surface geological conditions must play a rôle too; Degg (1987, 1989), for example, found that the 1985 earthquake in Mexico City caused greatest damage to buildings situated on the clays of an old lake bed. Building damage of Grade 3 or 4 severity occurs over the whole of the *centro storico*, and in all but one borehole in this area (S7) clay, (either black clay, terra rossa or a reddish-yellow clay), is found close to the surface; in only one case (S3) does the depth to clay exceed 2.2m (6.4m). The situation is not helped by the predominance of timber framed buildings in the *centro storico*, which have a much less rigid structure than reinforced concrete, are not built on a platform or 'raft' and are therefore much more susceptible to damage. Combined with this, an inadequate knowledge of the sub-surface conditions, has meant that many buildings in the *centro storico* has been inappropriately sited and badly constructed with, in particular, foundations of inadequate depth to counter the effects of unfavourable geology.

- **Sheet FF2**

The distribution of damage for the area shown on sheet FF2 around the Porto di Maratea and between the base of Capo la Timpa and Monte San Biagio, occurs to buildings built during the 1950s and 1960s. All of these buildings have a reinforced concrete frame and display predominantly vertical and sub-vertical cracking. The distribution of damage, coupled with data from the Italian railway authorities (see Chapter Three) which notes the need for repeated realignment of the railway track in the area, suggests that slope stability may be a major cause of building damage.

Damage in other parts of the area covered by the map sheet may have a different causal mechanism. For example, it is significant that the Intessa textile factory is the only very seriously damaged building in an area which otherwise displays little damage. Buildings FF2/198 - FF2/202 and FF2/312 - FF2/313 are all in the immediate vicinity of the factory (FF2/188), are all undamaged and are all of the same basic construction type and age. In this region it may well be that the factory foundations have penetrated an area where there is but a skeletal covering of detritus over a clay layer close to the surface. The hypothesis is given further weight by the fact that the 1982 earthquake caused such serious damage to the factory that it had to be closed down, yet houses in the immediate vicinity remained undamaged. Unfortunately, while this hypothesis may well be correct, it must remain an hypothesis until sub-surface information for the area is available. An alternative hypothesis must also be considered, namely that the building has suffered damage because of its size; in much the same way as a very large ship will have a tendency to break its back in a heavy sea, so a large building on a large concrete raft may suffer similar seismic stresses during an earthquake.

In other areas of Fiumicello, clusters of damaged buildings may be related to a similar causal mechanism, namely earthquake shaking exacerbated by the presence of a shallow clay substratum. For the same reasons discussed above, this too must remain an hypothesis.

- **Sheet FG4**

Building damage for the area shown on sheet FG4, is concentrated along the length of the transition zone between the detached limestone blocks and the valley floor. Spring lines can be seen along the length of this zone and their presence always coincides with areas of building damage. As with the *centro storico*, a high water table is evidence of an impermeable clay layer close to the surface. If the hypothesis of a step fault mechanism forming the limestone blocks is accepted, a clay layer would be expected in this area; the blocks pushing-up the clay with a ploughing action as they moved forward and sqeezing-out clay from beneath them. Detrital material from the scarp face would fill the void behind the blocks and so not be seen in this area, hence a deep clay layer with a thin detrital covering would result. It must be stressed that this scenario is an hypothesis only and no evidence exists to support it; a comprehensive borehole survey would be required to test these ideas. Nonetheless, if such an hypothesis were correct it could explain building damage along the transition zone, resulting from destructive seismic shaking in areas where foundations have penetrated the clay layer.

The only area where a different causal mechanism may be postulated is in the area of buildings FG4/119 - FG4/121. This area is immediately downslope (west) of the block from which 'modern' radiocarbon dates were obtained and recent movement postulated. There is no geomorphological evidence that building damage anywhere along the transition zone is due to continuing block movement. If block movements were very 'recent', that is within the lifetime of building construction in this area, geomorphological indications of ground disturbance should be observable. However, the geomorphological map revealed no such evidence; no tension cracks could be identified at the trailing edges of the blocks, no evidence could be seen of any serious road damage along the basal concavity, neither were there any signs of pressure ridges caused by the settling of the blocks. The lack of geomorphological evidence does not invalidate the radiocarbon dates which cannot be more precise than ± 400 years BP, but does suggest that seismic shaking, possibly exacerbated by building foundations that penetrate to the underlying clay layer, provides the main causal mechanism of building damage in this zone.

9.9.2 Remedial Measures

Only 78 houses in Maratea have had any form of major remedial work carried out to them. Of the other damaged buildings, 179 have had cracks repaired and 18 shored-up by timber struts (Plate

9.5). Because of its architectural significance, and perceived importance to the tourist trade, the *centro storico* is the area that has benefited most from investment in remedial work (Plate 9.6).

Work has concentrated on the replacement of timber joists by ferro concrete RSJs (reinforced steel joists) and pillars. Initial experiments on this type of repair work were carried out to a pre-war building - FG3/127. A tour of this building during the 1987 survey and discussions with the owner, revealed that remedial measures had not worked well. Ferro-concrete pillars and RSJs were found to be too heavy for the ashlar construction causing severe cracking of the walls and subsidence due to pressure on the foundations. As a result, all buildings of this type are now provided with a rigid ferro-concrete 'cage' which fits inside the original facade of the building. The cage replaces pillars and RSJs and provides a more stable building structure as it is tied into the wall structure. Doors and windows are provided with a similar, but lighter weight, frame.

The cost of such remedial work is considerable, although the price varies depending on the size of the building. For FG3/127 the owner estimated that about L.12 million (£6,000) would be required. As a result, this type of work has only been carried out in the *centro storico* in order to preserve the essential character of the area.

9.10 Conclusion

The survey of building damage set out with the intention of answering four questions:

(i) Have slope movements had any effect on the buildings of Maratea?

(ii) What are the effects of earthquake shaking? Can it be divorced from landslide damage?

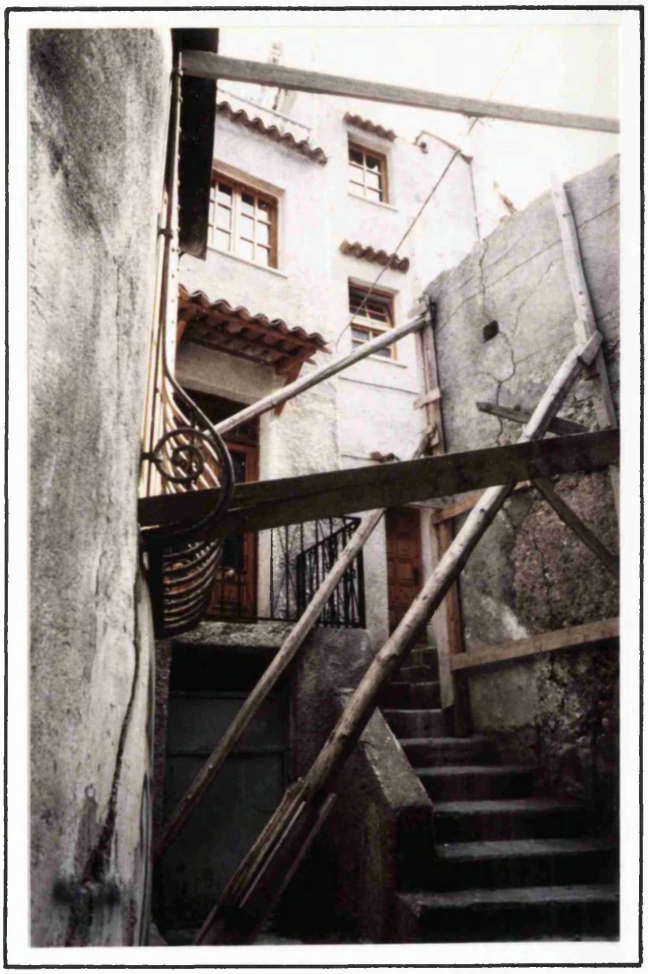


Plate 9.5: Timber struts holding-up a building in the *centro storico*.

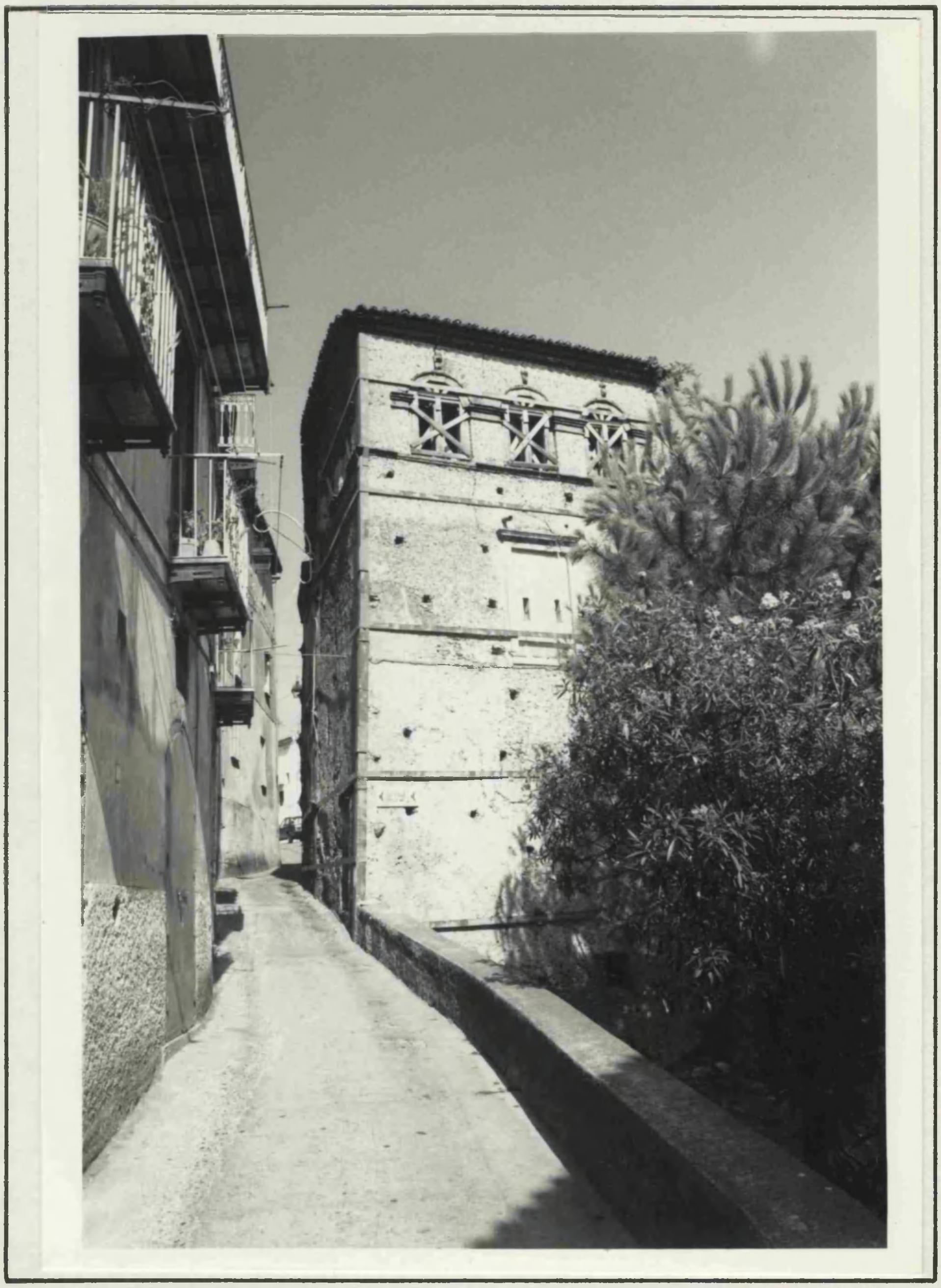


Plate 9.6: External steel ties used to support building number FG3/157 in the *centro storico.*

(iii) Is the construction and design of buildings adequate to withstand the effects of slope instability and seismic shaking?

(iv) Have remedial measures proved adequate?

To take questions (i) and (ii) first, it is clear from the preceding discussion, that building damage in the Maratea area results from the complex interaction of a number of factors. In the *centro storico* area both landslide and earthquake damaged buildings seem to occur; Fiumicello displays a predominance of earthquake damage and the Porto may be experiencing damage due to problems of slope instability. In the other main area of building construction, sheet FG4, seismic shaking rather than block movements appears to be the main cause of building damage.

Without adequate sub-surface information the causes of building damage which have been advanced must remain hypotheses. Nonetheless, if the *Comune* are serious about implementing the recommendations of the 1978 Structure Plan and if they are interested in increasing tourist and housing accommodation, then they must as a matter of urgency, commission a thorough sub-surface survey of the area. This survey must be much more rigorous than that of Regione Basilicata (1978). The sampling framework should be designed to provide a detailed picture of the sub-surface geology of the area. In the *centro storico* this could be achieved by a grid network with boreholes drilled at the nodal points of the grid. Other parts of the valley should be selected on the basis of the damage survey presented here, choosing areas of no damage and serious damage. For example, it would be instructive to drill boreholes along the line of the limestone block - valley floor transition zone and in the Fiumicello area near the Intessa textile factory and along the base of Capo la Timpa. Above all, however, geomorphological mapping can play a vital rôle in determining the location of possible boreholes, (see for example, Halcrow Middle East, 1977; Doornkamp *et al*, 1979; Cooke *et al*, 1982) and clearly, a vital part of any future work in the valley will be the extension of the present authors geomorphological map.

Questions (iii) and (iv) on building design and remedial work are important in minimising the effects of slope instability and seismic shaking. The strong positive correlation observed in section 9.6 between age of construction, type of construction and building damage, suggests the view that in the past building design has not been adequate to withstand unstable surface conditions. This situation has arisen because early constructions used local building materials and were erected by builders who were probably largely unaware of ground conditions. Houses were built in the first instance to provide accommodation against hot summers and cold winters and it was these environmental problems, not ground conditions, that influenced building design. As a result many towns in Basilicata have suffered notable damage (for example see Alexander and Rendell, 1986; Hughes, 1981; Lagorio and Mader, 1981; Rendell, 1985).

Reinforced concrete structures with a concrete base acting as a 'raft', are much more rigid and able to withstand seismic shaking. As a consequence the incidence of damage to these structures is much lower. It should be noted, however, that even these structures require careful construction and design. In particular the basal raft must be larger than the building by at least one metre all round in order for it to act as a platform during a seismic episode. This building technique is common even in non-seismic zones such as the UK. Here it is normal practice when building house extensions, particularly in areas of shrinkable clay, to extend the foundations beyond the building line. In this way any settlement of the foundations is spread over a larger area and neither the house nor the extension will show signs of distress. Nonetheless, it must be stressed in the Maratea situation, that these structures would be even less susceptible to damage if sub-surface conditions were investigated prior to construction.

On remedial measures and reconstruction, little can be said in the Maratea case because so little is being carried out. Ferro-concrete 'cages' within older houses seem to be providing, on the basis of experiments to FG3/127, a measure of success although the long term suitability of the technique has yet to be evaluated. But the work is expensive, although it does provide the only way of maintaining a number of buildings in the *centro storico* which would otherwise have to be demolished and yet need to be maintained to provide the 'feel' of the old town.

CHAPTER TEN

NEOTECTONICS, LANDSLIDES AND PLANNING. THE CASE OF MARATEA

10.1 Introduction

Chapter three concluded with the remarks that there were six key issues that need to be addressed before development of Maratea becomes a reality. These issues were broadly grouped under the three headings of neotectonics, landslides and planning. The work of the author in the Maratea Valley has added to the knowledge of the first two headings; the primary objective of this final chapter is to draw together these strands of knowledge, assess their planning implications and point the way towards future work.

10.2 Neotectonics and Seismicity

Before the author began work in Maratea the fault plane scarp along the eastern side of the valley was regarded as a Pleistocene relic, currently inactive and along which no contemporary tectonic or landslide processes were operating (Lazzari *pers. comm.*). However, no detailed work had been carried out on the fault plane scarp to either confirm or reject this hypothesis and there was certainly no direct knowledge of the phase, in the neotectonic evolution of southern Italy, during which the fault was formed or last moved, although Ciaranfi *et al* (1983) had placed the formation of the Maratea fault in Phase IIIb (2.0 - 0.7 MY BP).

An examination by the author of the distribution of seismic shocks in Basilicata has revealed that either the Maratea fault is not an active tectonic feature or that there is an extremely long return period between shocks. There are, however, clear signs of recent movement which have the effect of exhuming the fault plane and these are considered to be the results of a major zone of on-going slope instability (see section 10.3 below).

The age of the fault is more problematic. As was discussed in Chapter Four, thick layers of calcite on the fault plane surface might be the result of a process known as seismic pumping. If this were the case then a reliable age for the calcite would reveal the date of the last movement of the fault. Seismic pumping cannot be confirmed although it is clear, at least, that the fault antedates the calcite. A U-series ($^{230}Th/^{234}U$) date for the calcite has suggested a date of $46.4 \times 10^3 \pm 3.5/3.4 \times 10^3$ years BP, although as was discussed in Chapter Four the date must be viewed as a maximum age as the $^{230}Th/^{232}Th$ activity ratio is low, indicating a concentration of non-radiogenic ^{230}Th.

Profiles of the slopes of Monte Crivo above the fault plane scarp (that is of the fault footwall), surveyed by the author, have indicated a distinct break of slope. It is the view of the author that this is an indication of at least a two-stage opening of the Maratea valley. Thus, it can be envisaged that the Maratea valley formed during a period of neotectonic activity between 2.0 MY and 700,000 years ago; the graben was accentuated by a subsequent neotectonic episode at around 46,000 years BP.

It is, however, readily accepted by the author that the timing of the last fault movement is based on only one absolute date from one site. Furthermore, the exact relationship between the calcite and the fault plane makes the U-series date more uncertain. If the calcite and the fault are contemporaneous, then the U-series date reveals the date of the last fault movement. If they are not contemporaneous, then because the fault antedates the calcite layer, the fault could be much older than the U-series date. However, Chapter Four described peels taken by the author through the calcite layer and fault plane scarp, which showed calcite veins within the fault plane scarp to be the source of the calcite layer. It is, therefore, the opinion of the author that the two are contemporaneous and that the last movement of the fault, and hence the last round of pronounced neotectonic activity in the Maratea valley, occurred at around 46,000 years BP during Phase IV of the neotectonic evolution of the Southern Apennines.

The hazard imposed by earthquake activity in the valley is much less problematic. It is unlikely that the 1980 earthquake had any effect on Maratea but the 1982 certainly did. Most of the urban problems resulting from the 1982 earthquake were probably a result of building design, construction and situation and these factors and their implications for future planning decisions will be summarised in section 10.4 below. In addition to this, however, seismic activity seems to play a major role in the landslide hazard.

10.3 Landsliding

It is clear that the fault plane scarp is not the result of contemporary tectonic processes. The existence of a freshly exposed fault plane in the landscape, therefore, suggests the exhumation of an ancient fault by the processes of mass movement. The rate of exposure has been estimated by the technique of lichenometry and indicates that about 15m of scarp face has been revealed in the last 300 - 600 years. The whole of the surveyed length of the fault plane scarp is thus considered to be affected by major mass movement involving either the settling of unconsolidated deposits or more widespread movements along an underlying slip surface, or slip surfaces.

The rate of landslide movement along the fault scarp is periodically accelerated by seismic shaking. Observations of a 'white line' at the base of the fault plane scarp suggest movements of sections of the landslide body as a direct result of the earthquakes in 1982, 1955 and 1934 all of which had their epicentres within an 80 km radius of Maratea.

There is no evidence to suggest, however, that any of these landslide movements have as yet had any affect on the stability of the limestone blocks situated immediately below the zone of talus deposition. Radiocarbon dating of a block fragment was inconclusive and not, in itself, sufficient to draw general conclusions about block stability over the whole valley. It is not inconceivable, however, that future talus accumulations behind the limestone blocks could eventually move them.

This thesis has not examined the sackung in detail and so must necessarily be more circumspect in drawing general conclusions about this feature. Guerricchio *et al* (1987), argued that the sackung is a relatively stable feature and that observed slope movements in the area of the *centro storico* are the result of mass movements. These mass movements, the authors argue, are of a creep type alternated by occasional phases of sliding. If the fault plane and the sackung are, as envisaged by the present author, part of the same feature, it is possible to hypothesise a two-stage evolution of the sackung similar to that of the fault. Similarly the slow on-going mass movements along the fault plane scarp which are periodically reactivated by seismic shaking, may be mirrored in the sackung.

10.4 Planning Implications

It is useful to consider the planning implications of these conclusions for Maratea both in terms of present planning and future policy.

The present situation has been described in Chapter Eight; there are three major poles of contemporary settlement, namely in the *centro storico*, Fiumicello and the Porto di Maratea, with the majority of pre-war development in the *centro storico* and post-war development in Fiumicello. The settlement pattern, age and construction techniques of the buildings in the valley are closely related to the degree of building damage which has been observed. The old timber framed buildings of the *centro storico* have suffered enormous damage due to landsliding, movements of the sackung, seismic shaking or possibly a combination of all three. Elsewhere in the valley 'pockets' of building damage are evident with an obvious belt of very serious damage running along the base of the limestone blocks.

As far as present planning, or more accurately, 'historical planning' is concerned therefore, there appears to have been little recognition by the Maratea planners of where not to develop or how to build and mitigate against damage. This is partly understandable in the *centro storico*, sited for defence purposes, but is less so in the case of Fiumicello, where a more haphazard urban development has taken place. One of the primary causes of this haphazard development is probably that the building damage survey carried out by the author remains the only survey of this nature conducted outside the confines of the *centro storico*. Hence, until the completion of the survey maps, the Maratea planners had no perception of the spatial distribution of damage.

The principal cause of the observed distribution of building damage in the Maratea valley is probably the highly variable sub-surface geology of the area. As was discussed in Chapter Nine, where building foundations penetrate the black clay layer, (in other words where there is a skeletal detrital covering and this layer is close to the surface), the affects of seismic shaking are magnified and greater building damage results. A fundamental control on future development must, therefore, be an understanding by the Maratea planning authority, of the sub-surface environment.

Future planning policy must also recognise the importance of the landslide hazard. Prior to this thesis there was no recognition of any slope instability hazard in the Maratea valley, apart that is from the sackung. The Maratea Structure Plan called for the construction of new residential and tourist buildings, the construction of new car parks and the provision of an improved road network. Because of the dearth of available land in Maratea (see Chapter One) it is inevitable that the planners will cast their gaze towards the area of relatively level land between the base of the talus deposition and the leading edge of the limestone blocks. This area has already seen a proliferation of holiday homes and, since work began on this thesis, a major road linking the col at the head of the valley to the *centro storico* has been constructed. This road, on which construction had only just begun when the author last visited the valley in 1989, is sited at the base of the zone of talus deposition and cuts the toe of the major debris cone. This cone had been demonstrated by the author to be the most unstable portion of the accumulation zone that runs along the entire length of the fault plane scarp. While the processes of mass movement along the fault plane scarp are slow (although accelerated by seismic shaking) and, as a result, unlikely to result in a catastrophic landslide failure, it is nonetheless apparent that major construction projects, such as the new road, are going to require continual remedial work. A further problem with the road link is the strong possibility of it encouraging development along its length; this should clearly be avoided.

10.5 Future Work

Suggestions for future work and lines of enquiry in the Maratea area, fall into two categories. The first of these categories is aimed at planning on the basis of what is now known about Maratea and the second at furthering the knowledge of the area.

If the recommendation of the author is accepted, regarding the prohibition of future development in the area between the base of the talus and the edge of the limestone blocks, then clearly new building of the type envisaged in the Structure Plan, must either be shelved or squeezed into the valley floor. If a valley floor location is chosen, then the Maratea authorities must instigate a thorough sub-surface survey of the area. This need not involve the whole valley floor, but must be focussed around the areas designated for new building and their immediate environs. In addition the Comune should undertake an environmental impact assessment of any such proposed development.

Virtually all the work undertaken by the author to further the information on the Maratea valley could be extended given more research time and funding. First, as far as the neotectonic evolution of the area is concerned, research should be aimed initially towards looking at the seismic pumping process in order to determine how, when, and under what conditions it operates. If it can be demonstrated that such a process existed and has operated in Maratea, then it would clearly be instructive to obtain at least another two U-series dates from the fault pane in order to confirm the date presented in this thesis. The same technique could also be applied to other fault systems in the limestone areas in the western Mezzogiorno in order to establish precise radiometric dates for them which could then be compared with the Neotectonic Map of Southern Italy.

It is unlikely that the lichenometric curve could be extended to any degree and certainly the present author is confident that no other suitable substrates of known age exist in the area. The same cannot, however, be said of the assessment of limestone block movement. Two problems existed with this work. Sampling difficulties were the first of these and certainly larger datable stalactites exist, although their sampling would require cranes or scaffolding. If this were possible, then cores could be taken from these stalactites in order to avoid destroying the feature. The second problem involved the radiocarbon dating of material derived from stalactite samples. Thus, while considerable confidence can be placed in the accuracy and reliability of the liquid scintillation method, it is probably not precise enough to do the job asked of it at Maratea, namely to precisely date depositional bands which may be of very similar age.

The building damage survey is the final item of work carried out by the author that would benefit from more research funding and time. On the positive side it is the only comprehensive survey of building damage ever undertaken in Maratea and has greatly aided the understanding of the problems of the urban environment, particularly in terms of the construction and location of damaged and undamaged properties alike. Nonetheless, the survey would undoubtedly benefit from a re-assessment by an architect and structural engineer.

10.6 The Future of Maratea.

When the author first came to the Maratea valley in 1985 very little was known about the area. Now major zones of instability have been recognised in the valley and the geomorphology and rates of process operation have been detailed. The documentation of this work provides the Maratea planners with their first real geomorphological understanding of the area and points the way to sustainable development. Many techniques have been used for the first time in such a context - lichenometry for the first time in the Mediterranean and a first absolute radiometric date for a fault scarp in southern Italy.

However, the author cannot help but conclude this thesis with the sincere wish that the development problems facing this lovely town, are to some extent mitigated by the work herein.

APPENDIX A

AN INTRODUCTION TO THE GEOLOGICAL EVOLUTION OF THE SOUTHERN APENINNES

A.1 Geostructural Elements of the Imbricate Thrust Belt

The orogenic deformation of the Southern Apennines, from the late Oligocene to the early Pliocene, is represented by a series of nappe structures along the Apennine thrust belt (Ogniben and Vezzani, 1975). The nappes are formed from the former domains of the Lagonegro, Molise and Irpinian Basins and the Latium-Campania-Lucania and Abruzzi-Campania Carbonate Platforms (see Fig. A.1). Within the thrust pile, geostructural elements can be recognised which have been derived from the deformation of these domains. The Apulia Carbonate Platform is a stable carbonate shelf which has not been incorporated into the imbricate pile, and consequently acts as a foreland to the Apennine thrust belt.

Ogniben (1969) attempted a reconstruction of the imbricate thrust pile based on the recognition of stratigraphical complexes. He described eight such complexes beginning at the base of the thrust pile (see Fig. A.2).

(i) **Basal Complex.** Ogniben argued that this was derived from the former domains of the Lagonegro Basin.

(ii) **Ex-basal Complex.** Numidian Flysch at the base passing up to Serra Cortina marls, flysch of the Masseria Palazzo Formation, Serra Palazzo marls grading to 1000m of Masseria Luci flysch.

(iii) **Panormide Complex.** Mesozoic Limestones and dolomites derived from the deformation of the external sectors of the Latium-Campania-Lucania Carbonate Platform.

(iv) **Liguride Complex.** Albidona flysch and black clays of the Crete Nere Formation.

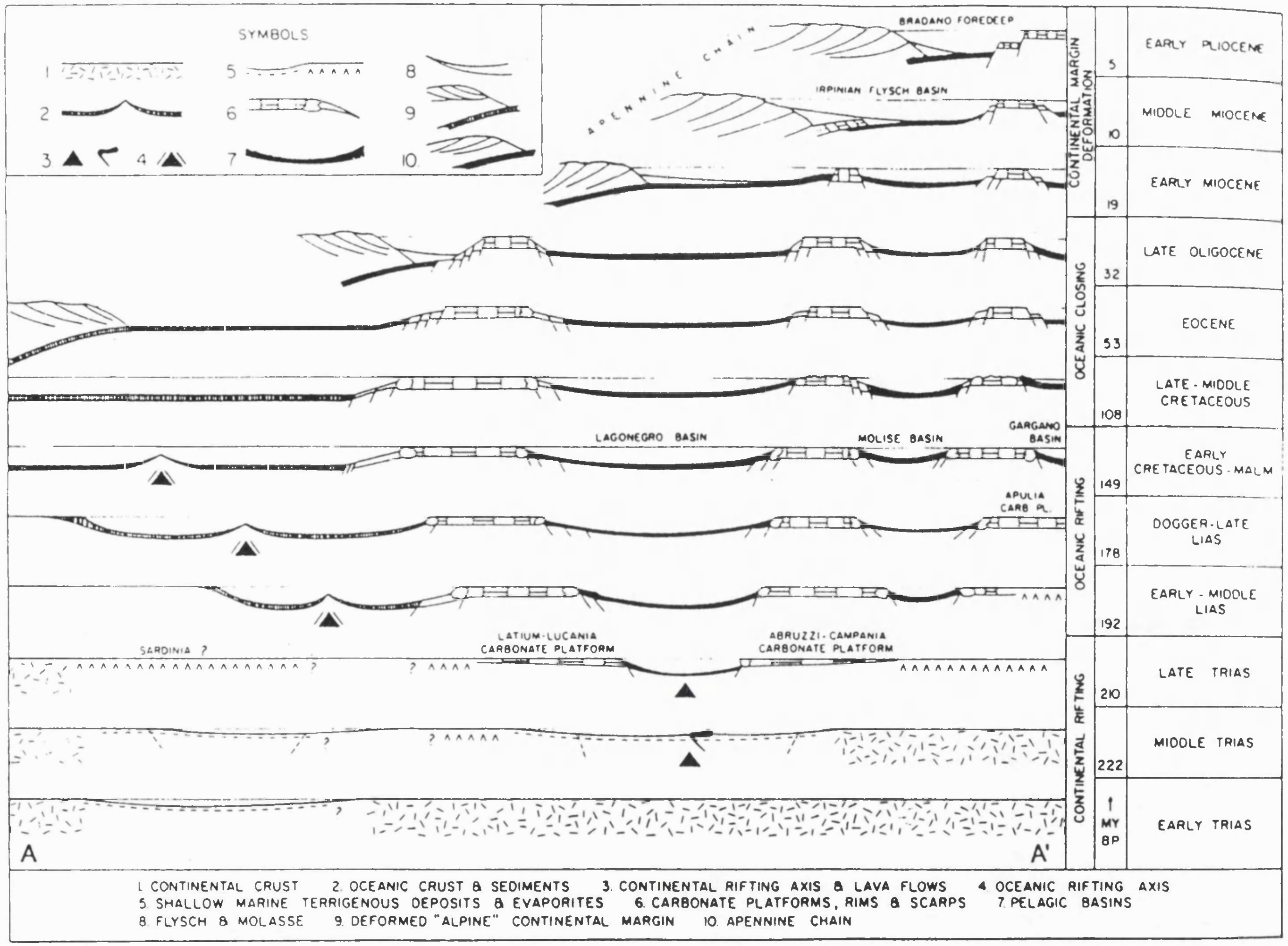


Fig. A.1: Palaeogeographic reconstruction of the imbricate thrust belt showing the stages in the evolution and deformation of the Southern Apennines. After D'Argenio and Alvarez (1980).
For location of composite profile see Fig 2.1.

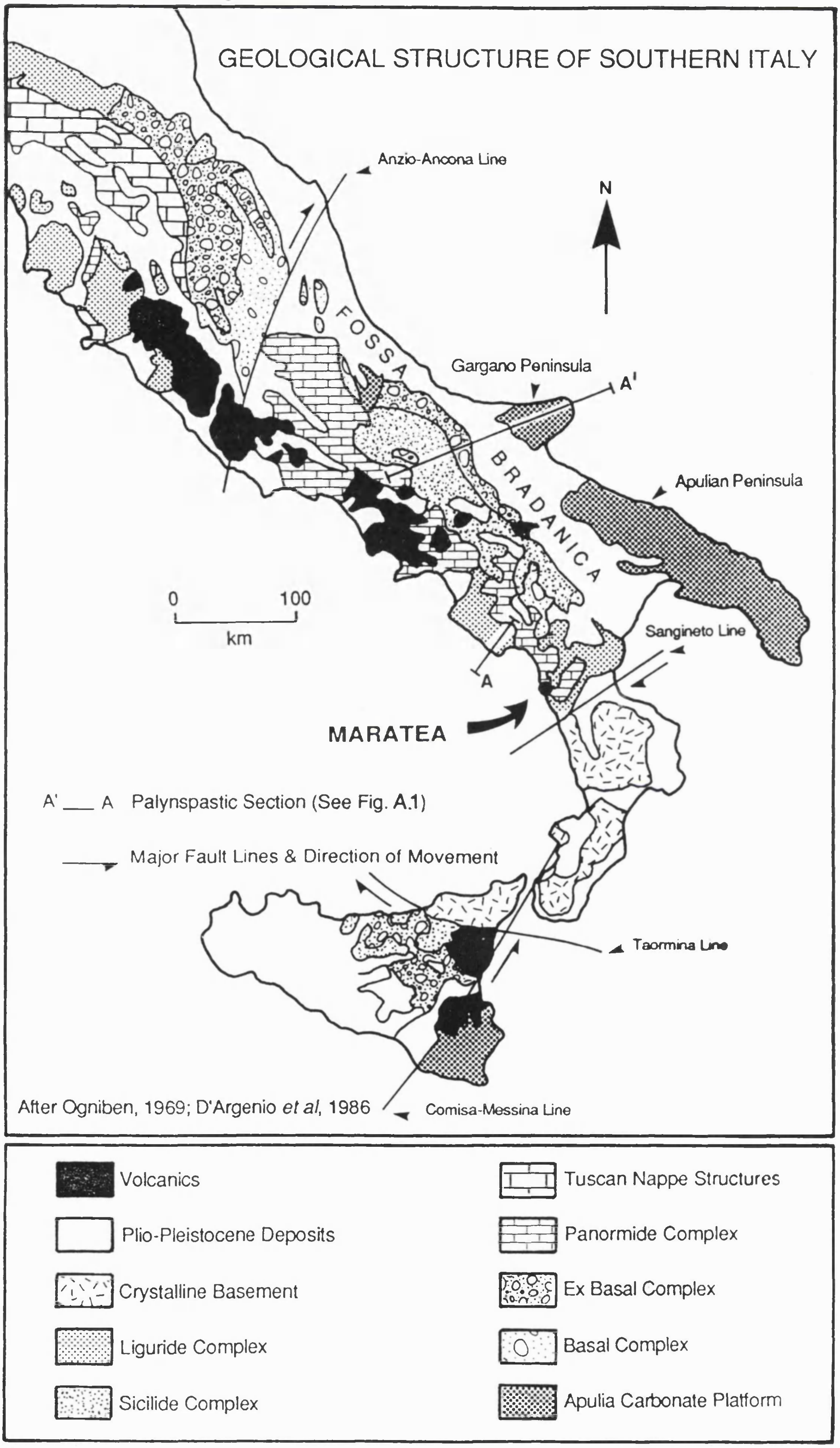

GEOLOGICAL STRUCTURE OF SOUTHERN ITALY
Anzio-Ancona Line
N
FOSSA
BRADANICA
Gargano Peninsula
A'
Apulian Peninsula
0
100
km
Sangineto Line
A
MARATEA
A' ___ A Palynspastic Section (See Fig. A.1)
Major Fault Lines & Direction of Movement
Taormina Line
After Ogniben, 1969; D'Argenio et al, 1986
Comisa-Messina Line
Volcanics
Plio-Pleistocene Deposits
Crystalline Basement
Liguride Complex
Sicilide Complex
Tuscan Nappe Structures
Panormide Complex
Ex Basal Complex
Basal Complex
Apulia Carbonate Platform

Figure A.2:

(v) **Calabride Complex (Crystalline Basement).** Crystalline Basement of the Calabria-Peloritani arc. In Basilicata it outcrops at Episcopia in the centre of the region.

(vi) **Sicilide Complex.** Nocara flysch, Gorgoglione flysch and Argille Varicolori shales of the Rocca Imperiales thrust sheet.

(vii) **Ex-post-orogenic Complex.** Mid-Pliocene deposits. See Plio-Pleistocene deposits on Fig A.2 for location.

(viii) **Post-orogenic Complex.** Plio-Pleistocene deposits of the Fossa Bradanica. See Plio-Pleistocene deposits on Fig A.2 for location.

While Ogniben's paper 'is a notable effort to organically represent within a theoretical scheme the complex structure of the Southern Apennines', (Ippolito *et al*, 1975, p. 230), it is simpler to understand the internal geometry of the imbricate thrust belt by reference to the framework of D'Argenio *et al* (1986). D'Argenio recognises the presence of three 'tectono-stratigraphic elements'. These are termed Higher, Intermediate and Lower tectonic elements and are derived from the deformation of the pre-orogenic sedimentary domains noted in Chapter Two. Fig. A.3 is a sketch of the relationships between the major units while Fig. A.4 describes the distribution of these elements in Basilicata. Together with the Apulia Carbonate Platform and the foredeep elements, D'Argenio *et al* describe five elements to the Southern Apennines thrust belt.

A.1.1 Foreland

The Apulia Carbonate Platform is a stable limestone shelf, over which the sedimentary domains were thrust during the Apennine orogeny. It still acts as a foreland to the thrust belt. There

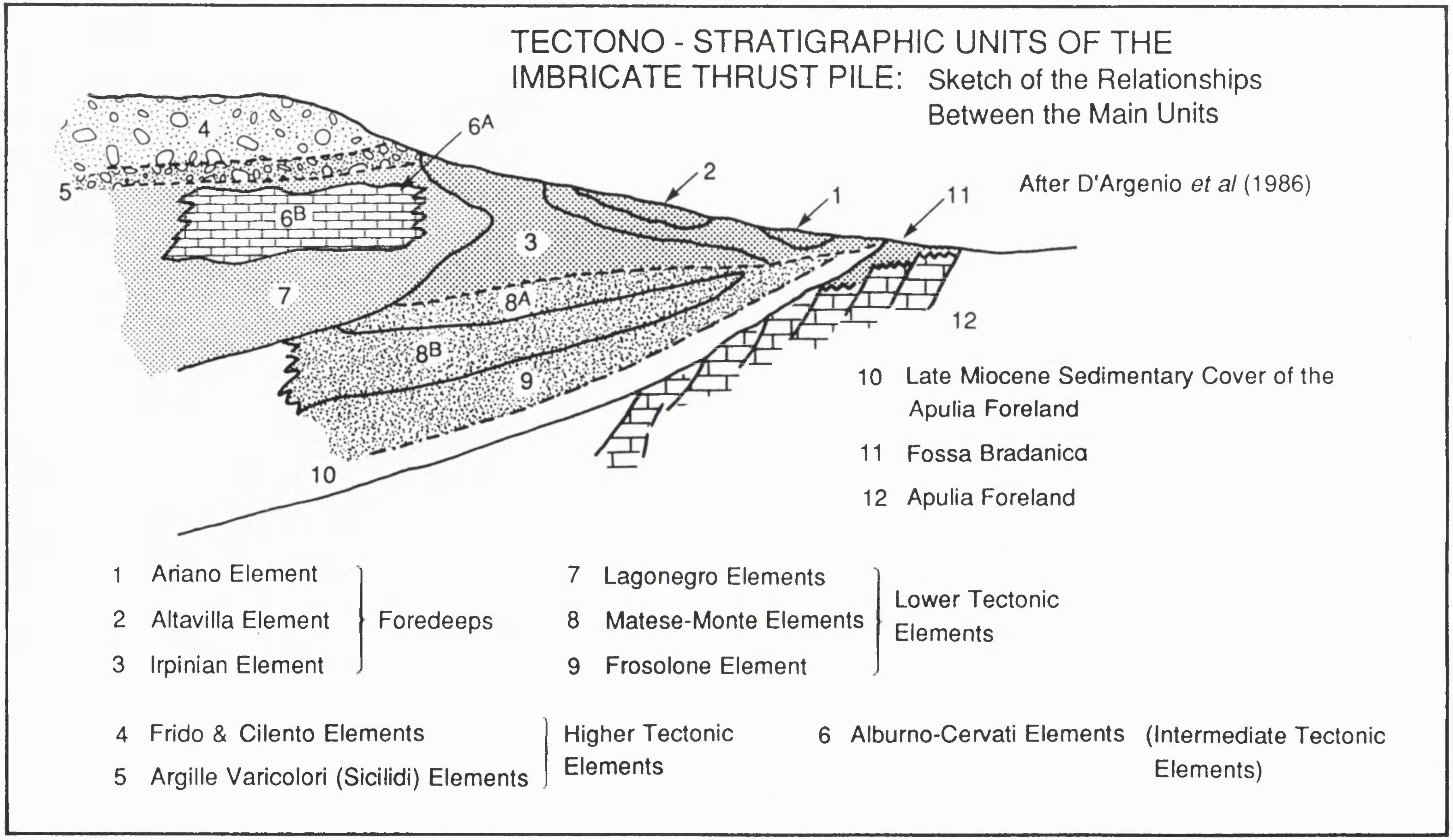


Fig. A.3: Tectono-stratigraphic units of the imbricate thrust pile: Sketch of the relationships between the main units. After D'Argenio *et al* (1986).

GEOLOGICAL STRU

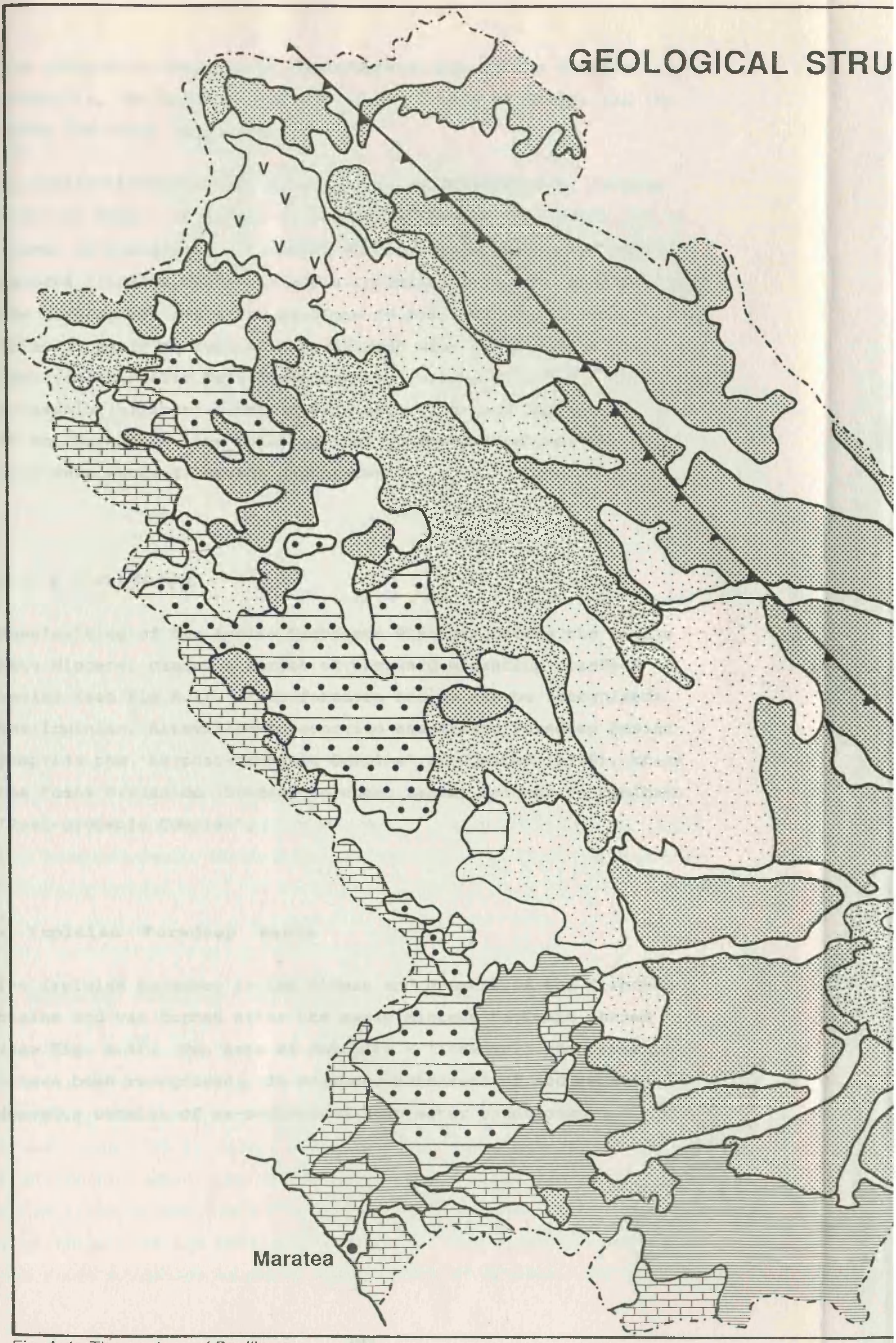
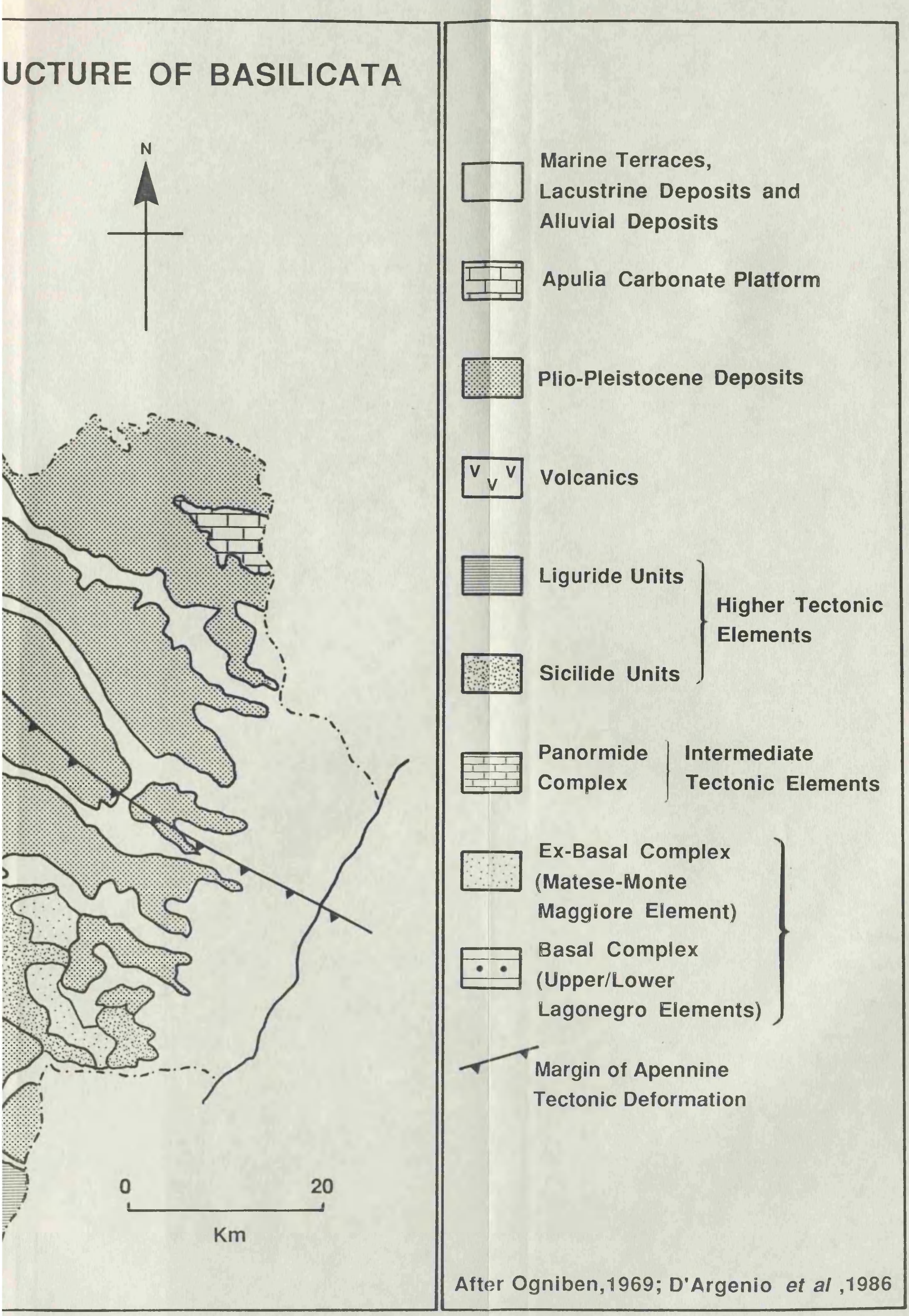


Fig. A.4: The geology of Basilicata.


UCTURE OF BASILICATA
N
Marine Terraces, Lacustrine Deposits and Alluvial Deposits
Apulia Carbonate Platform
Plio-Pleistocene Deposits
V V V
Volcanics
Liguride Units
Sicilide Units
Higher Tectonic Elements
Panormide Complex
Intermediate Tectonic Elements
Ex-Basal Complex (Matese-Monte Maggiore Element)
Basal Complex (Upper/Lower Lagonegro Elements)
Margin of Apennine Tectonic Deformation
0
20
Km
After Ogniben,1969; D'Argenio et al ,1986

are three main outcrops of the Apulia Platform; the Gargano peninsula, the Apulian peninsula (the 'heel' of Italy) and the Iblei peninsula in Calabria.

In Apulia the Platform outcrops for over 300km with an average width of 50km. It ranges in thickness from 4000m - 6000m and is formed of Cretaceous - Jurassic shallow water carbonates passing to late Triassic dolomites and evaporites in the sub-surface. In the Gargano peninsula the Platform is transgressed by late Triassic marls tectonically associated with volcanics of the Punta delle Pietre Nere Formation, an outcrop of mafic rocks containing silicate minerals especially iron and magnesium. Also in the Gargano a late Triassic reef belt separates shallow water from deep water (eastern) carbonates.

A.1.2 Foredeeps

Downfaulting of the Apulia Carbonate Platform during the middle - late Miocene, caused a series of eastward migrating foredeep basins (see Fig A.1). Four foredeep basins can be recognised; the Irpinian, Altavilla-Montecorvino and Ariano Foredeep Basins comprise the 'Ex-post-orogenic Complex' of Ogniben (1969), while the Fossa Bradanica (Bradano Foredeep Basin) belongs to Ognibens 'Post-orogenic Complex'.

- **Irpinian Foredeep Basin**

The Irpinian Foredeep is the oldest and deepest of the foredeep basins and was formed after the early Miocene tectonic phases (see Fig. A.1). Two sets of deposits - 'internal' and 'external' - have been recognised. In essence, both sets of sedimentary deposits consist of re-sedimented deep water sandstones.

- **Altavilla-Montecorvino Foredeep Basins**

This basin was formed after the middle Miocene tectonic phases but before the Pliocene. Two cycles of deposition have been identified. The lower (Montecorvino) cycle consists of clays, sandstones and diatomites, developed in a lagoonal or brakish marine environment during the late - late-middle Miocene. The deposits are several hundred metres thick and fill an elongate basin at the base of the Apennine chain. The upper (Altavilla) cycle is separated from the lower by a limestone conglomerate discontinuity derived from the Apulia Carbonate Platform. The Altavilla cycle consists of clays, evaporites (especially calcium sulphates), sandy conglomerates and sands and were deposited in a shallow marine or deltaic environment.

- **Ariano Foredeep Basin**

The Ariano Foredeep was formed after the early Pliocene but before the Bradano Foredeep. Sediments were deposited in a shallow marine environment and now outcrop in many areas of Basilicata, chiefly, Ariano, Irpino, Benevento, Potenza and the Ofanta Valley. As with the Altavilla-Montecorvino Foredeep Basin, two sedimentary cycles have been recognised. The upper cycle consists of hundreds of metres of clays, sandy clays, sands and conglomerates, resting unconformably on the lower, heavily deformed, cycle.

- **Bradano Foredeep Basin (Fossa Bradanica)**

The Fossa Bradanica is the youngest of the foredeep basins and has the largest areal extent. It was formed by the downfaulting of the Apulia Carbonate Platform during the late Pliocene - early Pleistocene. It is filled with thousands of metres of Plio-Pleistocene, shallow to deep water, clays and conglomerates. Large areas of the Basin are covered with alluvial deposits, particularly in the Gulf of Taranto. In this area too, some of the Fossa Bradanico is still under marine conditions. In

Basilicata the deposits of the Foredeep have been deeply dissected by (from west to east) the Sinni, Agri, Cavone, Basento and Bradano rivers.

A.1.3 Lower Tectonic Elements

The lower tectonic elements of D'Argenio *et al* (1986) occupy the lowest stratigraphical position in the imbricate thrust pile and as such are broadly equivalent to the Basal and Ex-basal Complexes of Ogniben (1969). Consequently, these elements derive from the deformation of the innermost (eastern) domains of the thrust belt and are the most mildly deformed of all the tectono-stratigraphic elements. The sedimentary domains from which they are derived belonged to the Abruzzi-Campania Carbonate Platform, the Molise Basin and part of the Lagonegro Basin (Fig. A.1).

D'Argenio identifies four lower tectonic elements, ranging from the lowest to the highest in the imbricate thrust pile.

- **Frosolone Element**

The age of the Frosolone Element is late Cretaceous - late Miocene although some sub-surface elements may date from the Jurassic or even Triassic. The unit is derived from the deformation of the Molise Basin and is formed from several hundred metres of cherty dolomites, shales and radiolarites. This sequence passes into Cretaceous - lower Tertiary calcarenites and marls and then upwards into Miocene calacarenites, marls, siltstones and sandstones.

- **Matese-Monte Maggiore Element**

The main outcrop of this element in Basilicata is Monte Alpi (1900m a.s.l.). The element is a carbonate sequence, greater than 3000m thick, derived from the deformation of the Abruzzi-Campania-Lucania Carbonate Platform. The lower part of the sequence is formed from upper Triassic - lower Jurassic dolomites passing to middle Jurassic - upper Cretaceous limestones in the higher parts of the sequence. A middle Cretaceous assemblage is often absent and the disconformity is marked by a bauxite horizon.

- **Lower Lagonegro Element**

The Lower Lagonegro Element derives from the deformation of the more internal (western) sectors of the Lagonegro Basin during the middle Miocene. The sequence is made up of upper Triassic cherty limestones, Jurassic shales and radiolarites, Jurassic - lower Cretaceous claystones, marlstones and calcarenites and Cretaceous - lower Tertiary marls and calcarenites. The sequence is topped by a 1000m layer of lower Miocene Numidian flysch and middle Miocene clays, conglomerates and calcarenites.

- **Samnitic Element**

The origin of the Samnitic Element is unclear but D'Argenio *et al* (1986) have suggested that it may be derived from a sedimentary domain that extended between the Molise and Lagonegro Basins. It has basal deposits of marl, re-sedimented calcarenites, breccias and pelagic limestones of Cretaceous - lower Tertiary age followed by quartzarenite and then lower - middle Miocene siltstones and clays.

A.1.4 Intermediate Tectonic Elements

The intermediate tectonic elements are derived from the deformation of the more external (western) sedimentary domains of the imbricate thrust belt. Consequently, they are found at a higher elevation within the thrust pile and are more severely deformed than the preceding lower tectonic elements. Four tectono-stratigraphic elements have been recognised by D'Argenio *et al* (1986) formed from the deformation of the Lagonegro Basin and the Latium-Campania-Lucania Carbonate Platform.

• Upper Lagonegro Element

The Upper Lagonegro Element has a similar facies pattern to the Lower Lagonegro Element. It is derived from the deformation of the majority of the Lagonegro Basin and is higher in the thrust pile than the Lower Lagonegro Element which was formed from only a small section of the eastern sector of the basin.

At the base are middle Triassic calcarenites, marls, sandstones and cherty limestones. Next in the sequence come cherty limestones of the late Triassic, Jurassic shales and radiolarites and Cretaceous claystones and marlstones. Finally there are marls and clays of late Cretaceous - early Tertiary age overlain by re-sedimented breccias. Resting unconformably on the Upper Lagonegro Element are deposits of the Irpinian Foredeep Basin.

• Monti della Maddalena and Monte Foraporta Elements

These units are equivalent to the Panormide Complex of Ogniben (1969) although the name was originally attached to the Mesozoic - Tertiary reef complex of the Palermo Mountains in Sicily by Trevisan (1960).

The complex is thought to have been derived from the deformation of the Latium-Campania-Lucania Carbonate Platform although controversy surrounds its origin. The Neopolitan geologists (for example, D'Argenio and Scandone, 1970; Ortolani and Torre, 1971), regard the Panormide Complex as being derived from two subsiding sectors of the Latium-Campania-Lucania Carbonate Platform originally separated by a small trench - the 'Lucania Basin'. They term these two elements (sectors) the Monti della Maddalena and Monte Foraporta Elements. The theoretical base to the arguements of the Neopolitan school is excepted by Pieri (1975). Nonetheless, Pieri argues that the difference in the facies pattern need not be the result of two carbonate shelves but could merely represent stratigraphical differences brought about by tectonic disturbance. In the discussion that follows below, the scheme of the Neopolitan school is described in detail, although the reader is requested to note the comments of Pieri (1975).

The Monte della Maddalena sequence is formed from shallow water Triassic dolomites and Jurassic limestones which are unconformably overlain by late Jurassic limestones and re-sedimented Cretaceous and early Tertiary calcarenites. Calcarenites and terrigenous sandstones of early Miocene age unconformably follow.

The Monte Foraporta sequence is similar. At the base are late Triassic - early Jurassic dolomites trending to re-sedimented late Jurassic - early Cretaceous limestones.

- **Alburno Cervati Element**

Formed from the deformation of the external sectors of the Latium-Campania-Lucania Carbonate Platform. The sequence is formed from about 4000m of middle Triassic carbonates. The Alburni Massif in Campania is part of this element.

- **Monte Bulgheria Elements**

Also formed from the external sectors of the Latium-Campania-Lucania Carbonate Platform. The element has discontinuous outcrops from Calabria to Capri. The lower part of the sequence is formed from shallow water carbonates of late Triassic - early Jurassic age. These are overlain by early Miocene calcarenites and terrigenous re-sedimented sandstones.

A.1.5 Higher Tectonic Elements

These tectonic units are the highest in the imbricate thrust belt and were the first to be deformed. Consequently they are the most chaotically disturbed and their recognition, stratigraphy and palaeogeographic origins are controversial. They are thought to derive from the deformation of the most external (western) sectors of the thrust belt (see Amodio Morelli *et al*, 1979). D'Argenio *et al* (1986) recognise three elements; the Sicilide, Liguride and Frido elements. Ogniben (1969), however, treats the Frido and Liguride elements as a separate complex (the Liguride Complex) belonging to a single tectonic unit known as the Trebisacce Nappe. This approach may be justified in Ogniben's area - the Calabria - Basilicata border regions - where the two units are indistinguishable. It is less justifiable in the context of the wider frame of the geology of the Southern Apennines, where two distinct facies patterns belonging to the Frido and Liguride elements can often be recognised.

- **Sicilide (Argille Varicolori) Elements**

These elements are the most controversial of all the tectonic elements of the Southern Apennines. D'Argenio *et al* (1986) recognise two main problems with their identification:

(i) the internal chaotic nature of their stratigraphy, brought about by intense deformation and;

(ii) their lithological similarity with deposits from the Molise and Lagonegro and Basins.

The most complete sequence of deposits is described by Cocco (1972). At the base are deep marine sediments of late Cretaceous - early Miocene age followed by variegated clays, marly clays and calcarenites. Next come marls, marly clays and calcarenites then sandstones and calcarenites of the Corleto Perticara Formation. Variegated clays and calcarenites follow and the sequence is topped by tuffites marls and limestones.

- **Frido Element**

This sequence is formed from several hundreds of metres of Cretaceous sediments, in particular schists and quartzarenites, which have been affected by low level regional metamorphism. Outcrops are found in the Cilento and southern Basilicata, where it is often known by other names - Frido Formation, Crete Nere Formation, Ascea Formation.

- **Liguride (Cilento Flysch) Element**

Ogniben (1969) considered this element to be a heterogenous sequence of terrigenous deposits over 4000m thick, lying tectonically over the Alburno Cervati Element. Recent work (Ietto, 1984) has argued that two phases of deposition can be observed. The first, termed the Crete Nere Formation is a sequence of Cretaceous black shales, fine sandstones and limestones which rests tectonically over the Frido Element. On the Basilicata - Calabria border Ogniben (1969) was unable to distinguish the Crete Nere Formation from the Frido Element. The second phase of deposition is termed the Pollica - San Mauro Formation, a 2500m thick sequence of Cretaceous - early Miocene sandstones, marls and conglomerates.

A.2 Palaeogeographic Reconstruction of the Thrust Belt

A.2.1 Introduction

It has already been noted that the present day landscapes of the Southern Apennines derive from the deformation, during the late Oligocene to the early Pliocene, of three sedimentary basins and two carbonate platforms. In order to appreciate the distribution of the tectonic elements described above, it is necessary to reconstruct the palaeogeography of the Southern Apennines thrust belt and to understand the mechanisms by which the carbonate platforms and sedimentary basins were incorporated into it during the Apennine orogeny. The section that follows will examine the pre-orogenic landscapes of the Southern Apennines; section A.2.3 looks at the way in which these landscapes were incorporated into the growing thrust pile.

A.2.2 Pre-Orogenic Landscapes of the Southern Apennines

The Apennine geosyncline was located along a promontory of the African plate known as Adria. This promontory extended from the Maghrebids of Tunisia to the Turkish Alps (Channel *et al*, 1979; Pescatore and Slaczka, 1984). During the middle - late Triassic, continental rifting began which formed a major basin - the Lagonegro Basin - in the central section of the future geosyncline (see Fig. A.1). D'Argenio and Alvarez (1980) suggest that rifting began without any apparent tectonic activity other than normal faulting. This leads the authors to believe that the subsidence of the Lagonegro Basin was nothing more than an isostatic response to crustal thinning. The assertions of D'Argenio and Alvarez (1980) are based on the crustal thinning mechanism of Bott (1971) who argued that unbalanced horizontal forces are present at the contact zone beneath crusts of different thickness (in this case Tethyan oceanic crust and African continental crust). These forces act even if the crusts are not in isostatic equilibrium. Using values for crustal density based on the work of Kinsman (1975) and Fischer (1975b) D'Argenio and Alvarez have calculated an average crustal thinning of 20.5% beneath the carbonate platforms and 44.8% beneath the sedimentary basins.

On either side of the subsiding Lagonegro Basin, shallow seas developed across shelf environments, in which formed late Triassic - early Jurassic shallow water dolomites and limestones. From late Triassic times these deposits can be recognised as two major shelves - the Latium-Campania-Lucania Carbonate Platform and the Abruzzi-Campania Carbonate Platform (see Fig. A.1).

Sedimentation of the Lagonegro Basin began shortly after its formation in the middle Triassic. The earliest recognisable sediments are terrigenous (land formed) deposits of middle Triassic age. Deposition into the Basin continued with alternations of fine-grained marls, clays and coarse-grained sandstones and calcarenites. Pescatore and Slaczca (1984) have estimated a 500m build-up of deposits during the middle Triassic, corresponding to a deposition rate of 50m/million years with a subsidence rate for the Lagonegro Basin of 200m/million years.

During the late Triassic, oceanic rifting took over from continental rifting (D'Argenio and Alvarez, 1980), along an axis located in the present Tyrrhenian Sea, east of Sardinia, although the Tyrrhenian Sea itself did not form until the late Miocene - early Pliocene (Scandone, 1979). Oceanic rifting continued throughout the middle Jurassic until the early Cretaceous (Dogger-Malm), and resulted in the formation of another sedimentary basin - the Molise Basin - and corresponding limestone platform (Apulia Carbonate Platform). A smaller basin to the east - the Gargano Basin - was formed by further oceanic rifting during the early - middle Cretaceous (see Fig. A.1).

By the end of the early - middle Cretaceous the future Apennine geosyncline had achieved its pre-orogenic form; two major sedimentary basins - the Molise and Lagonegro Basins - bordered by three shallow water carbonate platforms - the Latium-Campania-Lucania, Abruzzi-Campania and Apulia Carbonate Platforms.

Carbonate Platforms: All three carbonate platforms were areas of high sedimentation and corresponding high subsidence. Sedimentation took place in the sub-littoral zone. Each carbonate platform has a slightly different lower facies pattern (Cocco and Pescatore, 1975; Pescatore and Slaczka, 1984; Scandone, 1975).

- **Apulia Platform:** Upper Triassic - lower Jurassic evaporites and shallow water dolomites.

- **Abruzzi-Campania Platform:** Mid - upper Triassic back-reef lagoon and supratidal dolomites.

- **Latium-Campania-Lucania Platform**: Upper Triassic mainly shallow water dolomites but with some intercalations of bituminous shales, marls and dolomites.

For all three, the upper facies pattern is similar, essentially back-reef lagoon carbonates. In addition, all three carbonate platforms are characterised by thick bauxite horizons of Eocene - Oligocene (Palaeogene) age. Both the Abruzzi-Campania Carbonate Platform and Latium-Campania-Lucania Carbonate Platform have 4000m thick sequences while the Apulia Carbonate Platform has a 6000m thick sequence. Pescatore and Slaczka (1975) have estimated the sedimentation rate at about 100m per million years for all three platforms.

Basinal Domains: In contrast to the carbonate platforms, the Lagonegro and Molise Basins were areas of high subsidence but low sedimentation (Pescatore and Slaczka, 1975; Scandone, 1975). The basal sedimentation of the Lagonegro Basin in the middle Triassic has been described above. Above the basal layers (in ascending order) are cherty limestones, radiolarites (cherts with high concentrations of radiolaria protozoa), marls and calcarenites formed from flow slides emanating from the surrounding carbonate platforms. The upper facies pattern of the Lagonegro Basin (upper Oligocene - early Miocene) is formed of a >1000m sequence of Numidian flysch (Ogniben, 1969) which Pescatore and Slaczka (1984) estimate had a sedimentation rate of about 100m per million years.

The Molise Basin has been described on the basis of borehole information supplied by Pieri (1966). The basal deposits are late Triassic to early - middle Jurassic, mainly, marls, radiolarites, some volcanics and calcarenites. As with the Lagonegro Basin, flysch deposits (this time middle - upper Miocene), form the upper part of the sequence.

A.2.3 Orogenic Deformation of the Southern Apennines

The internal structure of the Southern Apennines thrust belt is largely derived from the deformation of the basinal and platform sedimentary units formed by the end of the early - middle Cretaceous.

The first interpretation of the orogenic evolution of the Southern Apennines was provided by De Lorenzo (1904). De Lorenzo argued for the autochthony of the Southern Apennines chain; that is although he recognised that the structural units had been faulted and folded, he believed that they had not been tectonically transported to any great extent. In others words, De Lorenzo envisaged that the pre-orogenic and post-orogenic distribution of the basinal and sedimentary units was similar and that the mountain-building process took place *in situ*.

While this view came to be doubted, it was not until Selli (1962) that the first complete picture of the thrust belt emerged. Selli agreed with De Lorenzo's interpretation of the autochthony of the Apulia Carbonate Platform, but recognised the existence of large thrust sheets in the Lagonegro, Cilento and northern Calabria areas. Selli also confirmed tectonic phases during the late Miocene - early Pliocene.

The tectonic phases which resulted in the Apennine orogeny, began much earlier than the late Miocene - early Pliocene (D'Argenio and Alvarez, 1980). During the middle - late Cretaceous crustal extension with oceanic rifting, gave way to crustal shortening with oceanic closing (see Fig. A.1). These movements closed the southern margin of the Tethys ocean (Fischer, 1975; Laubscher and Bernoulli, 1977; Scandone, 1975). Argano (1924) was among the earliest to postulate that the Apennine thrust belt was part of the southern margin of Tethys. Channel *et al* (1979) have argued on the basis of palaeomagnetic data, that this southern margin should be regarded as a northern extension of the African plate. This view is not supported by Lort (1971). Lort argues that the Adriatic forms a microplate (an 'Adriatic' or 'Apulian' microplate) which is moving north-west relative to the European plate (Fig. A.5). McKenzie (1972) while agreeing that the

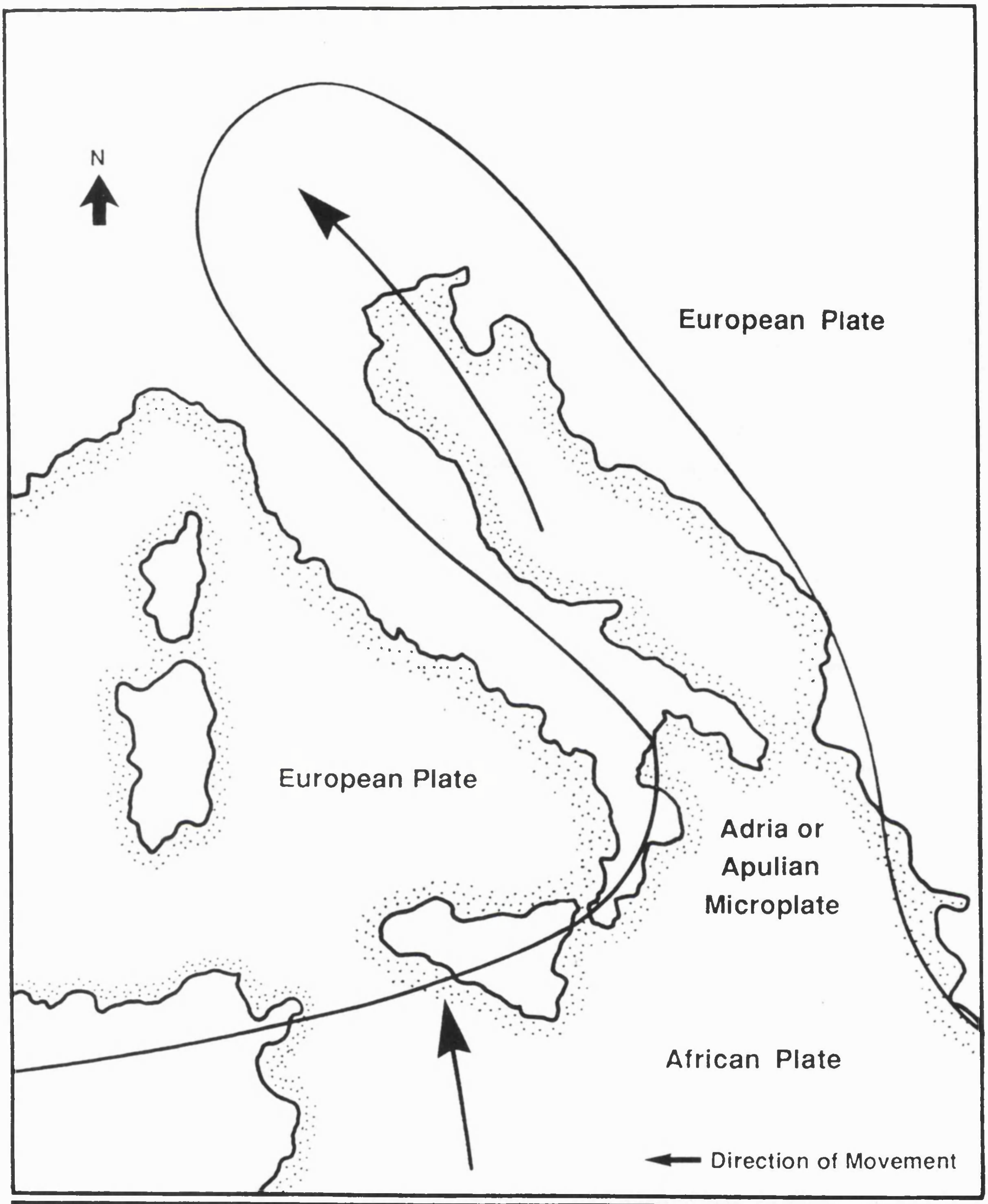


Figure A.5: Possible plate boundaries in Italy and the Adriatic with the direction of movement. The diagram is from McKenzie (1972, p.135) who argues that ' the seismicity is too weak to define the plate boundaries, and the fault plane solutions are too scattered to show the motion clearly. Hence this arrangement of plate boundaries is compatible with the [seismic] data, but may well be incorrect'. In the diagram the Adriatic is shown as a northern extension of the African Plate, although it may well form a separate microplate (see Appendix A), once again the seismicity is too weak to define it with certainty.

movement is consistent with the published fault plane solutions and work of Ritsema (1969), that is normal faulting in Italy with overthrusting in the Yugoslavian Dinarids, has argued that the data are not sufficient for an accurate plate interpretation. Nonetheless, Lort's hypothesis would not be inconsistent with either the views of Dewey *et al* (1973), who believe that Jurassic oceanic spreading gave rise to the separation of Adria from the African plate (see also D'Argenio and Alvarez, 1980), or Platt *et al* (1989). Platt *et al* used kinematic data, such as stretching lineations on mylonites and crystal fibres, to argue that the Adriatic has had a separate motion history since the late Cretaceous.

Lort's microplate hypothesis is similarly consistent with the peculiar nappe structure of the Calabria-Peloritani arc (Bonardi *et al*, (1982). This arc is part of the Apennine chain but, unlike the rest of the thrust belt, is formed of nappe structures involving the crystalline basement rocks (the Liguride Complex of Ogniben, 1969). It is delimited by the Sangineto thrust fault to the north and the Taormina line to the south (Fig. A.2). Some crystalline rocks outcrop at Episcopia in Basilicata and seem to be the northernmost outcrop of the Calabria-Peloritani basements (Ogniben, 1969). Bonardi *et al*, (1982) have advanced four explanations to account for the arc;

(i) the innermost element of the Apennine geosyncline, (this is also the view of Ogniben, 1969);

(ii) a fragment of the European plate overthrust on the emerging Apennine geosyncline;

(iii) a fragment of the African plate deformed and overthrust onto the Apennine chain or;

(iv) a remnant of the Europe verging Alpine chain deformed and incorporated into the Apennine chain.

Certainly, Bonardi *et al's* third hypothesis would not rule out the formation of the Calabria-Peloritani arc by a north-west moving microplate which had broken away from the present African plate.

Whether plate movement was confined to an Adriatic microplate or involved the entire northern margin of the African plate, oceanic closing was followed by a continent-continent collision during the late Oligocene - early Miocene (see Fig. A.1). The Latium-Campania-Lucania Carbonate Platform was downfaulted and thrust under the deformed Alpine continental margin. The early - middle Miocene saw the deformation of the Lagonegro Basin which, together with the Abruzzi-Campania Carbonate Platform, was similarly downfaulted and thrust under (or overthrust by) the growing imbricate thrust pile. The collision orogeny caused a series of north-east trending nappe structures. In addition the downfaulting of the Latium-Campania-Lucania and Abruzzi-Campania Carbonate Platforms, as well as the action of strong compressional forces, resulted in the formation of a major new basin which rested partly over the old Lagonegro and Molise Basins (Pescatore, 1978a & b).

This new basin was known as the Irpinian Basin (see Fig. A.1). The Irpinian Basin was much deeper than either the Molise or Lagonegro Basins as its genesis was the result of continental collision and subduction rather than crustal thinning. The basin is the oldest (early Miocene) foredeep basin of the Apennine orogeny although some very much smaller basins caused by the downfaulting of the Lagonegro basin can be recognised beneath it. Two sets of deposits can be recognised within the basin; the internal deposits are deep water re-sedimented sandstones and conglomerates with a thickness of several hundred metres. The deposits rest unconformably over the deformed deposits of the old Lagonegro Basin from which they derive and can be individuated chiefly by their method of deposition; the result of flow slides in the case of the Lagonegro Basin and downfaulting in the case of the Irpinian Basin. The external deposits are similar deep water re-sedimented sandstones calcarenites and marls. Ogniben (1969) has estimated that they have a depth of up to 1000m.

Repeated thrusting during the middle - late Miocene - early Pliocene, deformed further the eastern sectors of the thrust belt and gave rise to transverse faulting across the Apennine belt; the Sangineto Line is one such example. Many of these lines now show distinct neotectonic overprint (see Chapter Two). The Irpinian Basin was deformed and thrust under the growing Apennine chain. Downfaulting of the Apulia Carbonate Platform caused a series of eastward migrating foredeep basins namely, the Altavilla Foredeep, Ariano Foredeep and Bradano Foredeep (Fossa Bradanico). The imbricate thrust pile was tectonically translated over the Apulia Carbonate Platform which became the lowest element in, and acted as a foreland to, the newly formed Apennine chain.

Compressive tectonics during the middle Miocene may have effected the overall external shape of the thrust belt in the area of the Calabrian Arc. Catalano *et al*, (1976), have noted a similarity between the facies pattern of the Sicilian and Southern Apennines sedimentary units formed during the late Mesozoic - early Cenozoic. The authors have advanced two explanations to account for this:

(i) an original Jurassic feature of the southern Tethyan margin or;

(ii) a bending of the Sicilian-Apennines belt (Perityrrhenian Orocline).

Palinspastic mapping carried out by the authors has revealed palaeogeographic units of the Southern Apennines and Sicilian Apennines which are directly comparable. These units they suggest were physically continuous prior to the Apennine orogeny. A complimentary palaeomagnetic study, revealed a substantial rotation of the thrust pile during the middle Miocene - anti-clockwise in the Southern Apennines, clockwise in Sicily - relative to the stable and undeformed units of the Apulian Carbonate Platform. Consequently, Catalano *et al*, (1976) suggest the acceptance of the second hypothesis, that during the middle Miocene the thrust pile underwent a considerable rotation.

By the end of the early Pliocene the structure of the Southern Apennines was much as it is today. The Lagonegro, Molise and Irpinian Basins with their corresponding carbonate platforms had been deformed and incorporated into the imbricate thrust pile. The Apulia Carbonate Platform was relatively undeformed and acted (and still acts) as a foreland to the mountain belt. West of the Apulia Platform was the final foredeep in the orogenic belt, the Bradano Foredeep (or Fossa Bradanica), now filling with a thick sequence of Plio-Pleistocene sediments and west of that the Southern Apennines thrust belt itself.

APPENDIX B

MM

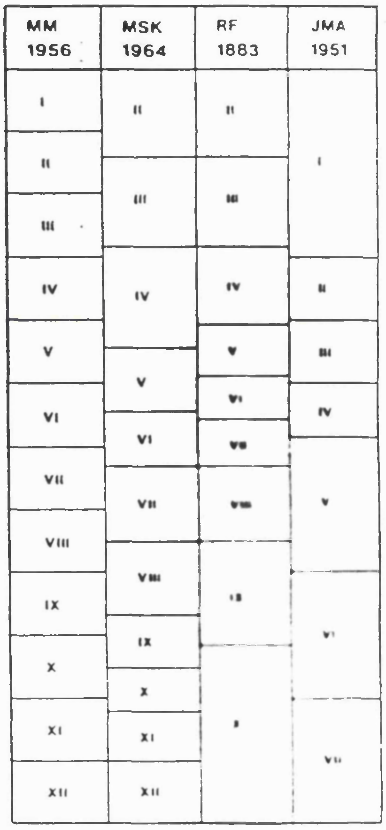
Number	Descriptive term	Effects	Acceleration cm s⁻²
I	Imperceptible	Not felt. Registered only by seismographs.	<1
II	Very slight	Felt in upper storeys solely by persons at rest.	1—2
III	Slight	Felt indoors. Vibrations like those caused by light trucks passing by.	2—5
IV	Moderate	Hanging objects swing. Vibrations like those caused by heavy trucks or a jolt such as that occasioned by a heavy object striking the wall. Parked cars are set in seesaw motion. Windows, doors and crockery rattle.	5—10
V	Fairly strong	Felt outdoors. Sleeping persons wakened. Small objects not anchored are displaced or overturned. Doors open and close. Shutters and pictures are set in motion. Pendulum clocks stop and start or change their speed.	10—20
VI	Strong	Walking is made difficult. Windows, crockery and glass break. Knick-knacks, books, etc. fall off shelves; pictures fall from the walls. Furniture moves or is overturned. Cracks in weak plaster and materials of construction type D. Small bells ring (church, school).	20—50
VII	Very strong	Noticed by car drivers and passengers. Furniture breaks. Material of construction type D sustains serious damage. In some cases, cracks in material of construction type C. Weak chimneys break at roof level. Plaster, loose bricks, stones, tiles, shelves collapse. Waves created on ponds.	50—100
VIII	Destructive	Steering of cars made difficult. Very heavy damage to materials of construction type D and some damage to materials of type C. Partial collapse. Some damage to materials of type B. Stucco breaks away. Chimney, monuments, towers and raised tanks collapse. Loose panel walls thrown out. Branches torn from trees. Changes in flow or temperature of springs. Changes in water level of wells. Cracks in moist ground and on steep slopes.	100—200
IX	Highly destructive	General panic. Material of construction type D completely destroyed. Serious damage to material of type C, and frequent collapse. Serious damage also sustained by material of type B. Frame structures lifted from their foundations, or they collapse. Loadbearing members of reinforced-concrete structures are cracked. Pipes laid below ground burst. Large cracks in the ground. In alluvial areas, water, sand and mud ejected.	200—500
X	Extremely destructive	Most masonry and wooden structures destroyed. Reinforced steel buildings and bridges seriously damaged, some of them destroyed. Severe damage to dams, dikes and weirs. Large landslides. Water hurled onto the banks of canals, rivers and lakes. Rails bent.	500—1000 ($\approx$ 1g)
XI	Disaster	All structures collapse. Even large, well-constructed bridges are destroyed or severely damaged. Only a few buildings remain standing. Rails greatly bent and thrown out of position. Underground wires and pipes break apart.	1—2 g
XII	Major disaster	Large-scale changes in the structure of the ground. Overground and subterranean streams and rivers changed in many ways. Waterfalls are created, lakes are dammed up or burst their banks. Rivers alter their courses.	>2 g

Construction method A:
Good workmanship, mortar and design; reinforced, especially laterally, and bound together using steel, concrete, etc.; designed to resist lateral forces.

Construction method B:
Good workmanship and mortar; reinforced but not designed to resist strong lateral forces.

Construction method C:
Ordinary workmanship and mortar; no extreme weaknesses such as failing to tie in at corners, but neither reinforced nor designed to resist horizontal forces.

Construction method D:
Weak materials such as adobe; poor mortar, low standards of workmanship; horizontally weak.



Intensity scales:
MM 1956 Modified Mercalli
MSK 1964 Medvedev-Sponheuer-Karnik
RF 1883 Rossi-Forel
JMA 1951 Japan Meteorological Agency

BIBLIOGRAPHY

Alexander, D. (1981): Preliminary assessment of landslides resulting from the earthquake of 23rd November 1980 in Southern Italy. **Disasters**, 5(4), 376 - 383.

Alexander, D. (1982a): In Italy: 'Creeping Disaster' Speeds Up. **Geotimes**, November 1982, 17 - 20.

Alexander, D. (1982b): Difference between "calanchi" and "biancane" badlands in Italy. In Bryan, R. and Yair, A. (eds.), **Badland Geomorphology and Piping**, Geo Books, Norwich, England. Chapter Four, 71 - 87.

Alexander, D. (1983): Earthquakes and the continuing problem of landslides in southern Italy. **Disasters**, 7(2), 88 - 90.

Alexander, D. (1984a): Housing crisis after natural disaster: the aftermath of the November 1980 southern Italian earthquake. **Geoforum**, 15(4), 489 - 516.

Alexander, D. (1984b): Building damage by landslide: the case of Ancona, Italy, 1982. **Ekistics**, 308, 452 - 462.

Alexander, D. (1985): Culture and the environment in Italy. **Environmental Management**, 9(2), 121 - 134.

Alexander, D. (1986): **Disaster Preparedness and the 1984 Earthquakes in Central Italy.** Natural Hazard Research, Working Paper No. 55, University of Colorado, Boulder.

Alexander, D. (1987): Land of disasters. **Geographical Magazine**, 226 - 231.

Alexander, D. and Rendell, H. (1986): Quality of construction, surficial geology and mass movement: the effect of the 1980 earthquake in southern Italy. **International Association of Engineering Geology. Proceedings of the International Symposium on Engineering Geology Problems in Seismic Areas**, Bari, Volume 3, 41 - 55.

Almagià, R. (1907): Studi geografici sopra le frane in Italia. **Memorie della Società Geografica Italiana,** 13, 342pp.

Almagià, R. (1910): Studi geografici sopra le frane in Italia. **Memorie della Società Geografica Italiana,** 14, 431pp.

Amodio Morelli, L., Bonardi, G., Colonna, V., Dietrich, D., Giunta, G., Ippolito, F., Liguri, V., Lorenzoni, S., Paglionico, A., Perrone, V., Picarretta, G., Russo, M., Scandone, P., Zanettin-Lorenzoni, E., and Zuppetta, A. (1979): L'arco Calabro-Peloritani nell'orogene Appenninico-Maghrebide. **Memorie della Societa Geologica Italiana,** 17, 1 - 6.

Ampferer, O. (1939): Über einige Formen der Bergzerreissung. **Sitzungsber. Akad. Wiss.,** 148, 1 - 14, Wien.

Ampferer, O. (1940): Zum weiteren Ausbau der lehre von den Bergzerreissung. **Sitzungsber. Akad. Wiss.,** 149, 51 - 70, Wien.

Andersen, J.L. and Sollid, J.L. (1971): Glacial chronology and glacial geomorphology in the marginal zones of the glaciers, Midtdalsbreen and Nigardsbreen, south Norway. **Norsk Geografisk Tidsskrift,** 25, 1 - 38.

Andrews, J.T. and Webber, P.J. (1964): A lichenometric study of the northwestern margin of the Barnes Ice Cap: A geomorphological technique. **Geographical Bulletin,** 22, 80 - 104.

Argano, E. (1924): La tectonique de l'Asia. **Proceedings of the XIII International Geological Congress, Brussels.**

Armstrong, R.A. (1974): Growth phases in the life of a lichen thallus. **New Phytologist,** 73, 913 - 918.

Arnould, M. and Frey, P. (1978): Analyse des reponses a une enquête internationale de l'Unesco sur les glissements de terrain. **International Association of Engineering Geology Bulletin**, 17, 114 - 118.

Baldassare, G. and Radina, B. (1980): Risultanze geolitologiche e morfologiche applicate alla progettazione di una variante stradale in Basilicata. **Geologia Applicata e Idrogeologia**, 15, 191 - 201.

Benedict, J.B. (1967): Recent glacial history of an alpine area in the Colorado Front Range, U.S.A. I. Establishing a lichen-growth. **Journal of Glaciology**, 6, 817 - 832.

Benedict, J.B. (1968): Recent glacial history of an alpine area in the Colorado Front Range, U.S.A. II. Dating the glacial deposits. **Journal of Glaciology**, 7, 77 - 87.

Beschel, R.E. (1950): Flechten als Altersmasstab rezenter Moränen. **Zeitschrift für Gletscherkunde und Glazialgeologie**, 1, 152 - 161. (Translated, 1973, Lichens as a measure of the age of recent moraines. **Arctic and Alpine Research**, 5, 303 - 309.

Beschel, R.E. (1957): A project to use lichens as indicators of climate and time. **Arctic**, 10(1), 60.

Beschel, R.E. (1961): Dating rock surfaces by lichen growth and its application to glaciology and physiography (lichenometry). In Raasch, G.O. (Ed.). **Geology of the Arctic**, 2, University of Toronto Press, Toronto, 1044 - 1062.

Beschel, R.E. (1965): Epipetric succession and lichen growth rates in the eastern neararctic. **International Association for Quaternary Research, 7th Imternational Congress, Boulder, Colorado, 1965.** Abstracts, General Sessions, 25 - 26.

Beschel, R.E. and Weidick, A. (1973): Geobotanical and geomorphological reconnaissance in west Greenland, 1961. **Arctic and Alpine Research,** 5, 311 - 319.

Birkeland, P.W. (1973): The use of relative dating methods in a stratigraphical study of rock glacier deposits, Mt. Sopris, Colorado. **Arctic and Alpine Research,** 5, 401 - 416.

Birkenmajer, K. (1980): Age of the Penguin Island volcano, South Shetland Islands (West Antarctica) by the lichenometric method. **Bulletin de L'académie Polonaise des Sciences, Serie des Sciences de la Terre,** 27, 69.

Birkenmajer, K. (1981): Lichenometric dating of raised marine beaches at Admiralty Bay, King George Island (South Shetland Islands, West Antartica). **Bulletin de L'académie Polonaise des Sciences, Serie des Sciences de la Terre,** 29, 119 - 127.

Bonardi, G., Cello, G., Perrone, V., Tortorici, L., Turco, E. and Zuppetta, A. (1982): The evolution of the northern sector of the Calabria - Peloritani arc in a semiquantitative palynspastic restoration. **Bolletino della Società Geologica Italiana,** 101, 259 - 274.

Bornfeldt, F. and Österborg, M. (1958): Lavarter som hjälpmedel i datering av ändmoräner vid norska glaciarer. **Stockholm Högskola, Geografiska Proseminariet,** October 1958.

Boschi, E., Pantosti, D. and Valensise, G. (1990): Paradoxes of Italian seismicity - The Irpinia earthquake of November 23, 1980. **EOS,** November 13 1990, 1787 - 1788.

Bott, M.H.P. (1971): Evolution of young continental margins and formation of shelf basins. **Tectonophysics,** 11, 319 - 327.

Bousquet, J.C. (1973): La tectonique récente de l'Apennin Calabro-Lucanien dans son cadre géologique et géophysique. **Geologica Romana,** Vol. XII.

Brancaccio, L., D'Argenio, B., Ferreri, M., Metcalf, G., Oliveri, A., Ortolani, F., Pescatore, T., Stanzione, D., Torre, M. and Vallario, A. (1979): Prospettive geotermiche e assetto strutturale dell'Appennino meridionale (Campania e Basilicata). **Commissione delle Comunità Europee, Direzione Generale della Ricerca Scientifica ed Educazione. Programma "Energia Geotermica"**, 28 - 59, Napoli.

Branno, A., Esposito, E.I.G., Marturano, A., Porfido, S. and Rinaldis, V. (1985): Studio, su base macrosismica, del terremoto della Basilicata del 16 dicembre 1857. **Bolletino della Società dei Naturalisti in Napoli**, Vol. 92, 249 - 338.

Broadbent, N.D. and Bergqvist, K.I. (1986): Lichenometric chronology and archaeological features on raised beaches: preliminary results from the Swedish north Bothnian coastal region. **Arctic and Alpine Research**, 18(3), 297 - 306.

Brogan, G.E., Cluff, L.S. and Taylor, C.L. (1975): Seismicity and uplift of southern Italy. **Tectonophysics**, 29, 323 - 330.

Brückner, H. (1982): Ausmaß von Erosion und Akkumulation im Verlauf des Quartärs in der Basilicata (Süditalien). **Zeitschrift für Geomorphologie**, 43, 121 - 137.

Brückner, H. (1983): Holozäne Bodenbildungen in den Alluvionen süditalienischer Flüsse. **Zeitschrift für Geomorphologie**, 48, 99 - 116.

Brunsden, D. and Jones D.K.C. (1972): The morphology of degraded landslide slopes in south-west Dorset. **Quarterly Journal of Engineering Geology**, 5(3), 205 - 222.

Bucknam, R.C. and Anderson, R.E. (1978): Estimation of fault-scarp ages from a scarp-height - slope-angle reationship. **Geology**, 7, 11 - 14.

Bush, P, Cooke, R.U., Brunsden, D., Doornkamp, J.C. and Jones, D.K.C. (1980): Geology and geomorphology of the Suez city region, Egypt. **Journal of Arid Environments,** 3, 265 - 281.

Caire, A. (1975): Italy in its Mediterranean setting. In Squyres, C.H. (Ed.): **Geology of Italy,** The Earth Sciences Society of the Libyan Arab Republic, Tripoli, 2 Volumes. Volume I, 11 - 74.

Calcagnile, G., Del Prete, M., Monterisi, L. and Panza, G.F. (1977): Seismic risk of Basilicata in its geostructural frame. **Bolletino di Geofisica Teorica ed Applicata,** 19(75-76), 117 - 139.

Carmignani, L., Cello, G., Cerrina Feroni, A., Funiciello, R., Kälin, O., Meccheri, M., Patacca, E., Pertusati, P., Plesi, G., Salvini, F., Scandone, P., Tortorici, L. and Turco, E. (1981): Analise del campo di fratturazione superficiale indotto dal terremoto campano-lucano del 23 novembre 1980. **Rendiconti della Societa Geologica Italiana,** 4, 451 - 465.

Carobene, L., Dai Pra, G. and Gewelt, M. (1986): Niveaux marins du Pléistocène moyen-supérieur de la côte tyrrhénienne de la Calabre (Italie méridionale. Datations $^{230}Th/^{234}U$ et tectonique récente. **Zeitschrift für Geomorphologie,** 62, 141 - 158.

Carozzo, M.T., De Visintini, G., Giorgetti, F. and Iaccarino, E. (1973): **General Catalogue of Italian Earthquakes.** CNEN, RT/PROT/73, 12.

Carrara, A. and Merenda, L. (1976): Landslide inventory in northern Calabria, southern Italy. **Geological Society of America Bulletin,** 87, 1153 - 1162.

Carrara, A., Pugliese-Carratelli, E. and Merenda, L. (1977): Computer-based data bank and statistical analysis of slope instability phenomena. **Zeitschrift für Geomorphologie**, 21, 187 - 222.

Carrara, A., Sorriso-Valvo, M. and Reali, C. (1982): Analysis of landslide form and incidence by statistical techniques, southern Italy. **Catena**, 9, 35 - 62.

Carrara, A., Agnesi, V., Macaluso, T., Monteleone, S., and Pipitone, G. (1986): Slope movements induced by the southern Italy earthquake of November 1980. **International Association of Engineering Geology, Proceedings of the International Symposium on Engineering Geology Problems in Seismic Areas,** Volume 2, 237 - 250.

Carraro, F., Dramis, F. and Pieruccini, U. (1979): Large scale landslides connected with neotectonic activity in the Alpine and Apennine ranges. **I.G.U./U.N.E.S.C.O. Commission on Geomorphological Survey and Mapping,** 15th Plenary Meeting, 7 - 15 September, 1979, Modena, Italy, 213 - 230.

Carton, A., Dramis, F. and Sorriso-Valvo, M. (1985): Earthquake induced geomorphological features. Observations after the Italian and Algerian seismic events. **Proceedings of the 1st International Conference on Geomorphology, Manchester, 15 - 21 September 1985.**

Catalano, R., Channel, J.E.T., D'Argenio, B. and Napoleone, G. (1976): Mesozoic paleogeography of the southern Apennines and Sicily. Problems of paleotectonics and paleomagnetism. **Memoire della Societa Geologica Italiana,** 15, 95 - 118.

Channel, J.E.T., D'Argenio, B. and Horvath, F. (1979): Adria, the African promontory, in Mesozoic Mediterranean palaeogeography. **Earth Science Reviews,** 15, 213 - 292.

Ciaccio, C. (1978): Tourisme et Mezzogiorno. **Mediterranée,** 3, 59 - 65.

Ciaranfi, N., Ghisetti, F., Guida, M., Iaccarino, G., Lambiase, S., Pieri, P., Rapisardi, L., Ricchetti, G., Torre, M., Tortorici, L. and Vezzani, L. (1983): **Carta Neotettonica dell'Italia Meridionale.** Consiglio Nazionale delle Ricerche, Pubblication No. 515, Bari.

Cinque, A., Lambiase, S. and Sgrusso, I. (1981): Su due faglie nell'alta valle del Sele legate al terremoto del 23 novembre 1980. **Rendiconti della Societa Geologica Italiana** , 4, 127 - 129.

Cocco, E. (1972): Torbiditi calcaree ed arenacee nelle variegate dei Monti del Sannio. **Memorie della Societa Geologica Italiana,** 2, 145 - 159.

Cocco, E. and Pescatore, T. (1975): Facies pattern of the southern Apennines flysch troughs. In Squyres, C.H. (Ed.) **Geology of Italy.** The Earth Sciences Society of the Libyan Arab Republic, Tripoli, 2 Volumes. Volume II, 289 - 303.

Cooke, R.U. and Doornkamp, J.C. (1990): **Geomorphology in Environmental Management: A New Introduction.** Oxford at the Clarendon Press, 410pp.

Cooke, R.U., Brunsden, D., Doornkamp, J.C. and Jones, D.K.C. (1982): **Urban Geomorphology in Drylands.** Oxford University Press, London, 324pp.

Costa, J.E. and Baker, V.R. (1981): **Surficial Geology: Building with the Earth.** John Wiley, New York, 498pp.

Cotecchia, V. and Melidoro, G. (1974): Some principal geological aspects of the landslides of southern Italy. **Bulletin of the International Association of Engineering Geology,** 9, 23 - 32.

Cotecchia, V., Dai Pra, G. and Magri, G. (1969): Oscillazioni tirreniane e oloceniche del livello mare nel Golfo di Taranto, corredate da datazioni col metodo del radiocarbonio. **Geologia Applicata e Idrogeologia**, 4, 93 - 147.

Cotecchia, V., Del Prete, M., Puglisi, S. and Trisorio Liuzzi, G. (1980): Studio sulle possibilità di stabilizzazione del rilievo collinare di San Arcangelo in Basilicata. **Geologia Applicata e Idrogeologia**, 15, 305 - 327.

Crescenti, U., Dramis, F., Gentili, B. and Praturlon, A. (1984): The Bisaccia landslide: A case of deep seated gravitational movement reactivated by earthquake. **Centre de Recherches en Geographie Physique de L'Environment: Association Française de Geographie Physique. Communications du Colloque, Caen, 22 - 24 March, 1984. Serie Documents du BRGM No. 83.**

D'Argenio, B. and Scandone, P. (1970): Jurassic facies patterns in the southern (Campania-Lucania) Apennines. **Coll. on Mediterranean Jurassic, Hungarian Geological Institute**, 1 - 27.

D'Argenio, B. and Alvarez, W. (1980): Stratigraphic evidence for crustal thickness changes on the southern Tethyan margin during the Alpine cycle. **Geological Society of America Bulletin**, 91(1), 681 -689.

D'Argenio, B., Ortolani, F. and Pescatore, T. (1986): Geology of the Southern Apennines. **International Association of Engineering Geology, Proceedings of the International Symposium on Engineering Geology Problems in Seismic Areas, Bari, 1986.** Geologia Applicata e Idrogeologia, Bari.

Day, M.J. (1980): Rock hardness: field assessment and geomorphological importance. **Professional Geographer**, 32, 72 - 81.

Day, M.J. and Goudie, A.S. (1977): Field assessment of rock hardness using the Schmidt test hammer. **British Geomorphological Research Group, Technical Bulletin**, 18, 19 - 29.

Debenham, N.C. and Aitken, M.J. (1984): Thermoluminescence dating of stalagmitic calcite. **Archaeometry**, 26(2), 155 - 170.

De Fiore, G. and Brando, A. (1978): **Piano di Recupero del Centro Storico di Maratea**. Comune di Maratea, Unpublished.

De Fiore, G. and Brando, A. (1985): **Piano di Recupero del Centro Storico di Maratea. Danni di Sisma, 23 Novembre 1980**. Comune di Maratea, Unpublished.

Degg, M.R. (1987): The 1985 Mexican Earthquake. **Modern Geology**, 11, 109 - 131.

Degg, M.R. (1989): Earthquake Hazard Assessment after Mexico (1985). **Disasters**, 13(3), 237 - 246.

D'Elia, B., Federico, G., Pescatore, T. and Rippa, F. (1986): Occurrence and development of a large landslide (Andretta - Italy) reactivated by the November 23, 1980, earthquake. **International Association of Engineering Geology, Proceedings of the International Symposium on Engineering Geology Problems in Seismic Areas**, Volume 2, 365 - 383.

De Lorenzo, G. (1904): **Geologie e Geografia Fisica dell'Italia Meridionale**. Laterza, Bari, 241pp.

Del Prete, M. and Petley, D.J. (1982): Case history of the main landslide at Craco, Basilicata, south Italy. **Geologia Applicata e Idrogeologia**, 17, 291 - 304.

Demek, J., Ed. (1972): **Manual of Detailed Geomorphological Mapping**. Academia Prague, 368pp.

Deschamps, A. and King, G.C.P. (1983): The Campania-Lucania (southern Italy) earthquake of 23 November 1980. **Earth Planetary Science Letters**, 62, 296 - 304.

Desio, A., Ed. (1973): **Geologia dell'Italia**. Utet, Turin.

De Stefano, A. (1978): **Maratea: Studio Geotecnico**. Comune di Maratea, Unpublished.

Dewey, J.F., Pitman III, W.C., Ryan, W.B.F. and Bonnin, J. (1973): Plate tectonics and the evolution of the Alpine system. **Geological Society of America Bulletin**, 84, 3137 - 3180.

Doornkamp, J.C. (1984): **Applied Geography**. Nottingham Monographs in Applied Geography, No.1., University of Nottingham, 53pp.

Doornkamp, J.C., Brunsden, D., Jones, D.K.C., Cooke, R.U. and Bush, P.R. (1979): Rapid geomorphological assessments for engineering. **Quarterly Journal of Engineering Geology**, 12, 189 - 204.

Doornkamp, J.C., Brunsden, D. and Jones, D.K.C, (1980): **Geology, Geomorphology and Pedology of Bahrain**. Geo Books, Norwich.

Dramis, F., Prestininzi, A., Cognigni, L., Genevois, R. and Lombardi, S. (1982): Surface fractures connected with the southern Italy earthquake (November 1980) - distribution and geomorphological implications. **Proceedings 4th International Congress, International Association of Engineering Geology**. New Delhi, VIII.55 - VIII.66.

Dramis, F. and Sorriso-Valvo, G.M. (1983): Two cases of earthquake-triggered gravitational spreading in Algeria and in Italy. **Rendiconti della Societa Geologica Italiana**, 6, 7 - 10.

Eichinger, L. and Rauert, W. (1981): Large-volume liquid scintillation counting of environmental ^{14}C (using the C02 absorption technique) and 3H in water. In: **Methods of Low Level Counting and Spectrometry,** International Atomic Energy Association, Vienna, 497 - 510.

Eichinger, L., Rauert, W., Salvamoser, J. and Wolf, M. (1980): Large-volume liquid scintillation counting of carbon-14. **Radiocarbon,** 22, 417 - 427.

Evans, D.J.A. and Rogerson, R.J. (1986): Glacial geomorphology and chronology in the Selamiut Range - Nachvak Fjord area, Torngat mountains, Labrador. **Canadian Journal of Sciences,** 23(1), 66 - 76.

Fairbridge, R. (1973): Friends of the Mediterranean Quaternary visit type sections. **Geotimes,** 18(11), 21 - 26.

Faure, G. (1986): **Principles of Isotope Geology.** John Wiley, New York, 589pp.

Fischer, A.G. (1975): Tethys. In Squyres, C.H. (Ed.) **Geology of Italy.** The Earth Sciences Society of the Libyan Arab Republic, Tripoli, 2 Volumes. Volume I, 1 - 9.

Fischer, A.G. (1975): Origin and growth of basins. In Fischer, A.G. and Judson, S. (Ed.), **Petroleum and Global Tectonics.** Princetown, New Jersey, Princetown University Press, 47 - 79.

Fletcher, B. (1967): **A History of Architecture on the Comparative Method.** Seventeenth Edition (Revised by Cordingley, R.A.), Athlone Press, University of London.

Forcella, F. (1984): The sackung between Mount Padrio and Mount Varadega, central Alps, Italy: A remarkable example of slope gravitational tectonics. **Méditerranée,** 51(1 - 2), 81 - 92.

Forti, P. and Postpischl, D. (1986): May the growth axis of stalagmites be considered as recorders of historic and prehistoric earthquakes? preliminary results from the Bologna karst area (Italy). **International Association of Engineering Geology, Proceedings of the International Symposium on Engineering Geology Problems in Seismic Areas**, Volume 1, 183 - 193.

Fulton, A.R.G., Jones, D.K.C. and Lazzari, S. (1986): The rôle of geomorphology in post-disaster reconstruction: The case of Basilicata, southern Italy. In Gardiner, V. (ed.): **International Geomorphology 1986 - Proceedings of the First International Conference on Geomorphology, Manchester, September 1985**, Part I, 241 - 262, John Wiley.

Gardiner, V. and Dackombe, R. (1983): **Geomorphological Field Manual**, 254pp, London.

Geological Society of London (1972, 1983): Working Party Reports on Land Surface Evaluation. **Quarterly Journal of Engineering Geology**, 15, 1 - 168.

Ghisetti, F. (1981): Upper Pliocene - Pleistocene uplift rates as indicators of neotectonic pattern: an example from southern Calabria (Italy). **Zeitschrift für Geomorphologie**, Supplement 40 (Neotectonics), 93 - 118.

Giorgetti, F. and Iaccarino, E. (1971): **Italian Earthquake Catalogue from the Christian Age up to 1968**. Contr. N.201 BIS O.G.S., Trieste.

Gordon, J.E. and Sharp, M. (1983): Lichenometry in dating recent glacial landforms and deposits, south-east Iceland. **Boreas**, 12, 191 - 200.

Guerricchio, A. and Melidoro, G.(1979): Deformazioni gravitative profonde del tipo "sackung" nei monti di Maratea (Lucania). **Geologia Applicata e Idrogeologia**, 14, 13 - 22.

Guerricchio, A. and Melidoro, G. (1981): Movimenti di massa pseudo-tettonici nell'Appennino dell'Italia meridionale. **Geologia Applicata e Idrogeologia,** 16, 251 - 294.

Guerricchio, A., Melidoro, G. and Rizzo, V. (1986a): Slope stability and earthquakes in the valley of Maratea (Basilicata Region, Italy). **International Association of Engineering Geology, Proceedings of the International Symposium on Engineering Geology Problems in Seismic Areas,** Bari, April 1986.

Guerricchio, A., Melidoro, G. and Rizzo, V. (1986b): Prime osservazioni strumentali delle deformazioni dei pendii e delle manifestazioni profunde nella valle di Maratea (Basilicata, Italia). **Geologia Technica,** 4, 35 - 48.

Guerricchio, A., Melidoro, G. and Rizzo, V. (1987): Sulla dinamica geomorfologica recente ed attuale delle valle di Maratea (Lucania). **Bolletino della Societa Geologica Italiana**, 106, 293 - 302.

Gupta, S.K. and Pollach, H.A. (1985): **Radiocarbon Dating Practices at ANU.** Radiocarbon Laboratory, Research School of Pacific Studies, Australian National University, Canberra.

Haines-Young, R.H. (1983): Size variation of *Rhizocarpon* on moraine slopes in southern Norway. **Arctic and Alpine Research,** 15, 295 - 305.

Halcrow Middle East (1977): **Report on Geomorphological Investigations in Dubai, April 1977.** Report prepared by Jones, D.K.C., Brunsden, D., Doornkamp, J.C., Bush, P.R. and Gibbons, M.J.

Hale, M.E. (1974): **The Biology of Lichens.** Second Edition, Edward Arnold, London, 181pp.

Harrison, J.V. and Falcon, N.L. (1936): Gravity collapse structures as exemplified in south-western Persia. **Quarterly Journal of the Geological Society of London**, 92, 91 - 102.

Hearn, G.J. and Fulton, A.R.G. (1986): Hazard assessment techniques for planning purposes: a review. In Culshaw, M.G. (ed.): **Planning and Engineering Geology**, Engineering Group of the Geological Society of London, 351 - 366.

Hennig, G.J., Bangert, U., Herr, W. and Poulianos, A. (1980): Uranium series dating and thermoluminescence ages of spelaeothem from Petralona Cave. **Anthropos**, 7, 174 - 214.

Hennig, G.J., Herr, W., Weber, E. and Xirotiris, N.I. (1981): ESR dating of the fossil hominid cranium from Petralona Cave, Greece. **Nature**, 292, 533 - 536.

Hobbs, B.E., Means, W.D. and Williams, P.F. (1976): **An Outline of Structural Geology**. John Wiley and Sons, New York.

Holmes, G. and Jarvis, J.J. (1985): Large scale toppling within a sackung type deformation at Ben Attow, Scotland. **Quarterly Journal of Engineering Geology**, 18(3), 287 - 289.

Hughes, R.E. (1981): Field survey techniques for estimating the normal performance of vernacular buildings prior to earthquakes. **Disasters**, 5(4), 411 - 417.

Hutchinson, J.N. and Del Prete, M. (1986): Landslides at Calitri. **Geologia Applicata e Idrogeologia**, 20(1), 9 - 38.

Ietto, A., Calcaterra, D., Del Re, M.C., Giani, A. and Pappone, G. (1984): Il Flysch del Cilento nella catena Appenninica. **Sci. Geol. Bull.**, 37(2), 107 - 118.

Ikeya, M. (1983): A trip to an interdisciplinary: Electron Spin Resonance (ESR) dating in archaeology and geology. **Jeol News**, 19^{A}, 26 - 30.

Ikeya, M. (1985): Dating methods of Pleistocene deposits and their problems: IX - Electron Spin Resonance. In Rutter, N.W. (ed.): **Dating Methods of Pleistocene Deposits and their Problems**, Geoscience Canada, Reprint Series 2, Geological Association of Canada.

Ikeya, M. and Miki, T. (1980): A new dating method with a digital ESR. **Naturwissenschaften**, 67, 191 - 192.

Ikeya, M., Miki, T. and Tanaka, K. (1982): Dating of a fault by Electron Spin Resonance on intrafault materials. **Science**, 215, 1392 - 1393.

Ikeya, M., Miki, T., Tanaka, K., Sakuramoto, Y. and Ohmura, K. (1983): ESR daing of faults at Rokko and Atotsugawa. **Pact Journal**, 9, 411 - 419.

Innes, J.L. (1982): **Debris flow activity in the Scottish Highlands**. Unpublished Ph.D. thesis, University of Cambridge.

Innes, J.L. (1983): The development of lichenometric dating curves for Highland Scotland. **Transactions of the Royal Society of Edinburgh Earth Sciences**, 74, 23 - 32.

Innes, J.L. (1984): The optimal sample size in lichenometric studies. **Arctic and Alpine Research**, 16, 233 - 244.

Innes, J.L. (1985): Lichenometry. **Progress in Physical Geography**, 9(2), 187 - 254.

Ippolito, F., D'Argenio, B., Pescatore, T. and Scandone, P. (1975): Structural-stratigraphic units and tectonic framework of the Southern Apennines. In Squyres, C.H. (ed.): **Geology of Italy.** The Earth Sciences Society of the Libyan Arab Republic, Tripoli. Two Volumes, Volume 2, 317 - 328.

Ivanovich, M. and Harmon, R.S. (1982): **Uranium Series Disequilibrium; Application to Environmental Problems.** Oxford University Press, Oxford.

Jochimsen, M. (1966): Ist die Grösse des Flechtenthallus wirklich ein brauchbarer Masstab zur Datierung von glazialmorphologischen Relikten. **Geografiska Annaler,** 48^{A}, 157 - 164. (Translated, 1973: Does the size of lichen thalli really constitute a valid measure for dating glacial deposits? **Arctic and Alpine Research,** 5, 417 - 424).

Karlen, W. (1973): Holocene glacier fluctuations and climatic variations in the Kebnekaise Mountains, Swedish Lapland. **Geografiska Annaler,** 55^{A}, 29 - 63.

Karlen, W. (1979): Glacier fluctuations in the Svartisen area, north Norway. **Geografiska Annaler,** 61^{A}, 11 - 28.

Kenney, C. (1984): Properties and behaviours of soils relevant to slope instability. In Brunsden, D. and Prior, D.B. (eds.): **Slope Instability,** John Wiley and Sons, Chichester.

Kershaw, K.A. (1983): The thermal operating environment of a lichen. **Lichenologist,** 15, 191 - 208.

King, R. (1968): **Land Reform: The Italian Experience.** Butterworth, London.

King, R. (1987): Italy. In Clout, H.D. (ed): **Regional Development in Western Europe,** Third Edition, Chapter 7, 129 - 163, David Fulton Publishers.

Kinsman, D.J.J. (1975): Rift valley basins and sedimentary history of trailing continental margins. In Fischer, A.G. and Judson, S. (ed): **Petroleum and Global Tectonics,** Princetown University Press, Princetown, New Jersey, 83 - 126.

Lagorio, H.J. and Mader, G.G. (1981): **Earthquake in Campania-Basilicata, Italy, November 23, 1980. Architectural and Planning Aspects.** Earthquake Engineering Research Institute, Berkeley, California.

Lamarca, G. (1986): **Racconto Storico Fotografico di Maratea - 1884 - 1986.** Centro Culturale di Maratea, 2[A] Edizione, 398pp.

Laubscher, H.P. and Bernoulli, D. (1977): Mediterranean and Tethys. In Nairn, A.E.M., Stehli, F.G. and Kanes, W. (eds.): **The Ocean Basins and Margins: 4.B. - The Eastern Mediterranean.** Plenum Press, London, 1 -28.

Levi, C. (1945): **Christo si è fermato a Eboli.** Einaudi, Turin, 222pp. (Translated into English, 1982: **Christ Stopped at Eboli,** Penguin Books, 253pp).

Lindsay, D.C. (1973): Estimates of lichen growth rates in the maritime Antarctic. **Arctic and Alpine Research,** 5, 341 - 346.

Locke, W.W. III, Andrews, J.T. and Weber, P.J. (1979): **A Manual for Lichenometry.** British Geomorphological Research Group, Technical Bulletin, 26, 47pp.

Lort, J.M. (1971): The tectonics of the eastern Mediterranean: A geophysical review. **Reviews of Geophysics and Space Physics,** 9(2), 189 - 216.

Mallet, R. (1862): **The Great Neopolitan Earthquake of 1857: The First Principles of Observational Seismology.** Chapman and Hall, London.

Mather, K. (1961): Competition and co-operation. In Milthorpe, M.L. (ed.): **Mechanisms in Biological Competition,** Symposia of the Society for Experimental Biology, 15, 264 - 281.

Matthews, J.A. (1973): Lichen growth on an active medial moraine, Jotunheimen, Norway. **Journal of Glaciology,** 65, 305 - 313.

Matthews, J.A. (1974): Families of lichenometric dating curves from the Storbreen gletschervorfeld, Jotunheimen, Norway. **Norsk Geografisk Tidsskrift,** 28, 215 - 235.

Matthews, J.A. (1975): Experiments on the reproducibility and reliability of lichenometric dates, Storbreen gletschervorfeld, Jotunheimen, Norway. **Norsk Geografisk Tidsskrift,** 29, 97 - 109.

Matthews, J.A. (1977): A lichenometric test of the 1750 end-moraine hypothesis: Storbreen gletschervorfeld, southern Norway. **Norsk Geografisk Tidsskrift,** 31, 129 - 136.

Matthews, J.A. (1980): Some problems and implications of 14C dates from a podzol buried beneath an end-moraine at Haugabreen, southern Norway. **Geografiska Annaler,** 62^A, 185 - 208.

Matthews, J.A. and Shakesby, R.A. (1984): The status of the 'Little Ice Age' in southern Norway: Relative dating of neoglacial moraines with Schmidt Hammer and lichenometry. **Boreas,** 13(3), 333 - 346.

Matthews, J.A., Dawson, A.G. and Shakesby, R.A. (1986): Lake shoreline development, frost weathering and rock platform erosion in an alpine periglacial environment, Jotunheimen, southern Norway. **Boreas,** 15(1), 33 - 50.

McKenzie, D. (1972): Active tectonics of the Mediterranean region. **Geophysical Journal of the Royal Astronomical Society,** 30, 109 - 185.

Miki, T. and Ikeya, M. (1982): Physical basis of fault dating with ESR. **Naturwissenschaften,** 69, 390 - 391.

Miyanishi, K., Hoy, A.R. and Cavers, P.B. (1979): A generalized law of self-thinning in plant populations (self thinning in plant populations). **Journal of Theoretical Biology,** 78, 439 - 442.

Mottershead, D.N. and White. I.D. (1972): The lichenometric dating of glacier recession, Tunsbergdal, southern Norway. **Geografiska Annaler,** 54^{A}, 47 - 52.

Mottershead, D.N. and White. I.D. (1973): Lichen growth in Tunsbergdal - a confirmation. **Geografiska Annaler,** 54^{A}, 143 - 145.

Mountjoy, A. (1973): **The Mezzogiorno.** Oxford University Press, Oxford.

Munsell Color (1975): **Munsell Soil Color Charts.** Munsell Color (Kollmorgen Corp.), Baltimore.

Nikonov, A.A. and Shabalina, T.Yu. (1979): Lichenometry and earthquake age determination in central Asia. **Nature,** 280, 675 - 677.

Nossin, J.J. (1973): Use of air photographs in studies of slope stability in the Crati basin (Calabria, Italy). **Geologia Applicata e Idrogeologia,** 8(1), 261 - 287.

Nydal, R., Lövseth, K., Skullerud, K.E. and Holm, M. (1964): Trondheim Natural Radiocarbon Measurements IV. **Radiocarbon,** 6, 280 - 290.

Ogniben, L. (1969): Schema introduttivo alla geologia del confine Calabro-Lucano. **Memorie della Societa Geologica Italiana,** 8, 453 - 763.

Ogniben, L. and Vezzani, L. (1975): Nappe structure in Sicily, Calabria and Lucania, Italy. In Squyres, C.H. (Ed.): **Geology of Italy**, The Earth Sciences Society of the Libyan Arab Republic, Tripoli, 2 Volumes. Volume II, 83 - 104.

Orombelli, G. and Porter, S.C. (1983): Lichen growth curves for the southern flank of the Mont Blanc massif, western Italian Alps. **Arctic and Alpine Research**, 15(2), 193 - 200.

Ortolani, F. and Torre, M. (1971): Il Monte Alpi (Lucania) nella paleogeografia dell'Appennino meridionale. **Bolletino della Societa Geologica Italiana**, 90, 213 - 248.

Paganelli, F. and Puglisi, S. (1973): Stabilization of landslides in the River Noce basin (Basilicata). **Geologia Applicata e Idrogeologia**, 8(1), 331 - 342.

Pentecost, A. (1980): Aspects of competition in saxicolous lichen communities. **The Lichenologist**, 12, 135 - 144.

Pescatore, T. (1978a): The Irpinids: A model of tectonically controlled fan and base-of-slope sedimentation in southern Italy. In Stanley, D.J. and Kelling, G. (eds.): **Sedimentation in Submarine Canyons, Fans and Trenches**, Dowden, Hutchinson and Ross, Stroudsbourg, Pennsylvania, 325 - 339.

Pescatore, T. (1978b): Evoluzione tettonica del bacino Irpino (Italia Meridionale) durante il Miocene. **Bolletino della Societa Geologica Italiana**, 97, 783 - 805.

Pescatore, T. and Slaczka, A. (1984): Evolution models of two flysch basins: The Northern Carpathians and Southern Apennines. **Tectonophysics**, 106, 49 - 70.

Pieri, M. (1966): Tentativo di ricostruzione paleogeografico-strutturale dell'Italia centro-meridionale. **Geologica Roma**, 5, 407 - 424.

Pieri, M. (1975): An outline of Italian geology. In Squyres, C.H. (Ed.): **Geology of Italy,** The Earth Sciences Society of the Libyan Arab Republic, Tripoli, 2 Volumes. Volume I, 75 - 142.

Platt, J.P., Behrmann, J.H., Cunningham, P.C., Dewey, J.F., Helman, M., Parish, M., Shepley, M.G., Wallis, S. and Weston, P.J. (1989): Kinematics of the Alpine Arc and the motion history of Adria. **Nature,** 337, 158 - 161.

Porter, S.C. and Orombelli, G. (1981): Alpine rockfall hazards. **American Scientist,** 69, 67 - 75.

Proctor, M.C.F. (1983): Sizes and growth rates of the lichen *Rhizocarpon geographicum* on the moraines of the glacier Valsorey, Valais, Switzerland. **Lichenologist,** 15, 249 - 262.

Radbruch-Hall, D.H., Varnes, D.J. and Savage, W.Z. (1976): Gravitational spreading of steep-sided ridges «sackung» in the western United States. **Bulletin of the International Association of Engineering Geology,** 14, 23 - 35.

Regione Basilicata (1978): **Opere di Consolidamento Abitati, Abitato di Maratea.** Report N°. 1492, March 1978, Ufficio del Genio Civile di Potenza.

Rendell, H. (1985): Earthquake damage in Tricarico, southern Italy. **Environmental Management,** 9(4), 289 - 302.

Renfrew, C. (1976): **Before Civilization: The Radiocarbon Revolution and Prehistoric Europe.** Penguin Books, 320pp.

Richter, C.F. (1958): **Elementary Seismology.** W.H. Freeman, San Francisco.

Ritsema, A.R. (1969): Seismic data of the west Mediterranean and the problem of organization. **Verhand. Kon. Ned. Mijnbouwk. Gen.,** 26, 105.

Rizzo, V. and Tzvetkov, S. (1984): Complex movements in deep block-type landslides. **C.N.R. - P.A.N. Meeting, Progress in Mass Movement and Sediment Transport Studies: Problems of Recognition and Prediction,** Consiglio della Ricerche Nazionale, Turin.

Savigear, R.A.G. (1965): A Technique of Morphological Mapping. **Annals of the Association of American Geographers,** 55, 514 - 538.

Scandone, P. (1975): The preorogenic history of the Lagonegro Basin (Southern Apennines). In Squyres, C.H. (Ed.): **Geology of Italy,** The Earth Sciences Society of the Libyan Arab Republic, Tripoli, 2 Volumes. Volume II, 305 - 315.

Scandone, P. (1979): Origin of the Tyrrhenian Sea and Calabrian Arc. **Bolletino della Societa Geologica Italiana,** 98, 27 - 34.

Schwarcz, H.P. (1980): Absolute age determination of archaeological sites by Uranium Series dating of travertines. **Archaeometry,** 22, 3 - 24.

Selli, R. (1962): Il palaeogene nel quadro della geologia del'Italia centro-meridionale. **Memorie della Societa Geologica Italiana,** 3, 737 - 789.

Spooner, D.J. (1984): The Southern Problem, the Neopolitan Problem and Italian regional policy. **Geographical Journal,** 150(1), 11 - 26.

Squyres, C.H., Ed. (1975): **Geology of Italy,** The Earth Sciences Society of the Libyan Arab Republic, Tripoli, 2 Volumes.

Steel, J. (1983): **A Study of Lichen Competition on Contrasting Glacial Forelands in Norway: Implications for Lichenometry.** Unpublished B.A. Dissertation, University of Nottingham.

Stoppelli, P. (1982): **Maratea Greca - Maratea Romana, Ipotesi Storiche Attraverso La Toponomastica.** Quaderno N°.4, Centro Culturale di Maratea.

Ten Brink, N.W. (1973): Lichen growth rates in west Greenland. **Arctic and Alpine Research**, 5, 323 - 331.

Topham, P.B. (1977): Colonization, growth, succession and competition. In Seaward, M.R.D. (ed.), **Lichen Ecology**, London, Academic Press, 31 - 68.

Trevisan, L. (1960): **Elementi di Geologia.** Fourth Edition, Vallerini, E.S., Pisa, 406pp.

Trudgill, S.T., Crabtree, R.W. and Walker, P.J.C. (1979): The age of exposure of limestone pavements - a pilot lichenometric study in Co. Clare, Eire. **Transactions of the British Cave Research Association**, 6(1), 10 - 14.

Varnes, D.J. (1978): Slope Movement Types and Processes. In Schuster, R.L. and Krizek, R.J (eds.), **Landslides - Analysis and Control**, Washington D.C., National Academy of Science, 243pp. (Transport Research Board, Special Report N°. 176).

Vassalluzzo, M. (1987): **Maratea.** Matonti, Salerno, 64pp.

Verstappen, H. Th. and van Zuidam, R.A. (1968): I.T.C. System of Geomorphological Mapping. **I.T.C. Textbook of Photo Interpretation (Delft)**, Ch. VIII 2, 49pp.

Vita-Finzi, C. (1969): Late alluvial chronology of Iran, **Geologische Rundschau**, 58, 951 - 973.

Vita-Finzi, C. (1975): Quaternary deposits in the Iranian Makran. **Geographical Journal**, 141, 415 - 420.

Vita-Finzi, C. (1983): First-Order ^{14}C dating of Holocene molluscs. **Earth and Planetary Science Letters**, 65, 389 - 392.

Vita-Finzi, C. (1986): **Recent Earth Movements: An Introduction to Neotectonics.** London, Academic Press, 226pp.

Vita-Finzi, C. (1987): Precision, accuracy and usefulness. **Geology Today,** November - December 1987, p.190.

Vita-Finzi, C. and Ghorashi, M. (1978): A recent faulting episode in the Iranian Makran. **Tectonophysics,** 44, T21 - T25.

Wallace, R.E. (1977): Profiles and ages of young fault scarps, north-central Nevada. **Geological Society of America Bulletin,** 88, 1267 - 1281.

Waters, R.S. (1958): Morphological Mapping. **Geography,** 43, 10 - 17.

Westaway, R. and Jackson, J. (1984): Surface faulting in the southern Italian Campania-Basilicata earthquake of 23 November 1980. **Nature,** 312, 436 - 438.

Whitten, D.G.A. and Brooks, J.R.V. (1985): **Dictionary of Geology,** Penguin Books, 516pp.

Winchester, V. (1984): A proposal for a new approach to lichenometry. **British Geomorphological Research Group, Technical Bulletin No.33 (Shorter Technical Methods (v)),** 3 - 20.

Winchester, V. (1988): An assessment of lichenometry and a method for dating recent stone movements at two stone circles in Cumbria and Oxfordshire. **Botanical Journal of the Linnean Society,** 96, 57 - 68.

Worsley, E.D. (1970): An initial application of a lichenometric dating technique to Austre Okstindbre. In Worsley, P. (ed.), **Okstindan Research Project, 1968, Preliminary Report,** University of Reading, Reading, 32 - 38.

Worsley, P. (1981): Lichenometry. In Goudie, A. (ed.), **Geomorphological Techniques**, British Geomorphological Research Group, Allen and Unwin, London, 302 - 305.

Yaalon, D.H. and Singer, S. (1974): Vertical variation in strength and porosity of calcrete (Nari) on chalk, Shefela, Israel and interpretation of its origin. **Journal of Sedimentary Petrology**, 44, 1016 - 1023.

Zaruba, Q. and Mencl, V. (1982): **Landslides and their Control**. Developments in Geotechnical Engineering, 31, Elsevier, New York.

Zischinsky, U. (1966): On the deformation of high slopes. **International Congress on Rock Mechanics**, Lisbon, 2, 175 - 185.

Zischinsky, U. (1969a): Über Bergzerreissung und Talzuscub. **Geologische Rundschau**, 58, 974 - 983.

Zischinsky, U. (1969b): Über Sackungen. **Rock Mechanics**, 1, 30 - 52.