GEOMORPHOLOGY OF THE CAPE PENINSULA

by

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The Cape Peninsula as seen from Bokbaai on the west coast north of Cape Town.

(Frontispiece)

"The flight of time is measured by the weaving of composite rhythms --- day and night, calm and storm, summer and winter, birth and death --- such as these are sensed in the brief life of man. But the career of the earth recedes into a remoteness against which these lesser cycles are as unavailing for the measurement of that abyss of time as would be for human history the beating of an insect's wing."

BARRELL, J., 1917

PREFACE

This study originated as a result of a number of Geography field courses which were conducted by the writer around the Cape Peninsula with matric students at first, and subsequently with students at Training College level.

Whilst preparing for these field courses many questions arose and these, together with those posed by the students --- both in the classroom and in the field --- prompted this attempt at formulating answers to some of them. This study makes no claims to being a definitive work. If, in the process of attempting to answer some questions new ones are raised, then some useful purpose would have been served by this attempt.

It gives the writer great pleasure to make the following acknowledgements. The writer wishes to express his sincere thanks to Professor R. Davies for making facilities available to him within the Geography Department. The writer is also deeply grateful to Dr. L.L.H. Impey who supervised the work, for his constructive ideas, criticism, guidance, meticulous approach to scholarship, his insistence upon finding the motte juste, and long hours spent in discussion.

It is apparent that the sections of this study which entailed fieldwork could not have been carried out unaided. For this reason the writer wishes to record his sincere thanks and appreciation to two of his ex-students, now colleagues in the teaching profession. Firstly, the writer wishes to thank Mitchell Clark who literally covered kilometres upon kilometres carrying the zero end of the steel measuring tape, together with the staff for use with the Abney Level. The writer is also greatly indebted to

Stemray Lesch who accompanied him on numerous occasions, and who was responsible for taking the photographs.

The writer also wishes to express his heartfelt thanks to his long-suffering family, and in particular to his wife Lilian for her unflagging interest, constant encouragement and support.

....

This study is gratefully dedicated to the memory of my parents.

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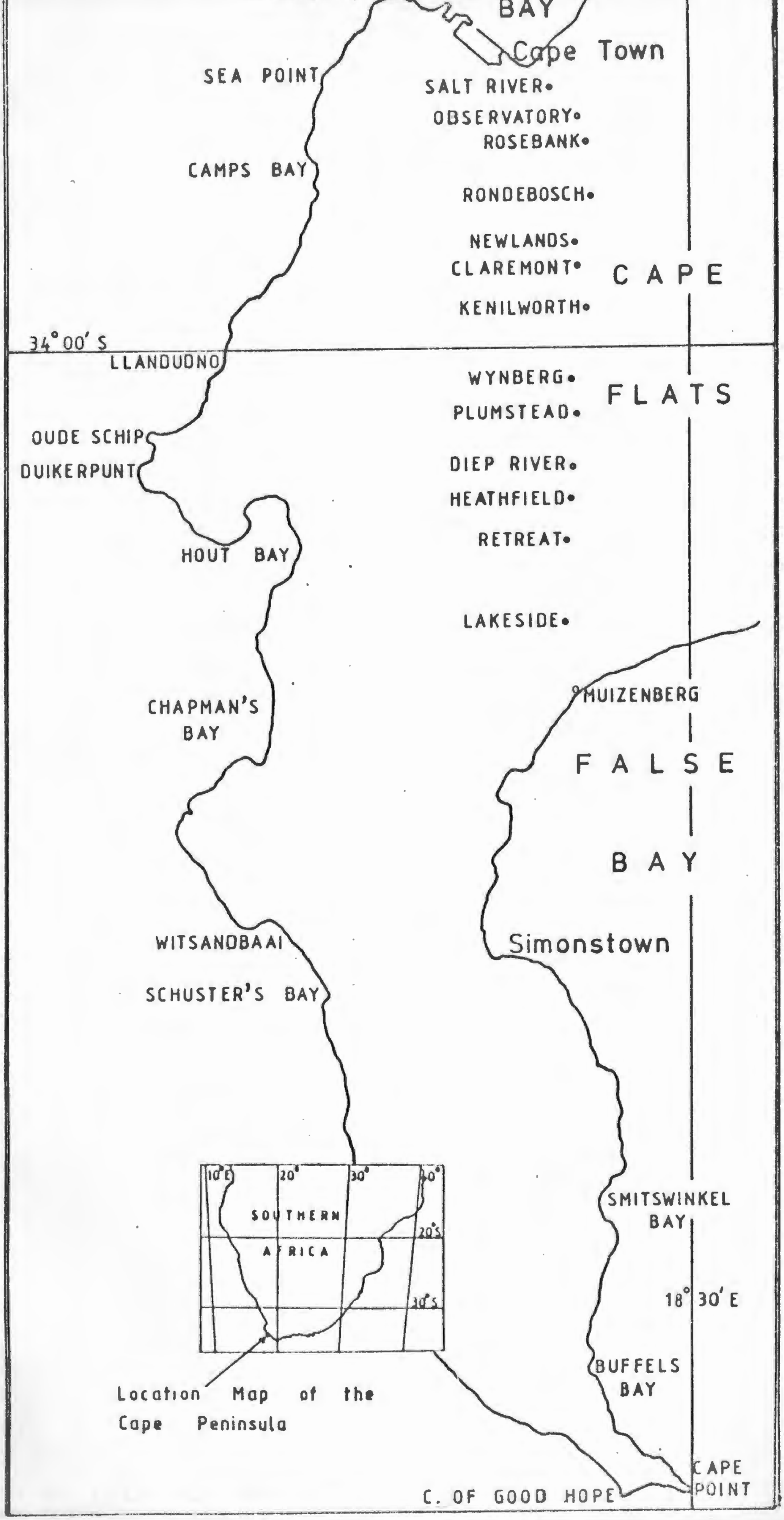
BAY
Cape Town
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ROSEBANK
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RONDEBOSCH
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CLAREMONT
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KENILWORTH
34° 00′ S
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WYNBERG
FLATS
PLUMSTEAD
OUDE SCHIP
DUIKERPUNT
DIEP RIVER
HEATHFIELD
RETREAT
HOUT BAY
LAKESIDE
MUIZENBERG
CHAPMAN'S BAY
FALSE
BAY
WITSANDBAAI
Simonstown
SCHUSTER'S BAY
10°E
20°
30°
40°
SOUTHERN AFRICA
20°S
30°S
SMITSWINKEL BAY
18° 30′ E
BUFFELS BAY
Location Map of the Cape Peninsula
CAPE POINT
C. OF GOOD HOPE

INTRODUCTION

The Cape Peninsula is distinctive in many ways. Apart from being ...."a most stately thing, and the fairest Cape in the whole circumference of the earth," and stretching like a curved finger into the Atlantic Ocean, it also possesses characteristic physical features such as the plateau-and-scarp topography plus a magnificient coastline.

The areal matrix stretches from 33° 54' S. to 34° 22' S. and from Duikerpunt, 18° 18' in the west to where the sands of the Cape Flats begin in the east. The study area encompasses amongst others, suburbs such as Woodstock, Observatory, Rondebosch, Newlands, Kenilworth and Diep River through to Muizenberg. The eastern section of the Peninsula is bounded by Table Bay in the north and False Bay in the south. The western margin is circumscribed by the Atlantic Ocean.

It is axiomatic that we live in a world characterized by opposites. We are thus aware of day and night, winter and summer, uplift and subsidence, lithosphere and hydrosphere, upland and lowland areas, past and present ----- the list is endless. This dichotomy or ambivalence is present in this study as well. On the one hand it attempts to trace the genesis and geomorphic history of the areal matrix, and on the other it looks at the contemporary landscape and the changes wrought through time. The writer is of the opinion that the past cannot be ignored, since the present physical landscape can be explained only in the context of geomorphic evolution. This is generally acceptable since today is the child of yesterday and the father of tomorrow.

Other aspects which are examined include evidence of changes wrought in the past in the form of denudation or erosion surfaces, the relationship between the underlying geological structure and present landforms, together with the strong structural and directional control which is manifested within the study area. Present drainage patterns are examined, whilst the role played by running water and the sea in creating and changing the physical landscape is a theme which runs through the greater part of this dissertation.

CHAPTER 1

GENESIS OF THE AREAL MATRIX

A. GENERAL

A relief map or an air photograph of the Cape Peninsula conveys an immediate impression of an island plateau, separated from the mainland by the sandy, dune-covered Cape Flats. Walker (1952,p. 1) refers to the plateau as ...."a mass of resistant sandstones overlying a foundation of softer rocks."

The study area extends over a distance of approximately 53km from Mouille Point in the north to Cape Point in the south. Its maximum width is 16km with an estimated average width of 8km. More than half of its total area of $435km^2$ stands at a height in excess of 300m above sea-level.

A rise in sea-level of less than 30m would submerge the low-lying areas, thereby separating the Peninsula from the mainland, and would convert the study area into two islands of approximately equal dimensions, separated by a narrow strait along the Fish Hoek valley. This valley divides the Peninsula into a northern and southern section, each having its own distinctive physical character.

B. EARLY BEGINNINGS

The geological history of the Cape Peninsula consists of a number of episodes separated by enormous time intervals of which practically nothing is known.

The first episode begins after the deposition of the Nama System. In his paper dealing with the nature and origin of the Cape Fold Belts, de Villiers (1944,p. 188) is of the opinion that such an investigation could not be limited to a study of post-Cape rocks only, but should also include a detailed study of the pre-Cape terrain as well.

Late Pre-Cape Time

Although the rock sequences assigned to the systems to which the names of Damara, Gariep and Malmesbury are attached are not spatially contiguous on the land, and although there is no actual proof that deposition in these areas in which they outcrop are synchronous, they possess certain common characteristics in their lithology and tectonics. Haughton (1969,p. 313) contends that it is possible to accept, lacking proof to the contrary that they represent sedimentation within a single complex geosynclinal depression that extended from at least Gabon in the north southwards, and then eastwards along the borders of an already formed continental area which itself was partly dissected by a lateral branch or branches from the main geosyncline.

During Malmesbury time, which, according to Martin (1965: Geological Map of the Republic of Southern Africa) preceded the Cambrian, the Damara geosynclinal complex developed along the western continental margin of southern Africa. (Fig.1.1). Rust (1973,p. 248) is of the opinion that it is difficult to visualize to what extent the various sub-units, referred to previously, were contemporaneous, but refers to the likelihood of the Nama unstable shelf merging with the Malmesbury eugo-synclinal trough in the south.

Haughton (1969,p. 317) is of the opinion that he considered the latest Precambrian event to have been the formation within a "presumably oceanic crust" of a complex of geosynclines in which were deposited the Malmesbury, Gariep-Numees, Damara and Katanga sediments.

Malmesbury Period

Thus, in the western and southern districts of the

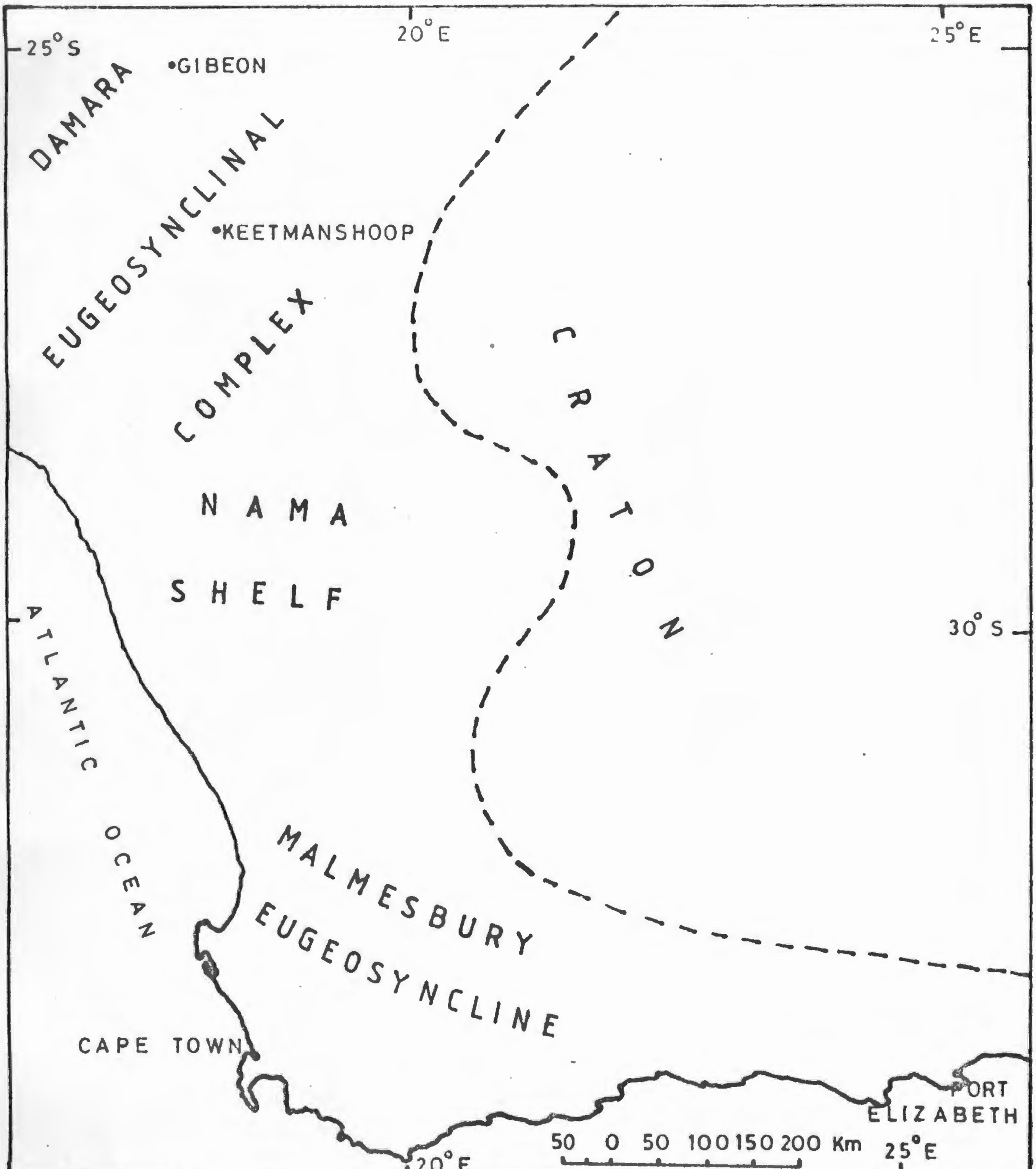

Fig. 1.1 Tectonic framework of the Damara eugeosynclinal complex showing the relationship between the Nama unstable shelf facies and the Malmesbury eugeosyncline.

(After Rust, 1973)

Cape there slowly developed a geosynclinal trough into which were deposited the erosion products of the uplifted areas to the north. The waters of the geosyncline remained fairly shallow and the climate was apparently cold. According to Hamilton and Cooke (1965,p. 327), the main sediments consisted of gritty material, sandy shales, silt, sand, mud, localised limestones and quartzites, but there was also a little volcanic lava. A tectonic phase concluded the sedimentary cycle.

Hamilton and Cooke (1965,p. 327) maintain that at the end of a long period of deposition, the rocks of the geosyncline were folded and invaded by stocks of Cape Granite. Haughton (1969, p. 317) refers to intrusions of "syntectonically emplaced" granite in parts of the system. It is generally accepted that during this intrusive phase medium-grade regional metamorphism with associated moderate deformation occurred. Walker (1952,p. 10) maintains that the deforming force which crumpled the Malmesbury Series came from the south-west, whereas van der Merwe (1963,p. 8), as a result of his investigations in the northern Cape Peninsula came to the conclusion that the deforming force must have come from E. N. E.

This pre-Cape diastrophism, which presumably elevated the strata above sea-level, and ended the period of deposition, was followed by a long period of crustal stability. Erosion was active, and as a result there was produced in the west "What must have been one of the most perfect peneplains in the geological history of South Africa." de Villiers (1944,p. 185). This occurred at the end of the Silurian Period. Visser (1957,p. xliii). The surface must have been very nearly level, as can be seen where the post-Cape movements have not disturbed it very much, for example, parts of the Western Province of which the Cape Peninsula is a good example. There is general agreement regarding a well-planed surface on the part of Visser (1957,p. xliii), Haughton (1969,p. 334) and Truswell (1970,p. 104 and 1977,p. 114).

Hamilton and Cooke (1965,p. 328) maintain that at the commencement of the Cape period, i.e. about Lower Devonian times, a shallow fluviatile basin developed over the southern part of what is now South Africa, extending from the west coast to Natal. (Fig. 1.2). This is corroborated by du Toit (1954,p. 559), who is more explicit, by stating that..."a vast and even peneplain" had been developed over the southern half of the Cape before the close of the Silurian, stretching from van Rhynsdorp in the west to Natal in the east ---- the pre-Cape platform. Visser (1957,p. xliii) refers to a "hinge-line" along which the pre-Cape platform was bent down and depressed towards the south, to be followed by a marine incursion. Rust (1973,p. 274) refers to the basin thus formed as" a submerged continental plate." This surface sloped southwards an east-west trough ---- the "Cape Geosyncline" ---- just beyond the limits of the present continent. Dingle (1973,p. 205) describes the trough as a composite one and maintains that the south Cape trough existed over the southern Cape from Late Precambrian (Table Mountain Group) to Devonian or early Carboniferous times (Bokkeveld Group). He considered the trough to be an ... "epicontinental depression" with limited access to the sea. Theron (1970,p. 197) recognizes two branches to the south Cape trough which he calls the Clanwilliam and Agulhas troughs.

This concept of a basin is echoed by Haughton (1969,p. 26), who contends that, "The Cape Basin or trough of deposition, filled with sediments that are in part of marine origin, lay in the southern part only of the sub-continent whose remainder consisted, as far as is known of Precambrian rocks undergoing denudation." is further corroborated by Martin (1973,p. 297), Tankard and Hobday (1977,p. 139) and Rust (1967,p. 82, 1973,p. 247 and 1977,p. 123).

Rogers and du Toit are of the opinion that at the commencement of the Cape period, that is about Lower Devonian times, a great tract of land lay west and north of the

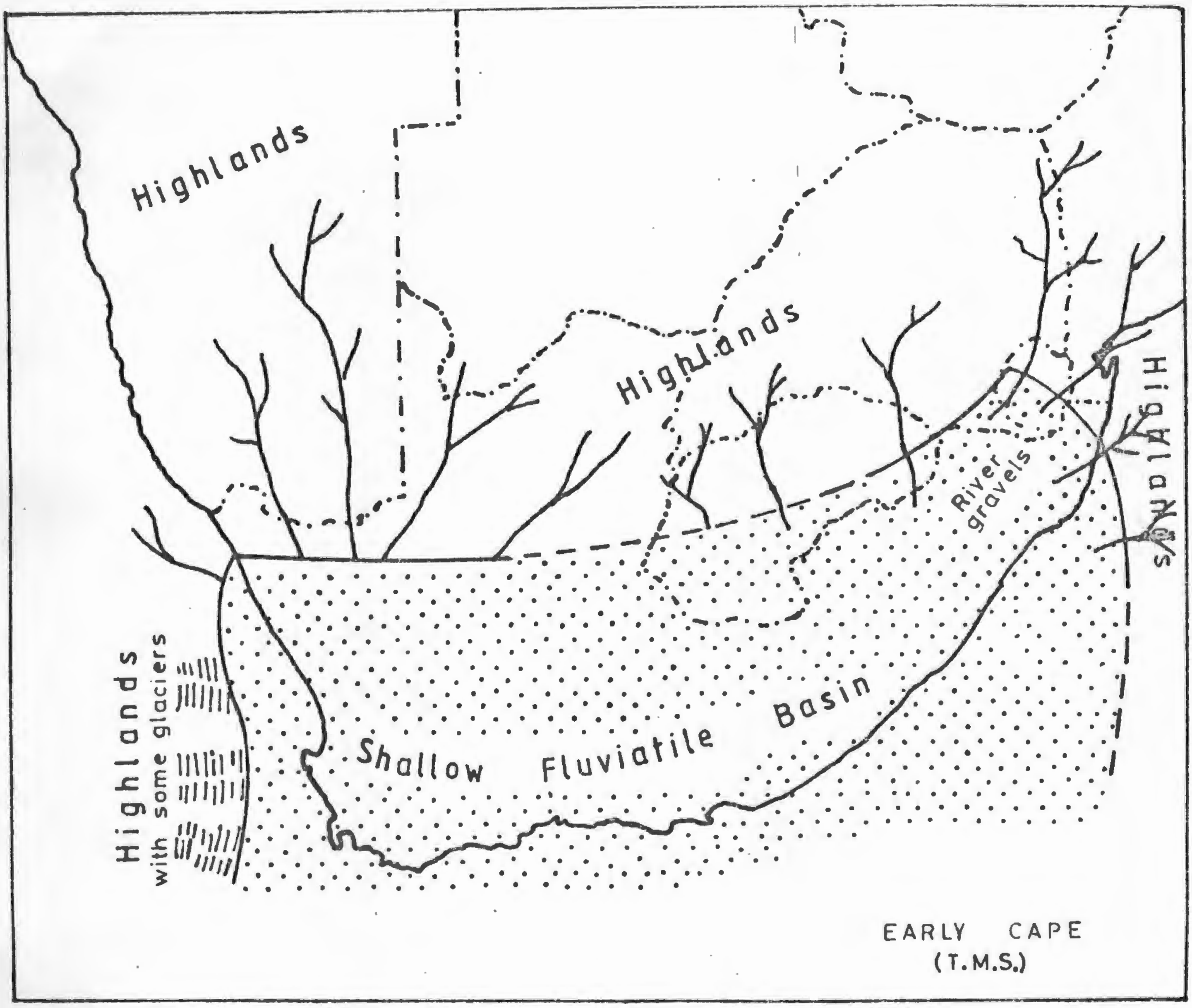

Fig. 1.2 Reconstruction of conditions prevailing in the earlier part of the Cape period.

(After Hamilton & Cooke, 1965)

southern part of what constitutes the Cape Province today, for the materials comprising the Table Mountain Series become somewhat coarser in those directions. Rust (1967,p. 90), concludes from a study of the dispersal pattern that an important land mass off to the N. W. represented what is now the Atlantic Ocean. He finds it difficult to estimate the areal extent of the Atlantic highland, except to state that it must have been extensive, if for no better reason than that of its long time span and the large bulk of the sediment it supplied. Martin (1973,p. 292) refers to the evidence for an elevated area of considerable size off the present west coast of South Africa. Further evidence to support such a claim comes from geochemical analyses, porosity and permeability determinations and petrographic studies which were carried out on a borehole and on some surface material from various parts of the Cape - Karroo basin. The results for different parameters show trends that are consistent with a general decrease in diagenesis from south to north over the basin as a whole. Rowsell and De Swardt (1976,p. 81).

There appears to be general agreement that the source area for the sediments was to the north and west of the Cape Basin on the part of Rogers (1929,p. 18), de Villiers (1944,p. 189), Swart (1950,p. 413), Truswell (1977,p. 114) and du Toit (1954,p. 246 and 559).

This land mass furnished the enormous amount of sand, almost entirely of quartz grains that now forms the Table Mountain sandstone. This sandstone, which is roughly in the form of a broad belt (805km .... long by 160km wide), was deposited over an area of at least 111 370km^2....., probably more than 233 100km^2 ...., and even then the Pondoland outcrops have been left out of account owing to the uncertainty of the nature of the rock between them and Algoa Bay.

The question of the conditions under which the Table Mountain Series was deposited has not yet been satisfactorily solved. Rogers and du Toit (1909,p. 137) are of the opinion that they cannot regard the Table Mountain Series as a marine formation, stating that it is probably a fluviatile deposit laid down near the source of origin of the materials composing it. Many years later du Toit (1954, p. 246) declared, "The precise manner of deposition of this extensive body of arenaceous sediment is not quite assured." The region was probably a "biological desert" because of the scarcity of vegetable life at that period. du Toit further maintained that Aeolian activity was rife as shown by the high angles of cross-stratification in certain bands. The uniformity, moderately coarse grain, prominent false-bedding, general absence of shaly layers and other peculiarities strongly recall the so-called "Nubian Sandstone Facies" of Egypt and Palestine. The region probably formed a vast coastal plain or series of broad deltas, studded by wandering dunes that were periodically levelled and re-worked by rivers or ponded streams. du Toit (1954,p. 247).

An earlier worker in the field, B. Swart (1950,p. 413), on the basis of his investigations interpreted conditions in the Table Mountain basin in a manner which accords well with the latest work done, in which more modern research techniques were utilised. He envisaged for the western region, invasion of water from the south over the peneplain and the existence of a large bay, with the bay-head pointing to the N. or N. N. W., bounded on the west by a land mass on which glaciers existed for a time. The most rapidly sinking part of the floor of this bay existed over the site of the present Cedarbergen, and it was there that deposition within reached its maximum. Swart (195o,p. 413) considers that the frequent cross-bedding in the sandstones points to rapidly shifting sands and turbid waters moved by strong currents. The western land mass must have lain to the west of the present coastline, for the rocks of the series are found in the western coastal belt and appear at places within this belt, such as at Baboon Point to be more conglomeratic than elsewhere.

Deposition of the Table Mountain Series

A study of the Table Mountain Sandstone in the Western Cape by Rust (1967,p. 14) had, as a consequence of his research, a reconstruction of the conditions in the Western Cape during the deposition of the Table Mountain sandstone. He established a more comprehensive succession than was formerly recognized. This succession actually consists of six formations, each characterized by its unique composition and position in the stratigraphical sequence.

T A B L E 1.1 (After Rust, 1967)

Nardouw Sandstone Formation Cedarberg Siltstone Formation Pakhuis Tillite Formation Peninsula Sandstone Formation Graafwater Siltstone Formation Piekenier Conglomerate Formation	TABLE MOUNTAIN GROUP

Since the Graafwater, Peninsula and Pakhuis Formations are the only three represented in the Cape Peninsula, the emphasis in the following pages will, of necessity have to fall upon these three formations, whilst reference will have to be made to the others in passing.

Rust (1967) utilised four methods of palaeogeographical reconstruction for the formations of the Table

Mountain Group. Firstly, he determined the shape of the basin in which the sediments accumulated by plotting on a map the thickness of the accumulated sediment as measured today in the field. On the map the values are usually contoured to form an isopach map which looks like a bathymetric map because the higher values indicate the deeper portions of the basin. Amongst the uses of the isopach map is the fact that it indicates the trend and position of the ancient shore.

The second method deals with the imprint left by the currents which transported and deposited the sediment in the basin so as to obtain the dispersal pattern. The imprints occur as varied records in the sedimentary rock. Cross-stratification, imbrication, ripple marks, glacial striae and pebble size variation are among the more common structures which were studies in the case of the Table Mountain sandstone.

The third method, as part of the palaeo-geographical reconstruction deals with the sediment which accumulated in the basin. Certain processes and circumstances cause characteristic sedimentary products eg. glaciation uields tillite and varved shale as well as striated pavements, whilst areas of rugged topography would deliver coarse-grained gravel to the basin. This enabled the researcher to make all kinds of palaeogeographical deductions from a study of the sediment-type in the basin.

In the final instance, a study of the fossil content also revealed something about conditions in the basin. Questions regarding the water in the basin (fresh or salt), and conditions regarding the climate could be answered to a greater or lesser extent by studying the fossils in the sediments of the basin.

The Table Mountain Basin reconstructed

The scene opens somewhere towards the end of the Cambrian Period or near the beginning of the Ordovician Period. Rust (1969,p. 353). The Palaeozoic Cape Basin southern margin of Africa, today represented by the Cape Supergroup sediments, was active continuously from early Ordovician to early Carboniferous time. Rust (1973,p. 247). This is known from the fossil evidence of the Table Mountain sandstone, supplemented by other information, for example fossils in older as well as younger formations, radiometric age determinations, and extrapolation of the estimated rate by which the Table Mountain basin filled with sediment. It is estimated that the last of the Table Mountain sediment was deposited more or less at the end of the Silurian Period, or possibly even during the beginning of the Devonian Period. Translated into millions of years this means that the deposition of the Table Mountain Group started more or less 500 million years ago and ended approximately 100 m.y. later.

The Table Mountain basin forms a fairly regular trough trending N. W. and has markedly wide marginal shelves. The deepest part, reflecting the area of maximum sediment accumulation is near Citrusdal (about 3 660 - 3 960 metres maximum), and marks the zone along which the downward pull of forces in the crust, aided by the weight of the sediment, was most severe. The northern shore was somewhere between Calvinia and Bitterfontein, and the south-western edge of the basin was probably some 160km west of Cape Town. Rust (1969,p. 353).

The Cape rocks were deposited on older strata ranging in age from 1 000 to 550 m.y. This floor is represented variously by the Namaqua Mobile Belt, by the Nama, Malmesbury, Cape Granite, Klipheuwel, Cango and equivalents in the Cape Province. J. F. Truswell (1977,p. 114).

The initial basin in which the Piekenier Formation was deposited was roughly elliptical, the long axis trending N. W. It is generally postulated that the Piekenier embayment was open to ocean-generated swell and that conditions in the basin were energetic.

The rather small Piekenier basin set the stage for the rest of the Cape basin, in which many thousands of metres of sediment eventually accumulated, and it is perhaps no accident that the initial sedimentation, like most of the rest which followed it, was characterized by the dominance of super-mature clastics. There are practically no signs that living forms inhabited the Piekenier basin.

The Graafwater Siltstone Formation concordantly overlies the Piekenier Formation. The basin in which the Graafwater Formation accumulated was larger than the Piekenier basin, whilst the tectonic framework was largely inherited from Piekenier time. Rust (1967,p. 97).

The palaeogeography of Graafwater time is seen as a tidal flat, flanked on the west by the now very much subdued Atlantic Mountainland, and on the north by the Bushman Mountainland, which was much more conspicuous at this stage than earlier. There was at least one delta along the northern shore, with deeper water to the south-east. Rust (1973,p. 253).

Three facies are recognized within a 70-m thick succession of inter-bedded red mudstone and other quartz arenites that form the Graafwater Formation. The quartz arenite facies shows a variety of structures attributed to tidal processes. This facies is interpreted as tide-dominated, shallow sub-tidal and low-tidal terrace deposits. Tankard and Hobday (1977,p. 135). This viewpoint is corroborated by Rust (1977,p. 123), who envisages "A general tidal environment" for the Graafwater Formation which is suggested by herringbone structures, a bimodal-bipolar cross-bedding pattern, and abundant mudcracks which record intermittent exposure and desiccation. Trace fossils in the central area of the Graafwater basin confirm a marine environment for parts of the sequence.

It is envisaged that during this period the previously energetic environment was transfigured into a relatively low energy environment in which the deposition of purple clays and comparatively fine-grained and immature detritus took place practically at sea-level. Why conditions changed so radically in the basin is not quite clear. The dispersal pattern and other sedimentary features indicate that the basin developed into a tidal flat. Worms and trilobites inhabited portions of it, and left behind profuse signs of their occupation; tubes, trails, burrows, tracks and faecal pellets. Rust (1969,p. 355).

The Graafwater tidal flat gives no indication of the erstwhile important river which supplied sediment to the Piekenier basin. It is inferred that the Atlantic highland was either reduced to lowland by river erosion during Piekenier time, or the highland suffered some degree of negative tectonism, thereby reducing its potential to supply debris.

A major change in the palaeo-geographic relationships of the Table Mountain basin developed during the transition from the Graafwater interval to the Peninsula period. It is envisaged that what was previously an embayment evolved into a sea strait as a result of a postulated connection with the open sea to the N. W. This theory is based on the palaeoflow pattern of the Peninsula formation. Rust (1967,p. 98). This sea passage was swept from north to south by seemingly never-ending bottom currents, and the roar of gigantic surf was heard once again on the beaches.

The Peninsula Formation is the major deposit of the Table Mountain basin. Its thickness in the east is between 3 000 and 4 000m. It consists almost entirely of supermature quartz sandstone with occasional stringers of small, well-rounded vein-quartz pebbles. The sandstone is well-bedded. The new source of sediment was the mountainous inland of what is present-day Bushmanland. This area was dissected and denuded by many rivers, all flowing south and S. W., and ceaselessly depositing sand and pebbles on the very wide beaches at the edge of the Peninsula basin. Rust (1967,p. 99) envisages the Peninsula landscape as being probably stark and sterile. This viewpoint accords well with that of du Toit (1954,p. 246), who referred to it as a "biological desert." The sand which eventually reached the beaches was further reduced to the most resistant components only, namely quartz and zircon. Rust (1969, p. 357) pictures the offshore current system as an enormous conveyor belt spreading layer upon layer of sand ever deeper into the central portion of the basin. The rate of sediment accumulation during this phase was particularly slow, being estimated at the order of 30cm of sand every 10 000 years.

Occasional marine storms agitated the bottom sediment, enabling the current system to remove the sand in suspension and leave behind in places the small well-rounded pebbles, which are today seen scattered on some of the Peninsula bedding planes. It has been suggested that the active process in the Peninsula basin was a combination of surf action and marine currents in water possibly shallower than 50 metres. The volume of Peninsula quartz sand in the Western Cape alone has been estimated in the order of 41 680 km^3 ---- an amazing accumulation. Rust (1969,p. 357). There is little doubt that the Peninsula sand was deposited sub-aqueously, and fossil evidence indicates that the milieu was marine. Rust (1973,p. 256). This unambiguous statement is in stark contrast to that of du Toit (1954,p. 247) to which reference was made earlier, whose considered opinion was that "deposition was effected upon a plain subjected to repeated flooding."

At the close of the Ordovician Period the climate became colder. The ice-cap on the distant Bushman Highland grew until the numerous valley glaciers coalesced on the low-veld to form a piedmont sheet. This ushered in the Winterhoek glacial epoch which consisted of two transgressive glacial pulses and one intra-glacial period of regression followed by the final deglaciation phase.

The Winterhoek is recorded in two thin, but extensive rock units, namely the Pakhuis Tillite Formation and the overlying Cedarberg Siltstone Formation. The combined thickness of the two formations is on average less than 60 m, yet the original extent must have been in excess of 100 000 km^2.

The first ice sheet, known as the Sneeukop Sheet invaded the basin and eventually pushed far south of Cape Town.

There is one striking feature which has some bearing on the palaeo-geographic reconstruction. At the base of the Pakhuis Formation, where it is in contact with the Peninsula sandstone, a remarkable zone of fold deformation developed. The fold axes strike essentially north, and in shape they vary from open canoe-shaped structures, measurable in a few metres to cascaded, over-folded, re-folded complexes with a maximum vertical thickness of 75 m. Present knowledge would put the extent of the fold zone at some 30 000 km^2 all of it in the west. Rust (1967,p. 103).

In the Western Province the glacial band lies upon quartzites that have undergone surface foldings to depths of up to 60 m and this zone of disturbance has been attributed to lateral pressures on semi-consolidated or recently-consolidated sandstones by ice-sheets or ice-floes moving from the west. Haughton (1969,p. 333). Rogers (1909,p. 18) refers to a glacial period which was responsible for evidence which suggested that in the south-west an ice-sheet moved eastwards in places rucking up the floor of tillite and the underlying sandstone into folds with north-south axes. On the evidence provided by the small thickness of the glacial formations, Rust (1967,p. 102) concludes that the glacial episodes occupied very little time in the total history of the Table Mountain basin, and estimates the length of the Pakhuis glacial interlude at less than 750 000 years.

In the wake of the waning Kobe sheet followed the deposition of the dominantly shaly and silty Cedarberg Formation. This formation is unique in the Table Mountain Group: it is the only truly shaly formation (in part only), and it contains undisputed and well preserved marine fossils, namely a variety of brachiopod shells, as well as some fragmentary crinoid stems and one or two trilobite carapaces. Rust (1969,p. 357). In the main, the Cedarberg Formation represents the deposits derived from the outwash glacial silt of the retreating Kobe Sheet. The fine grain of the sediments show that during Cedarberg time the turbulence in the basin was at a minimum. The fossils afford two important clues regarding the Cedarberg Formation; firstly, that it is a marine deposit, and secondly, that its age is practically on the boundary of the Ordovician and Silurian Periods.

The short interlude provided by the glacial episode was followed by the rapid re-establishment of former energetic marine conditions during the deposition of the Nardouw Formation. The extreme northern position of the shore lay near Calvinia. All other circumstances in the basin were, for the next 30 million years or so identical to those appertaining during Peninsula time.

The end of the Table Mountain cycle was signalled by an abrupt downwarp of the basin, so that deep water replaced the previously shallow water. Instead of sand, now only black, organic mud of the Bokkeveld Group was accumulated, and for many millions of years the basin did not revert to shallow water conditions.

The Table Mountain basin in the Western Cape therefore most probably came into being during the uppermost Cambrian, and the period of some 50 m.y. is available for accomplishing the impressive erosion of the Cape Granite, as well as for the deposition and partial erosion of the Klipheuwel Group prior to the development of the Table Mountain basin. The duration of the Winterhoek glaciation has been put at 1 m.y., which is comparable to the Pleistocene Epoch, while the Nardouw and Peninsula Formations correspond almost to the entire duration of the Silurian and Ordovician Periods.

C. OROGENESIS

By the end of Ecca times, the activity of the Cape Geosyncline was declining and it became completely filled with sediment until its extent was represented largely by swamps subject to periodic flooding and desiccation. In these swampy areas there lived during the Beaufort Period a wide variety of reptiles, some near water and others in the higher drier areas.

In the extreme south, folding began along the axis of the geosyncline. The folding continued in Molteno times, producing the forerunners of the existing Cape folded ranges. Hamilton & Cooke (1965,p. 332). Brock (1959,p. 326) declares, "The only unambiguous and clearly defined orogenies in Africa occupy its extremities like a pair of brackets : the Atlas range and the Cape foldings." It should be noted that both are post-Proterozoic in their manifestations.

de Villiers (1944,p. 202), when referring to the deformation of the sediments in the Cape geosyncline recognizes three stages which are applicable namely, a weak Carboniferous pulse that affected only the western belt, (of which the outliers in the Cape Peninsula form part), a stronger Permian pulse and finally a Middle-Triassic pulse that ended the geosynclinal phase in the south.

It is maintained by Visser (1957,p. xliv) that during the Late Permian and Early Triassic, the geosyncline in the south gradually disappeared as the land towards the south of it began to rise. This was the beginning of the Cape foldings. It was followed by the culmination of the great compressive movements from the south during the Middle Triassic. Dingle (1973,p. 206) supports this viewpoint in its entirety by stating that towards the end of the Permian the first movement of the main phase of the Cape orogeny folded all the strata up to and including the Lower Beaufort sediments. This was followed by the climax of the Cape orogeny which occurred in Mid-Triassic times.

The Cape Fold-belt, of which Table Mountain, the Constantia, Steenberg, Swartkop mountains and others in the Cape Peninsula are outliers, forms one of the major structural features of southern Africa. The Cape Fold-belt is one of the few examples of an early Mesozoic orogeny in the southern hemisphere. It displays several distinctive features which must be accounted for in any explanation of its origin. Newton (1973,p. 145).

These features include the following :-

(i) the sharp change of strike at its western end which results in its consisting of a main east-west branch and a lesser north-south branch;

(ii) the complete absence of any visible igneous or metamorphic features associated with either the depositional or deformational phases, and

(iii) its over-all asymmetry, with overturning directed towards the continental interior.

In the following pages, it is intended to examine some of the hypotheses put forward to explain the Cape orogeny in the past and then, in the final analysis, to put forward a viewpoint of one's own.

Two models are postulated. With gravity-folding, a body force is involved (i.e. one acting on all particles in the rock), but this alone cannot cause folding. It can, however, induce movement of the rock body down a slope, and folding can then occur either from differential rates of flow within the mass or due to the resistance building up against the movement, usually from some physical obstacle. In this case the stress is applied to only one side of the mass of rock, the other side being unconstrained.

In the other model often referred to as "the jaws of a vice concept" compressional forces are involved in which the stresses are transmitted through the deforming mass, which is forced to thicken and does so by folding, faulting and thrusting according to the mechanical properties of the constituent rocks.

Before discussing the different hypotheses and the points of divergence, it might perhaps be best to consider those aspects upon which there tends to be general agreement. A study of the great ranges of folded mountains of the world leads one to the following conclusions :-

(a) All the great folded ranges are built mainly of marine sediments.

(b) These deposits are invariably thick, having been formed over a lengthy period of time.

(c) The mountain ranges originated where the pile of sediments had attained the greatest thickness.

(d) Many of the mountain ranges are characterized by the intrusion of granite at their roots.

(e) The basins or geosynclines in which the deposits have accumulated must gradually have become deeper during the process of deposition or sedimentation and this implies tension in the earth's crust.

(f) There were certain periods in the earth's history during which great mountain-building movements were particularly active, eg. at the end of the

Archaeozoic Era, when the Algoman revolution took place in North America; at the end of the Proterozoic Era characterized by the Killarnean orogeny in North America, the Charnian in England, and the Karelian in Scandinavia.

From these conclusions two generalizations emerge, viz. the dualistic nature of the mountain-building process i.e. the alternation of epochs of crustal tension with epochs of crustal compression and the periodicity of the orogenic movements.

With reference to the periodicity of orogenic movements we note that Umbgrove's theory of pulsations (1947) or rhythms in the development of the earth's crust has been elaborated by Bucher (1941), and in particular by Holmes (1956), who has given an age-figure of 200 million years to the different orogenic cycles. This figure has been endorsed by Newton (1973,p. 149).

The Gravity-Folding Model

In his hypothesis to explain the Cape Fold Belt, Newton (1973,p. 150) suggested that diastrophism arose from gravity movement, following vertical uplift. This elevation on the southern side of the depositional trough, that is to the south of the present onshore outcrops, in a series of step-like faults would have created a slope down which sliding took place ... "in a succession of cascading folds." The sliding mass would tend to pile up against some rigid obstacle or other. In this case the stress is applied to one side only of the rock mass, the other side being unconstrained.

In the model postulated by Newton (1973,p. 151), uplift would have to take place in the southern part of the geosynclinal prism to create the slope -- he stipulated a slope as low as 2^{o} --- down which the sediments would slide in a northerly direction toward the rigid land mass of southern Africa. He is supported in this particular assertion by Visser (1957,p. xliv), who contends that during the Late Permian and Early Triassic the Cape geosyncline gradually disappeared as the land towards the south of it began to rise, this being the beginning of the Cape foldings. de Villiers (1944,p. 190) is of the same opinion, maintaining that the southern border of the geosyncline was in all probability rising until where there was once an ocean, land appeared to provide the bulk of the post-Dwyka sediments in the south.

This viewpoint, however, runs counter to that enunciated by Rogers & du Toit (1909,p. 431), who refer to a rising of the floor taking place in the country north of the thirty-third parallel at the same time during the Bokkeveld period as well as the Witteberg.

The "Jaws of a Vice" Model

In his paper de Villiers (1944,p. 185), whilst reviewing the Cape orogeny stated that the Cape System could not be discussed in isolation from its diastrophic history. In this particular instance, the past held the key to the present. He is of the opinion that the nature of the surface of deposition of the Cape System and the varying competence within the pre-Cape foundation are bound to have exercised a very important control over the appearance and arrangement assumed by the Cape rocks after their formation. de Villiers (1944,p. 188) is further convinced that these old strikes gave a bias to the folding when the great thickness of the Cape and Karroo beds came to be affected in Beaufort times.

As an explanation of the forces necessary to cause folding, de Villiers (1944,p. 203) makes use of a mechanism propounded by Lawson (1927,p. 256) for the Rocky Mountains which involves "horizontal collapse of the crust" as a result of primary pervasive compressive stress and thinning of the earth's crust beneath the trough. This thinning was thought to be the result of flow which transferred crustal material from beneath the subsiding trough to adjacent areas where uplift and erosion were supplying sediment to the geosynclinal prism.

de Villiers (1944,p. 204) extended this model to the Cape Fold-belt, and suggested that since the rock flow was away from the trough, it would combine with the primary stress to form a vertical couple which was responsible for the asymmetry and overfolding observed. Later, de Villiers (1956) modified this concept, suggesting that this couple acted in a plane having a north-east strike and a steep south-east dip, resulting in arcuation of the fold axes and giving them their plunging in echelon arrangement. A north-east - south-west stress direction was suggested for the Cedarberg foldings, of which the mountains of the Cape Peninsula form the southern outliers. The south-west trend was the result of compression from the south "against the rigid buttress of southern Africa," whose south-eastern edge ran approximately from Gordon's Bay to Worcester.

From the preceding it is to be expected that the competency of the pre-Cape platform would vary from place to place. Highly rigid areas of firmly rooted plutonic rocks would tend to resist deformation to an extent largely governed by their size. The resistance offered by some of these intrusions, when contrasted with the inherent incompetence of the Malmesbury Series as a whole, as well as other zones of weakness in the pre-Cape platform must have exercised a certain measure of control over the effects of post-Cape flexing and faulting. There are two important relationships which would appear to justify and substantiate the conclusion arrived at above, viz.:

(a) the general parallelism of structural features in the pre-Cape and post-Cape rocks;

(b) the apparently undisturbed condition of the Table Mountain sandstone in the Cape-Stellenbosch area may be attributed in part to a rigid granitic foundation and to the nature and direction of application of tectonic pressure during the mid-Carboniferous to the Late Triassic period of orogeny.

With reference to the granitic base du Toit (1954, p. 174) points out that, "The Cape Town granite extends the full length of the Cape Peninsula." Truswell (1977,p. 98) makes the same point, stating that although only 23km^2 of the Cape Peninsula pluton is exposed, the widely scattered nature of these outcrops would suggest that the approximate total area of this pluton may exceed 500km^2 .

A similar model, which attempts to explain the origin of the Cape Fold Belt is put forward by De Beer, van Zijl & Bahneman (1974,p. 256) in which they state that an oceanic plate underthrust Gondwanaland coincident with the present southern limit of Africa, and that the Cape Fold Belt resulted from an ensuing continent-continent collision directed from the south. Most authorities are agreed that the force which resulted in the formation of the Cape Fold mountains must have been applied from the south. Visser (1957,p. xlv) refers to "compression from somewhat south of west" whilst du Toit (1944,p. 196) states, "Such could be taken as agreeing with current ideas of a pressure during the Triassic from the south." de Villiers (1944,p. 205) also makes the point of pressure applied from the south.

The same model is put forward by Martini (1974, p. 115) in which he maintains that a collision occurred at the end of the Palaeozoic, during the early Mesozoic between a volcanic arc and the continental margin of southern Africa. He quotes the presence of ash beds and turbidíties in the Ecca, and of possible Late Palaeozoic granite clasts in the Beaufort sediments as evidence to suggest the existence of such a volcanic complex with associated granites to the south of the African continent.

du Toit (1937) in his book "Our Wandering Continents" put forward his hypothesis of Continental Drift to explain the Mesozoic palaeogeography of the southern Cape, and declared that geological evidence almost entirely must decide the probability of his hypothesis. He provided evidence to support his hypothesis by drawing lithological, palaeontological and structural parallels between South Africa and eastern South America during the Devonian epoch. Taken in conjunction with the evidence of a similar kind during the Permian and Triassic, it proves the intimate connection of these two continents over an enormous period of time. Later, du Toit (1944,p. 196) considered the direction of the application of force responsible for the formation of the fold mountains of the Cape with special reference to Continental Drift as the cause of the pressure.

D. IN CONCLUSION

Newton (1973,p. 145) maintains that a satisfactory explanation for the origin of the Cape Fold Belt cannot be found within the framework of past or present hypotheses concerning geosynclines and orogenesis because of certain anomalous features present within the Cape Fold Belt itself. The writer, however, feels that whilst endorsing the viewpoint expressed by Newton (1973,p. 145), an explanation could perhaps be sought within the broader global context of Gondwanaland, the re-assembled supercontinent of the Southern Hemisphere as enunciated by du Toit (1937,p. 106 & 1944,p. 196), together with the hypothesis of Plate Tectonics since these two models complement and reinforce each other. Furthermore, a vast body of evidence has been accumulated over the years to support such an hypothesis.

In attempting to formulate an explanation of the Cape orogeny, use is made of the definition of a geosyncline as formulated by Haugh (1900) and quoted by Krumbein and Sloss (1951,p. 321), ... "as the mobile belt between rigid continental masses."

The attempt to explain the Cape orogeny will also be formulated in terms of Bucher's (1941) concept of a cycle of events which are characterized by various phases of its development, viz. :

(i) a tensional or geosynclinal phase during which deposition takes place and the geosynclinal prism grows larger;

(ii) a compressional phase characterized by folding, compressional faulting and the main uplift of the mountain masses;

(iii) a tensional phase during which large gravity faults are formed; and

(iv) a magmatic phase characterized by the invasion of the root zones of mountains by bodies of intrusive rock.

In the preceding section evidence has been provided regarding the deposition which took place within the Cape Geosyncline or Basin from Late Precambrian to Devonian or Early Carboniferous times. Evidence has also been provided regarding the presence of a land mass to the west and south of the mobile belt, the then supercontinent of Gondwaneland in the Southern Hemisphere. All the sources cited are in agreement that the compressive force exerted upon the geosyncline came from the south and south-west, i.e. from the landmass to the west and south of Southern Africa. With the stress being applied from one side only, i.e. from the south-west and south against ..."the rigid buttress of southern Africa" (de Villiers, 1944 p. 207), the overfolding and the en echelon arrangement of the folds can perhaps be explained. The fact that the compressive force came from one side only can also be explained by reference to two sources. In a paper read at Moscow, du Toit (1944,p. 196) refers to his contention that Africa was moving northwards prior to the Triassic. This statement is supported by Dietz & Holden (1970, p. 4948), who point out that before the break-up of Gondwanaland, the south Cape lay in a mid-continental setting, and at a high latidude. During the course of Mesozoic times (160 m.y. B.P.) it became detached from Antarctica (Late Triassic) and from South America during the Late Jurassic and Early Cretaceous. Africa was thus moving northwards and would not thus have exerted a compressive force when pressure was applied from the south-west and south. This resulted in overfolding.

The sharp change of strike at the western end of the Cape Fold Belt, which results in its consisting of a main east-west branch and a lesser north-south branch can perhaps be best explained with reference to Rogers (1944,p.198). He expresses the viewpoint that the old strikes gave a bias to the folding when the great thickness of the Cape and Karroo beds came to be affected in Beaufort times. He maintains that ..."just as it is difficult to bend corrugated iron except parallel to the corrugations," so the earlier formations exercised a controlling influence during the Cape foldings. "This difference in strike affected the country from Namaqualand to the Cape, and east to Algoa Bay at least."

Apparently no volcanic action accompanied the rift in the south Cape, although it is possible that intrusives exist at depth on the present-day Agulhas Bank. (Dingle, 1973 p. 207). This could be the reason for the complete lack of visible igneous or metamorphic features accociated with the depositional or deformational phase referred to earlier.

Large southward-throwing tension faults along the northern limbs of many of the long, frequently overturned anticlines of the Cape Fold Belt were initiated by the process of rifting, and facilitated the downward movement of what is now the Agulhas Bank. Dingle (1973,p. 207).

Scrutton (1973,p. 230) refers to the South Atlantic region where a classic example of igneous activity associated with continental break-up is to found. The same point is made by Le Pichon & Hayes (1971,p. 6287) regarding the opening of the South Atlantic about a pole situated at 19^{0} north 40^{0} west which commenced about 140 m.y. B.P., and was associated with the outpouring of basaltic lavas and tuffs. Here the basalts and dolerites in the Parana Basin in southern Brazil are the counterparts of the Kaoko basalts in South-West Africa estimated at 125 m.y. B.P. Dingle (1973,p. 208). This can be effectively correlated with evidence from marine magnetic anomalies in the South Atlantic (Larson & Ladd 1973, p. 209), that demonstrates fairly convincingly that the initial rift referred to by Le Pichon & Hayes (1971,p. 6292) first occurred in the Early Cretaceous --- 125 - 130 m.y. B.P. Scrutton (1973,p. 230) dates the Kaoko basalts between 114 - 136 m.y.B.P.

Finally, palaeomagnetic evidence provided by Le Pichon (1968,p. 3689) indicates that the South Atlantic opened rapidly during the Cretaceous Period and that by the end of the Mesozoic Era South Africa was surrounded on three sides by open ocean.

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CHAPTER 2

GLYPTOGENESIS AND THE EMERGENT LANDSCAPE

Although the sediments comprising the Table Mountain Series had been deposited in the Cape Geosyncline during the Ordovician-Silurian and early Devonian periods (505 - 400 m.y. B.P.), it was not until the Late Triassic -- Early Jurassic that they were exposed above the surface of the ocean when, as a result of the Cape Orogeny a series of high, newly-formed mountains comprising the Cape Fold Belt lay along the sites of the former Clanwilliam and Agulhas troughs. Dingle (1973,p. 206). Visser (1957,p. xlv) subscribes to the same viewpoint when he states: "Towards the close of the Jurassic period, the great mountain chains, composed of anticlinally folded Table Mountain Sandstone of the Cape Folded Belt were already in existence." The pre-Cretaceous landscape was, therefore rugged. Walker (1952,p. 12) set the date for this occurrence at 160m.y. B.P.

Mabbutt (1952,p. 23) maintains that since the Hottentots Holland and other mountains of the Southern Cape were last disrupted by faulting in Late Cretaceous times -- approximately 70m.y. B.P. -- the upland relief of the Peninsula could be of the same age. Since the oldest features in the landscape of the Peninsula are the mature plateau valleys of Table Mountain, the surface manifestation of the study area can thus be said to date from this time --- not necessarily in its present form though.

It is the considered opinion of the writer that the Cape Peninsula was "born" largely as a result of the action of running water which transported vast quantities of sediment from the north-western and northern provenance areas in the interior to the Cape Basin where it was deposited. Earlier, reference has been made to the work done by Rust (1973,p. 256) in which he declares rather emphatically that there is little doubt that the Peninsula sand was deposited sub-aqueously, and that fossil evidence indicates the milieu to have been marine. (See p. 17). Since its formation and subsequent uplift, water has once again played a dominant role in sculpturing the Peninsular landscape --- whether that water happens to be the ocean lapping its shores at present or the running water in the form of myriads of streams traversing the surface of the study area on its way back to the oceans whence it came --- to complete the Hydrologic Cycle.

It must be pointed out though, that whereas the work of the sea in sculpturing the landscape is restricted to the littoral zone as presently constituted, this was not always so because the land-sea relationship is a constantly changing one. Throughout the Phanerozoic the sea-level has been variable. (Fig. 2.1) In his estimated of the magnitude of terrestrial oscillation for Southern Africa during Miocene and Pliocene times, Prof. Schwarz (1912,p. 549) puts vertical rise and sinking at 2 640m of total movement. Krige (1927,p. 24) put the entire oscillation of uplift at 720m. Mabbutt (1952,p. 24), in his reference to the mature plateau valleys of Table Mountain estimates that their subsequent uplift after formation to be approximately 720m. In his discussion relating to the Denudation of the Hinterland du Toit (1933,p. 4) estimates that the interior must have experienced an effective uplift of at least 600m, probably much more. This would yield an average estimated uplift of 1 170m. Whilst figures such as these do not have any real value as such, they do, however, provide some index of the estimated uplift which has occurred during the past.

If it is accepted that movements of South Africa were in a vertical plane, during which transgressions and regressions by the sea would have taken place, and conditional

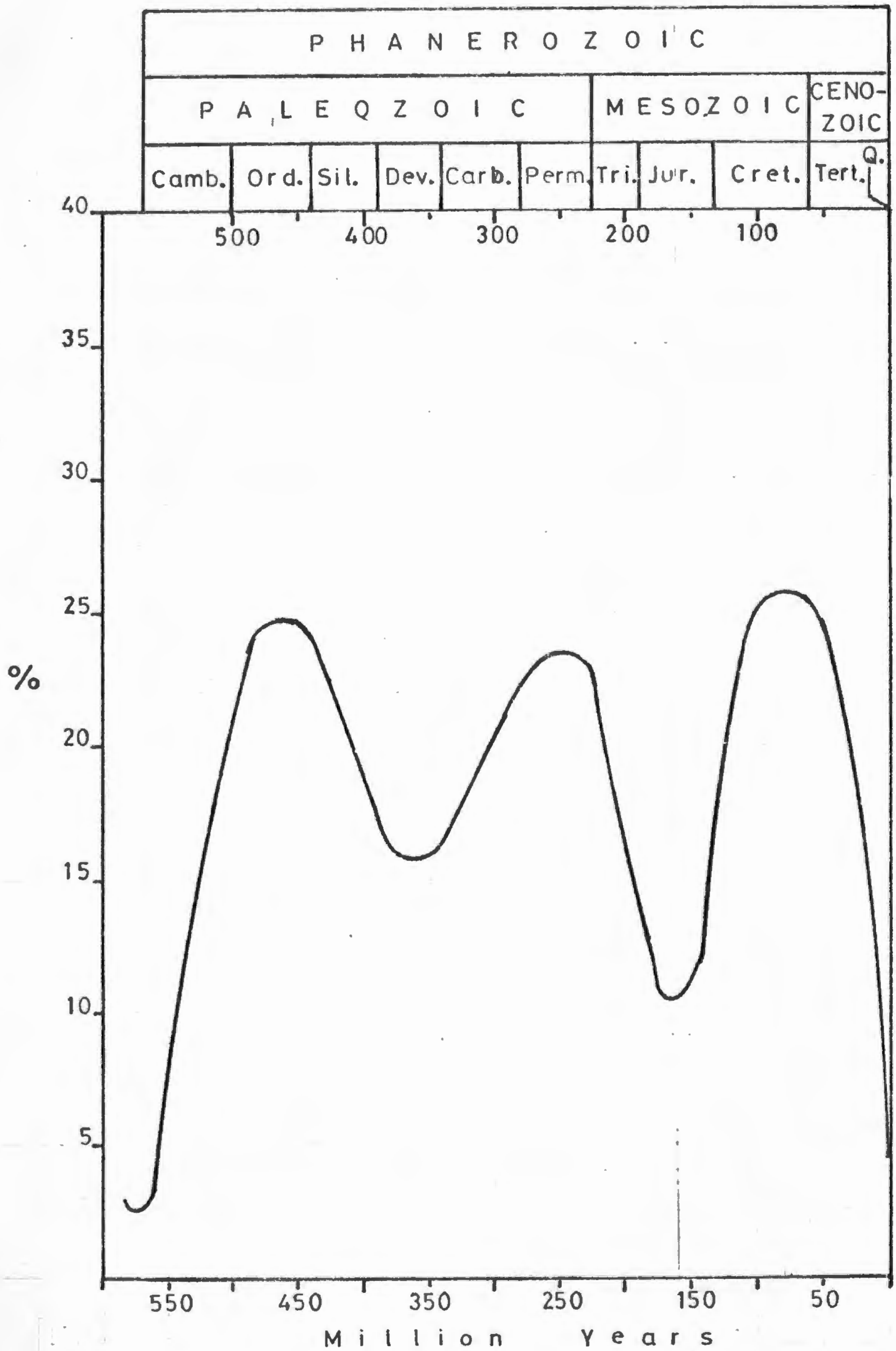


Fig. 2.1

Phanerozoic sea-level changes

(After Damon, 1971 in Mörner, 1976 p. 140) upon acceptance of the estimated uplift of 1 170m, then it is clear that the sea could possibly have planed over large parts of the study area and at times even over the entire Cape Peninsula. Dependent upon the period of zero movement the sea would also have left its imprint upon the surface of the areal matrix. In the following pages an attempt will be made to produce evidence to support the above assertion.

In his search to identify a few main sea levels which could be used as planes of reference for locating the minor ones Baulig (1935,p. 8) turns to Geomorphology which, to him, seems to open more promising ways. He finds erosional forms, especially when cut in harder rocks to be much more significant and reliable than constructional ones on account of the length of time required for their development, because of their durability, and also since they occur at definite levels. He further asserts that such protracted pauses could not have occurred very often during the short duration of the Pleistocene, for example. Both Gatehouse (1955,p. 256) and Mabbutt (1955,p. 263) also find constructional features to be unsatisfactory guides to former water planes.

Evidence of erosional forms within the study area will be cited to emphasise the important role which has been played by the sea in sculpturing the landscape. Attention will be paid to the role running water has played at a later stage.

THE OCEAN LEVEL

Mörner (1976,p. 128), writing about the ocean level states that there are four terms related to sea-level changes, each having its own implication and meaning: (i) relative sea-level changes or shore level displacement, (ii) ocean water volume changes, (iii) eustatic changes (= vertical ocean level changes), and (iv) geodetic sea-level changes or geoid changes (= ocean level distribution changes).

The relative sea-level changes (or shorelevel displacement) can thus be said to be the f'nction of land / sea changes, the land being influenced by crustal movements and the sea being controlled by eustasy and local meteorological, hydrological and oceanographic changes. Mörner (1976,p. 135) avers that the relative sea-level records are a function of eustasy and crustal movements, plus the local effects of changes in the geoid itself. There are thus three main eustatic variables: (1) glacial eustasy, (2) tectono-eustasy and (3) geoidal eustasy.

In the Cape Peninsula the presence of coastal and other features such as:-

(i) planation surfaces
(ii) raised beaches
(iii) a breached watershed
(iv) old littoral or marine benches
(v) wave-vut platforms
(vi) marine terraces and
(vvi) old sea caves

all bear silent testimony to (a) movements of emergence and (b) marine erosion in the past.

It is intended to discuss this evidence of relative changes of level between land and sea in terms of the following, namely:-

(1) orogenesis
(2) the subsequent break-up of Gondwanaland
(3) changes in the geoid itself
(4) continent-making or epeirogenic movements
(5) eustasy.

(1) Orogenesis

In an earlier section, the Cape orogeny was discussed within the framework of four main points (see p. 29), and the resultant tensional conditions in the crust of the sub-continent together with the various theories extant regarding the formation of the Cape Fold Belt.

In a reference to orogenesis Ollier (1981,p. 237) points out that periods of mountain-building correspond with regression by the sea whilst intervals of continental erosion are accompanied by transgression.

(2) The break-up of Gondwanaland

At times between the Middle Jurassic and Early Cretaceous periods the super-continent rifted and its various fragments began to glide laterally across the face of the globe to their present relative positions. King (1936,p. 206) points out that the rifting of Gondwanaland, with the production of the present continents created new coast-lines and low, fresh base-levels --- thus promoting large-scale erosion by the sea and running water, together with other agents of denudation.

(3) Changes in the geoid itself.

Mörner (1976,p. 140) is of the opinion that at the time of the Gondwana super-continent, the earth in all probability had a drastic pear shape. He further contends that if the geoid relief moves and/or changes its magnitude, it will produce sea-level changes of sufficient amplitude that differ in amount and even sign over the globe.

During the remainder of the Mesozoic the erosion of the "post-Gondwana landscape" produced vast amounts of detritus which, in the case of the Cape Peninsula was deposited largely seaward where it covered the downwarped surface of the primitive continental shelf. It was also deposited in the adjacent ocean basins.

The Middle Cretaceous is well known as a period of world-wide crustal instability, so far as this part of the world is concerned. There are reasons for presuming that the process of disruption of Gondwanaland was specially active during this period, is the contention of du Toit (1922,p. 6).

(4) (a) Denudation and Changes during the Cainozoic

During the Tertiary, degradation took place on a vast scale. Prof. Schwarz (1912,p. 544) writes: "There seems to have gone on a contemporaneous erosion and deposition of a peculiar kind and on a gigantic scale." The vast amounts of sediments which have been deposited along the South African coasts indicate how much sialic material has been deposited in the sea as a result of fluvial and marine action. du Toit (1933,p. 1) is of the opinion that the mean rate of erosion over South Africa is some 30cm during 2 500 - 3 000 yrs. This figure is distinctly greater than those obtained in other countries such as the United States where the surface is being lowered at the rate of 30cm in 9 170 yrs.

By means of seismic refraction Ewing, Carpenter, Windisch and Ewing (1973,p. 85) found the average thickness of sediment in the South Atlantic to be 0,7 km. Dingle (1971,p. 177) determined that the Tertiary sediments on the continental margins of South Africa were not of a uniform thickness, but, as a result of an uneven ocean floor varied appreciably from place to place. Using a 3 000 Joule E.G. & G. Sparkarray System he measured three large zones between Cape Point and longitude 21° E and found them to be covered with sediments less than 200m thick. Just north of the Cape Peninsula he found Tertiary sediments with a thickness in excess of 600m. The measurements were carried out from the U.C.T. research vessel Thomas B. Davie.

The thickness of these deposits provide an index of the extent to which the surface of the study area has been lowered and the amount of compensatory uplift which would, no doubt, have resulted during geologic times.

Using the present Disa river as an example of a geomorphic agent in modifying the surface of the study area, the writer feels that it is not unreasonable to infer that the present amphitheatre consisting of Cape Town and environs located between Devil's Peak, Table Mountain and Signal Hill could have been carved out by a drainage system no longer in existence. This could have occurred under climatic conditions differing markedly from those appertaining at present. This would account for the "anomalously thick" layers of sediment just to the north of the study area measured by Dingle (1971,p. 177).

(4) (b) Erosion - Epeirogenic movements and Isostasy

There are two theories concerning the way in which isostasy acts to buoy up or compensate mountain masses and continents. Pratt's theory assumes that different parts of the lithosphere have a different density and float on a uniformly dense substratum. The less dense crustal blocks float higher, forming mountains and the more dense blocks form basins and lowlands. This seems to be essentially the case, for the difference between continents and oceans. Airy's theory assumes that the various parts of the lithosphere have approximately the same density, but have different thicknesses. As a result, high mountains not only project upwards, but also have roots extending into the deeper substratum. Thick parts of the lithosphere should form mountains, and thin parts should form lowlands. Both theories assume the presence of a dense fluid or substratum which is plastic, in which the lithospheric blocks float — the layer now referred to as the asthenosphere. (See Fig. 2.2). Both theories account for the deficiency of mass under high mountains, but Airy's theory is now thought to provide a better explenation of mountains within continental regions.

The laws of tectonics act on the continents just as they would on a raft or iceberg. If we melt the top of an iceberg, the berg rises further out of the water. If, on the other hand the load on a raft or ship is increased, it sinks further into the water. Thus, on the same basis, if the continents are loaded with vast amounts of sediment or an ice-cap they will be depressed. Ollier (1981,p. 238) thus is of the opinion that periods of erosion and deposition should produce partially-planated continents and marine transgression, whilst periods of mountain-building on the other hand should cause uplift to get ahead of erosion and so bring about marine regression or a negative shift in sea-level.

RISING OF THE COASTAL ZONE

The continual wearing-down of the land by the action of the rivers, wind and other agents gradually lightens the land mass, consequently it tends to rise, while deposition upon the ocean floor adjoining weigh down the latter and tends to make it subside. There are, consequently, two opposed movements in action over the continents and the oceans respectively, and the continental borders therefore constitute belts along which either flexing and faulting of the crust would have to take place, and where tilting of the surface in a seaward direction might consequently result. This is particularly noticeable in the southern Cape Peninsula where the strata dip in a westerly direction.

So long as land and sea maintain their general position, so must there be this continual adjustment, though

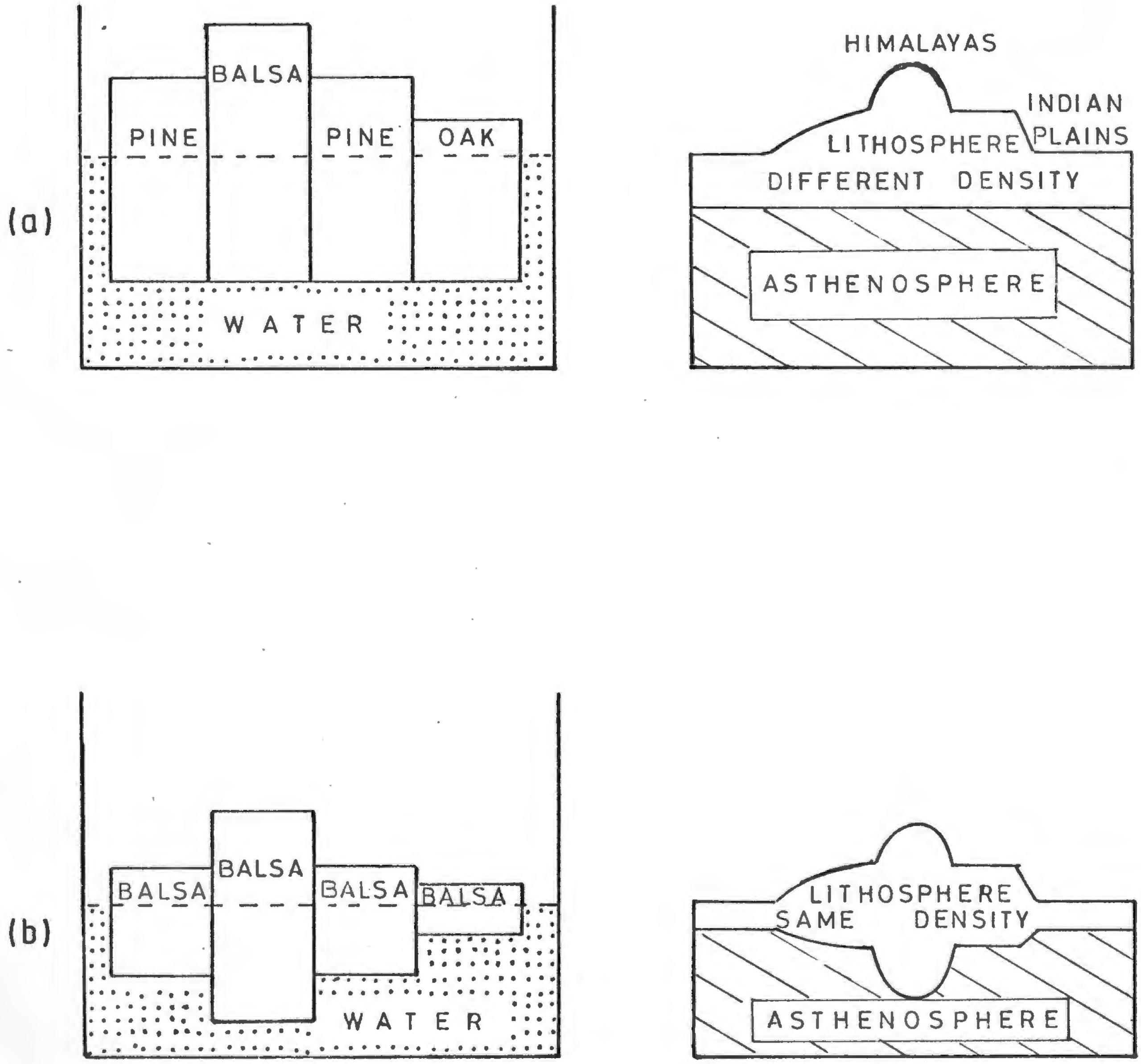


Fig. 2.2 (After Ollier 1981, p. 31)

(a) The Pratt theory of isostasy explains topography by blocks of different density above a general level of compensation.

(b) The Airy theory of isostasy explains topography by varying thicknesses of material of uniform density over an irregular base.

for various reasons the process is commonly not a steady one, but intermittent and occasionally spasmodic. Prof. Schwarz (1912,p. 92) whilst writing about Dynamic Geology asserts that the relief from or adjustment to overloading is usually obtained by fits and starts, not continuously, so there is a long period of quiescence, during which the strain becomes too great and the earth's crust gives along a line of fault.

Not only so, but it usually happens that when movement does occur of this nature, the segment of the earth springs up more than equilibrium demands, and as a result there is an adjustment afterwards when the section elevated sinks slightly. In an analysis of upheaval and subsidence Prof. Schwarz (1912,p. 92) maintains that ..."sinking and rising go on continuously, now one predominating, now the other." He contends further that South Africa at present is on the rise, but that the movement is one following a period of subsidence. Krige (1927,p. 10), whilst discussing the history of the South African coastline comments as follows: "A phenomenon which certainly deserves attention is the apparent uniformity of movement both of emergence and subsidence in South Africa since Middle Tertiary time."

Philip King (1955,p. 723) in his paper "Orogeny and Epeirogeny through time" is of the opinion that orogeny and epeirogeny are episodic rather than continuous. The same point is made by du Toit (1922,p. 22), who maintains that the response of the land to unloading may not always be immediate or complete, and that the rising of the land would be irregular rather than continuous, that is to say, a period of rapid upheaval until equilibrium has been attained, being followed by one of apparent crustal quiescence.

From the Middle Cretaceous onwards the intense and localised orogenic disturbances that produced belts of folding and fracture gave way to more widespread and even movements, but in an upward or downward direction instead, predominantly the former, accompanied only by slight warping. Bucher (1933, p. 1 403), whilst commenting on orogenesis and epeirogenesis has the following to say,

> "In the one case the horizontal displacement dominates the results, in the other, the vertical. Are we really gaining anything fundamental by calling the former 'orogenic' and the latter 'epeirogenic'? The way we speak of one kind of deformation 'dominating' suggests the possibility that the two are due to two components of one and the same fundamental process."

Visser (1957,p. xlviii) is in agreement with this line of thought and avers, in a discussion relating to the Cape orogenic period that, subsequent to the folding, the onward adjustment of the crust to tangential stresses became significantly unimportant and radial stresses made themselves felt in uplift and subsidence of the continent which is well evidenced in the coastal regions.

"It can be doubted whether there is any other land except South Africa that can show so simply and convincingly the results of unloading under erosion, uncomplicated by other disturbing influences," writes du Toit (1933,p. 2). He goes on to assert that conditions in Central Africa were rather different, and declares emphatically that in his own mind he is convinced that in South Africa isostatic adjustment was the dominating control.

The chief objective of the preceding has been to emphasise the considerable amount of emergence which has occurred in Southern Africa in general, and the Cape Peninsula in particular.

PLANATION SURFACES, WAVE-WASHED PLATFORMS, RAISED BEACHES ....

It has been pointed out in the preceding that the elevation of the land is not a continuous even process, but rather an intermittent and occasionally spasmodic one. Baulig (1935,p. 29), whilst writing about isostasy asserts that what-ever the true explanation might be, it would appear that for isostasy to comply with the requirements of geomorphology, it could not be perfect and continuous, but only approximate and intermittent. Prof. Schwarz (1906,p. 70) refers to what he terms "set-backs" which allow the wash of the breakers to cut level plateaux of marine denudation. He further contends that Southern Africa seems to have been subjected to lifts of 180-210m or so with smaller intermediary halts and set-backs. In a subsequent paper Prof. Schwarz (1912,p. 95) refers to smaller shifts of 15 - 30m at a time. Mabbutt (1952,p. 25) also recognizes what he terms "sub-stages" in the elevatory process.

THE PRE - PENINSULAR LANDSCAPE

The False Bay Anticline

Little is known of the history of the research area during the period which followed the folding and faulting of the beds of the Cape System. This period preceded the planation and uplift which resulted in the formation of the various denudational levels now preserved as the few visible records of that time.

Haughton (1933,p. 58), however, maintains that there are theoretical grounds for believing that the form of the low-lying area now called the Cape Flats was initiated at an early stage of that period referred to above, namely Middle Jurassic to Late Cretaceous ($\pm$ 160 m.y. B.P. - $\pm$ 70 m.y. B.P.) He is of the opinion that the T. M. S. of the Peninsula after the Cape Orogeny was continuous with that of the Hottentots Holland, and was probably bent in the form of an anticlinal arch over the present-day Cape Flats. He is supported in this assertion by Walker (1952,p. 23). The latter refers to the Cape Flats as an area which must already have existed as a broad lowland where the T. M. S. had been removed along the axis of an upfold. Prof. Schwarz (1906,p. 78), in his reference to the Cape Flats describes it as a

... "dune-covered area underlain by ironstone-gravel (the so-called laterite), which rests on the original surface of the Malmesbury Beds." Haughton (1933,p. 12) reinforces this point by emphasising the fact that there are very few outcrops of solid rock in the area under consideration. This is further verified by the Map of the Peninsula by Scholtz (1946). (See Fig. 5.2). Since the Malmesbury Beds are not very resistant to the forces of erosion Prof. Schwarz (1906,p. 78) has no hesitation in declaring, "Therefore I see no hindrance in the nature of the deposits found in the Cape Flats, to the acceptance of the agency of sea-waves in cutting the original plain." King (1963,p. 66), in his reference to Table Mountain as an example of ..."a fine synclinal mountain" makes the same point. Prof. Talbot (1971,p. 7) refers to Table Mountain as representing ... "the last remaining fragment of the western limb of a broad anticline." Swanevelder (1975, p. 10), too, refers to the possibility of an anticline having once existed over False Bay. du Toit (1922,p. 12), whilst not as explicit as the authorities previously referred to, writes about the post-glacial epoch of the Pleistocene as follows: "The waves of the invading ocean attacked the old land mass and soon the present outline became established in all but details." He also states that the softer formations elsewhere resulted in the formation of such large indentations as False, Mossel, Plettenberg and Algoa Bays.

In view of the fact that most of the Cape mountain ranges are anticlinal structures and that the formation of strike valleys has taken place along the synclinal axes, it is scarcely possible to assume that the crest of what may be termed the False Bay anticline would give rise to a valley without the superposition of disrupting forces resulting in the weakening of the anticlinal structure. These forces are most likely to have produced faulting similar to that seen in the remnants of the arch. van der Merwe (1963,p. 75) has classified the fault structures of the Peninsula as belonging to three different periods, with the Fish Hoek Fault as an example of the youngest of these faults. Such faulting, resulting in either a rift-valley structure, or in a series of steps need not have been of large dimensions. If it took place when the crest of the arch was at or near sea-level, and was followed by slow uplift, the postulate of a "False Bay anticline" becomes a feasible hypothesis.

If one accepts the continuity of Table Mountain with the Hottentots Holland mountains via the False Bay anti-cline, the presence of the primitive isopodus crustacean Phreatoicus, which is now confined to similar localities in the Hottentots Holland and other mountains of the Southern Cape is not an anomalous occurrence.

If the question is put: "Why has the False Bay anticline disappeared and Table Mountain as a synclinal structure, together with the rest of the study area sur-vived?": then the answer has to be sought within the frame-work of structural geology.

T. V. Bulpin (1977,p. 32), in a reference to the Cape Peninsula puts the matter as follows: "The sea lashes at it, and great rollers relentlessly pound at its rocky shore. Only a solid foundation of granite gives it the strength to defy innumerable storms." His allusion to a granitic base is verified by du Toit (1954,p. 174) and Truswell (1977,p. 98) in their statements regarding the size of the Cape Peninsula Pluton.

The False Bay anticline on the other hand, as indicated earlier by reference to Prof. Schwarz (1906,p. 78), Haughton (1933,p. 12) and Scholtz (1946 : Map) lacked this granitic base and only rested upon a weak foundation con-sisting of the Malmesbury Beds. As such it was unable to resist the forces of destruction.

CYCLICAL LANDSCAPES

It has been argued by Prof. Schwarz (1912), Dixey (1942), Scholtz (1946), du Toit (19[illegible]4), King (1963), Buckle (1978) and others, that the geomorphology of South Africa is policyclic, representing a series of partially complete erosion surfaces, with the earliest dating back to an unfragmented Gondwanaland in the Jurassic: that each cycle was initiated at the coastline following uplift. This is a viewpoint to which the present writer also subscribes.

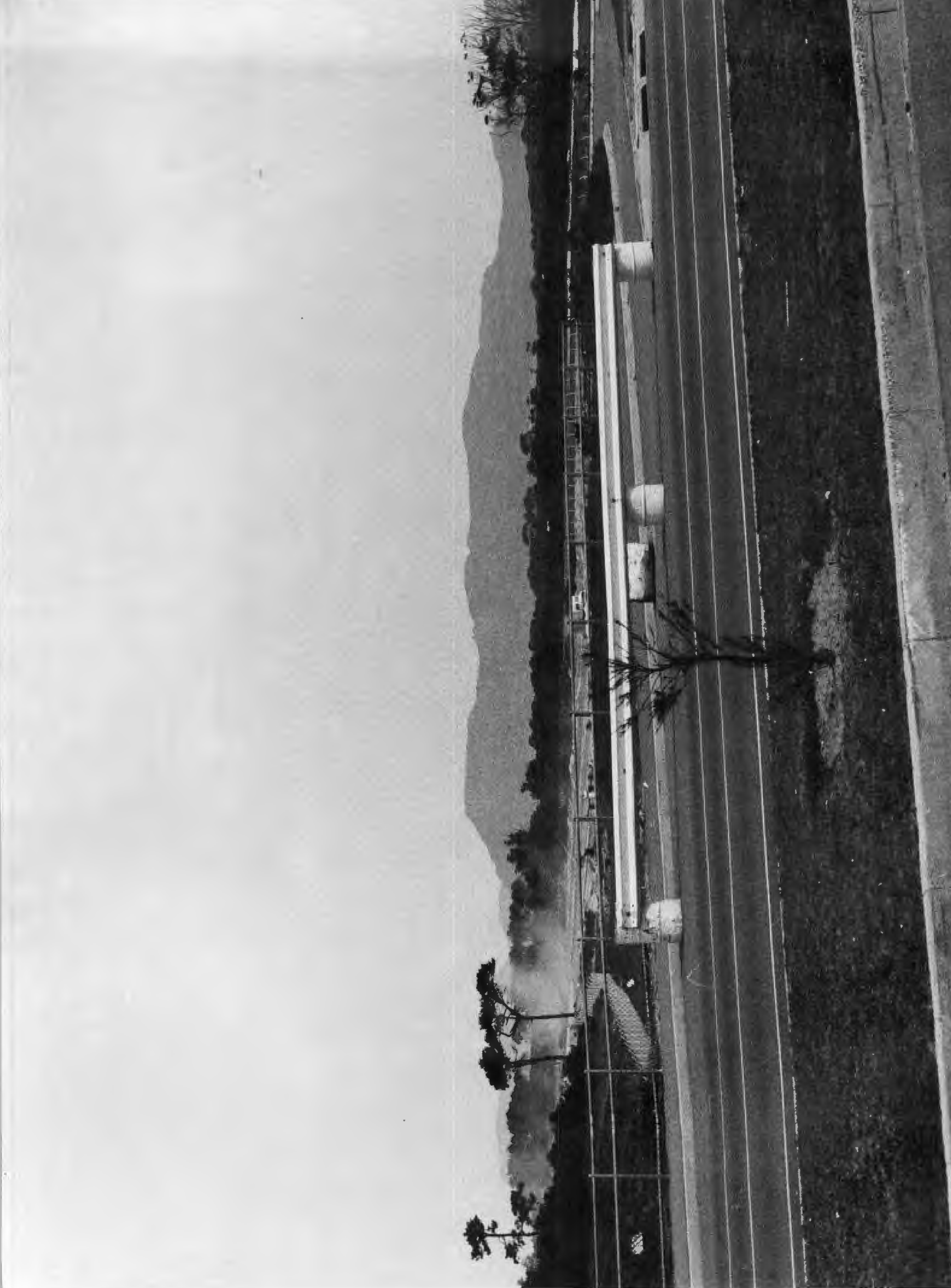
In the past attention has repeatedly been drawn to the presence in South Africa of a succession of plateaux, including submarine shelves, dissected to varying degrees. Prof. Schwarz (1912,p. 548) recognizes a peneplain of Middle Tertiary age at a height of 1 200m inside the coastal ranges and along the southern escarpment of the Amatolas. He also refers to a widespread peneplain at 750m, called in his paper on Coastal Terraces the Kentani Plateau. Another rise enabled a coastal shelf to be cut at 300m. From now onwards he states that there is a succession of ledges --- a klimaktopedion --- cut at intervals of 15 - 30m down to the 90 fathom isobath on the outer edge of the Agulhas Bank.

This viewpoint accords well with the work done by King (1963,p. 202-204), who views Southern Africa as a multicyclic landscape which has experienced strong uplift during the past 150 million years or so. He envisaged strong uplift on at least six different occasions and devised his model of landscape development which he calls the Standard Cycle of Denudation.

In the study area, with the sea as one of the major agents of weathering and erosion, different erosional levels are to be found indicating the land-sea relationship at various times in the past.

PLATE

1



The Steenberg Plateau: a denudational terrace of Middle Tertiary age 420 - 450 metres above sea-level.

DENUDATIONAL LEVELS

In a paper relating to the marine origin of the rock shelves and levels in the south-western Cape, Prof. Schwarz (1906,p. 83) suggests the summit of Table Mountain as a possible 1 050m denudational terrace. Prof. Schwarz, however, decides not to press this physical feature into a theory unless other confirmatory facts can be gathered. One reason given by him for desisting from such a line of thought is the fact that no other examples of a 1 050m terrace on the coast-side of the mountains along the south coast is to be found. If, on the other hand the estimated average uplift of 1 170m for the study area is accepted, then such a postulate sounds feasible and acceptable.

At some time during the Tertiary the South African continent must have stood nearly 450m lower than it does at present, and a broad continental shelf was cut by the sea, with an equally extensive coastal plain stretching inland from the shore. Evidence of such a denudational terrace in the study area is to be found in the plateau landscape of the Steenberg mountains between 420 - 450m above sea-level. Allowing sufficient time for planation, this surface would appear to be of Middle Tertiary age, making it approximately 30 million years old. (See Plate 1).

Subsequent uplift of approximately 150m followed and the next still-stand in the elevatory process occurred around the 300m contour. East of Red Hill Farm and Dido Valley the remnants of such a plateau are to be found. Most of the ridges and hills in the area attain a height of between 285 - 315m. This would appear to indicate that an extensive level plateau must have existed prior to valley formation by running water. In the absence of deposits it is difficult to determine how much was eroded by rivers and how much by the waves. The shoreline then must have been near the 300m contour.

In the northern sector of the study area, along the Atlantic coast there is evidence of a bench which occurs at approximately 285m above sea-level. It is covered in places by a large amount of recent scree material. This bench occurs along the slopes of the mountain south of Kloof Nek. Its best exposure occurs along the pipe track which runs south from Kloof Nek, between Diepsloot and Slangoolie Ravine on the flanks of Table Mountain (Western Table) and the slopes of the Twelve Apostles. It is indicated by an abrupt change of profile at the altitude indicated above. Here the ordinary graded slope of the granite surface on which the talus rests is interrupted on the seaward side by a sudden increase in steepness, forming a well-marked step.

Dingle (1971,p. 183), as a result of his study of seismic profiles across the continental shelf of the south and west coasts of the Cape Province concludes that there can be little doubt that a major transgression took place during Early Tertiary time (Palaeocene - Eocene). du Toit's (1954,p. 454) "Higher Peneplane" which rises from about 300m in the west (False Bay) corresponds with this. In the eastern Cape, Ruddock (1968,p. 228) too has found evidence of a major marine incursion during Early Tertiary times.

At the northern end of Signal Hill there is a marked decrease in slope with the formation of a narrow bench just below the Signal Station at a level that is practically the same as the top of the ridge between the station and the foot of Lion's Head. Haughton (1933,p. 11) refers to a better marked terrace on which the Battery is placed around the 155m mark.

Running parallel to the bench previously referred to (i.e. at a height of 285m) another well-marked step at a lower altitude of 160 - 165m occurs. This has been cut in the granite slopes above Clifton.

Kloof Nek has been cut at an elevation of 165m. So too is Hout Bay Nek, and on the eastern slopes of

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Planation by the sea has produced this level, open terrain at an altitude of approximately 120 metres within the Cape of Good Hope Nature Reserve.

Lion's Head a distinct bench is noticeable at the same height. If these 165m levels should be joined as a surface, it would follow that local proof exists of an elevation of approximately 165m for the continental surface relative to sea-level. It can be interpreted therefore that it is no mere coincidence that Hout Bay Nek and Kloof Nek are points of equal elevation. They were once part of a more level surface, and elevated since, whilst the ledges would have been cut in the mountain slopes during that period of quiescence or still stand.

Related valley and plateau levels occur south of Kommetjie and elsewhere in the southern Peninsula, whilst the higher ground surfaces near Constantia at this elevation may have been fashioned at that time.

The next uplift, followed by a period of still stand saw the commencement of a new period of planation. The area to the south of Scarborough and the Schuster's river to the west of the Swartkop mountains, Kanonkop, Die Boer and Paul's Peak fringing the western margin of False Bay in the Cape of Good Hope Nature Reserve was planed down during this period. Planation by the sea produced a fairly level, open area with very slight gradients having indecisive and poorly defined drainage. This feature is brought out fairly well in Plate 2. The area slopes in a westerly direction. This open area runs up against the Swartkop mountains, Kanonkop and other peaks to the east of the area at an altitude of approximately 120m indicating the sea-level at that time.

The surface of the study area referred to in the paragraph above was greater then in an easterly direction, since the watershed and certain valleys tributary to the Smitswinkel Flats have been subsequently truncated by the action of the falling sea on the western shores of False Bay. (See Plate 3).

Uplift between the 120 - 60m stage was very gradual, with the result that extensive planation by the sea occurred

PLATE

3

The watershed near the False Bay coast south of Smitswinkel Bay breached by the action of the falling sea during Late Tertiary times. Judas Peak (323 metres) in the foreground. Note the inclined strata.

during this period of slow uplift and equally slow regression by the sea. This had the effect of producing a level, open landscape with gentle gradients. During this period the Klaasjagers Valley was extended north-westwards as a result of shoreline retreat, whilst the watershed near the False Bay coast south of the Swartkop mountains was breached by cliff retreat. (Plate 3).

The next pause in uplift occurred at the 60m mark. This shelf, between 60 - 75m above sea-level can be clearly discerned in the field along much of the Atlantic coast of the southern Cape Peninsula extending from Cape Maclear to the vicinity of Italiaanse Kerkhof in the Cape of Good Hope Nature Reserve. Plate 4, taken along the west coast of the Cape of Good Hope Nature Reserve shows up this aspect of the landscape fairly well. Cape Maclear, according to Mabbutt (1955,p. 63) could have been initiated by marine planation during this period. It has, however, been modified since by sub-aerial erosion.

This shelf is also reflected in the northern half of the study area. Here the less resistant slopes reflect a decided change in gradient with flattening of the profile near the base of the Steenberg and Constantia mountains, and along the northern foot of Devil's Peak between Cape Town and Woodstock near the 60m contour.

The sea has subsequently fallen to its present level. Before this stage was reached though, the land was further elevated up to the time of the Early Pleistocene period. Dingle (1971,p. 183) declares that he finds it unlikely that the Tertiary sea-levels referred to thus far were the result of sea-level movement per se, but that the phenomena were brought about by epeirogenic movement of the continent and its margin, sometimes accompanied by seaward tilting.

Both Dingle (1971,p. 183) and Tankard (1974,p. 265) are of the opinion that a second and third major trans-

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A shelf between 60 - 75 metres above sea-level along the Atlantic coast within the Cape of Good Hope Nature Reserve. Italiaanse Kerkhof in the centre of the picture.

-gression occurred during Miocene and Pliocene times. During this latter period the Varswater Formation was laid down in the vicinity of Saldanha Bay. Reference has previously been made to the work done by Ruddock (1968,p. 228) in the eastern Cape, who has found evidence of three major transgressions --- Early Tertiary (See p. 43), Miocene-Pliocene and Late Pliocene. Visser (1957,p. xlvii) refers to subsidence of approximately 45m during the Quaternary in the north-western Cape, where it was accompanied by warping along a north-south axis. This correlates well with the work done by Tankard (1974,p. 265), who found that the present beach zone in the Saldanha Bay area was approximately 50-55m above sea-level.

During this epoch the area between St. Helena and Saldanha Bay, and between Table Bay and False Bay, together with the zone between Chapman's Bay and Fish Hoek Bay were depressed below sea-level. This was, in all probability Shand's (1913,p. 153) "Cape Strait" which converted the study area into two off-shore islands. The "Cape Strait" separated the northern half of the Peninsula from the mainland via the submerged Cape Flats, and the "Fish Hoek Strait" separated the two halves of the research area via the submerged section between Chapman's Bay and Fish Hoek Bay.

In the adjacent Saldanha Bay area Tankard (1974,p. 265) found the deposits of the Varswater Formation to be located at 30m above the present sea-level. In the Bredasdorp area and neighbouring districts a new coastal plain was cut on which soft, cross-bedded sandy limestone (the Bredasdorp Formation) was deposited during the subsequent emergence. This viewpoint is supported by King (1972,p. 248), who asserts that the Tertiary limestones of the Bredasdorp district are part of the general sedimentary record of the Pliocene transgression. King, by way of substantiation points out that the story of Pliocene marine transgression, followed by regression is consistent over 2 080km of coastline -- thus providing a fair measure of reliability for attempts at correlation. The writer tentatively suggests that the limestone deposits within the study area at Buffels Bay, Bordjiesrif and Kalk Bay could have been deposited during the period referred to above, since their respective heights above sea-level are in phase with those found by King (1972,p. 248) and Tankard (1974,p. 265).

Further evidence for this submergence comes from various sources. Haughton (1929,p. 160) points to the change in the ecological environment which is reflected by the changed fauna, since the raised beaches around Saldanha Bay contain Ostrea and other mollusca which no longer exist on the west coast, but are to be found today in the warmer waters of the south coast. Haughton (1933,p. 59 & 1969,p. 528) refers to other evidence in the form of a shell of Petunculus pilosa, which he picked up on the beach at Blaaubergstrand -- a species which has thus far been recorded only in the Alexandria Beds of the south coast. Haughton (1933,p. 59) refers "well-fossilised shells of Dosinia pubescens and Chamelea" picked up on the beach at Milnerton which are only found on the higher raised beaches of the west coast. Tankard (1974,p. 281), writing from a palaeoenvironmental viewpoint finds that the molluscs present in the Varswater Formation suggest water temperatures considerably warmer (about 3 - 5^{o}C) than today.

This change in ecological environment referred to in the preceding, in which the replacement of warm-water fauna, found in the higher beaches of the west coast by a cold-water fauna in the lower beaches can perhaps be best explained by reference to the work carried out by Siesser (1978,p. 108 - 109). Siesser has presented evidence from Deep Sea Drilling Project (D. S. D. P.) core 361 raised from the sea floor approximately 300 km south-west of Cape Town, which indicates that significant changes in the character of the Benguela Current occurred progressively from Late Miocene - Pliocene times onward. Siesser deduced this from the increased amount of diatom fustules which were present in the core. Abundant diatom production is a feature of cold upwelling water, and this change in character of the Benguela Current from a warm to a cold-water current could be posited as the reason for the change in ecological environment along the west coast of Southern Africa including the study area.

Evidence of a different kind comes from the botanical field. Levyns (1952,p. 67) found that the present-day flora of the Cape Peninsula reflects its past history in its surprisingly large number of endemic species, a feature often associated with insular floras. In this regard Taljaard (1949, p. 25) comments as follows: "The southern peninsula during these times was an island, and as such it still retains many insular aspects." Levyns (1952,p. 67) goes on to point out that within the study area, that part lying south of a line drawn from Fish Hoek to Kommetjie has a distinctive flora and that many species found there do not occur in the northern part of the Peninsula. This would seem to indicate that during the Pliocene-Miocene which, according to Twidale (1976,p. 547) lasted for approximately 24 million years, this southern half of the study area was separated from the northern section by the "Fish Hoek Strait" and over such a long period was enabled to develop its own special species of plants. Taljaard (1949,p. 25) sees the submergence of this zone, with its subsequent uplift as being responsible for the origin of the shallow pans and vleis in the vicinity of Kommetjie.

(5) Eustasy

(a) Late Tertiary

At the close of the Tertiary (Pliocene) the land, as a result of a period of refrigeration had become extended by a very considerable margin southwards. This retreat of the sea apparently did not halt anywhere near the existing coastline --- at least not for long,but continued to regress until the area of the continent had been still more appreciably enlarged. du Toit (1922,p. 12) is of the opinion that this migration of the strand-line was probably the most extensive of any since the beginning of the Cretaceous period. It has been estimated that a belt of between 48 - 72 km must have been laid bare along the Atlantic coastline and in the vicinity of the Cape Peninsula, together with the greater part of the Agulhas Bank in the extreme south.

(b) The Quaternary

The Quaternary for purposes of convenience is divided into the Pleistocene and the Holocene. "The former includes the "ice-age" which started 1.8 m.y. B.P. at the beginning of the Pleistocene, whilst the Holocene is characterised as the short period with higher average temperatures which commenced about 11 000 years ago." Truswell (1977,p. 189). It is difficult to be dogmatic about these estimated periods since Twidale (1976,p. 547) is of the opinion that the Pleistocene may be as little as 600 000 years or as long as 3 to 3,5 m.y. in duration.

It is generally accepted that at the close of the Pliocene a period of refrigeration set in over the globe and that during the "ice-age" of the Pleistocene a vast quantity of water became withdrawn from the oceans to be locked up in the two polar ice-caps and in the extensive sheets of ice that enveloped certain lands. The withdrawal of this water resulted in glacio-eustatic changes in sea-level over the surface of the globe.

Various estimates have been made regarding the volume of water abstracted during this period of refrigeration. Fairbridge (1968,p. 333) asserts that 80×10^6 Km^3 of water in the form of ice was withdrawn from the oceanic resevoirs, which resulted in a lowering of 200m or so of the Pleistocene sea-level. This figure appears to be slightly exaggerated. Ollier (1981,p. 233) estimates that lowering during the last glaciation ranged from 80 - 140m with a present 'best estimate' of about 130m.

That eustatic changes in sea-level occurred during the Pleistocene is generally accepted, but the simplistic explanation that these changes are entirely to be ascribed to the growth and decline of continental glaciers and polar ice-caps is being questioned more and more. Mörner (1976, p. 130) lists no fewer than sixteen multi-disciplinary factors and phenomena that affect the ocean level such as land uplift and subsidence, gravitation and tide-generation forces, different wind effects, water discharge from rivers, and so on.

The Period of Regression

At Strandfontein and Swartklip in False Bay, just outside the study area, beach rock in approximately the present inter-tidal zone has been analysed by Siesser (1974, p. 1849). A C^{14} dating on the beachrock of $25\ 860 \pm \frac{1040}{1190}$ y. B.P., and a date of $25\ 430 \pm \frac{1050}{1210}$ y. B.P. for the laminated calcrete layer overlying the beachrock proved the rock to be relict. Siesser interpreted this to mean that the beachrock was formed in an inter-tidal environment during the withdrawal of the sea from its Würm 1 / 11 interstadial high.

There is abundant evidence for a world-wide high sea-level, equivalent to or slightly lower than the present one during this interstadial. Perhaps the most convincing evidence is the work based on numerous radiocarbon dates by Milliman & Emery (1968,p. 1122), who found that sea-level on the U. S. Atlantic coast was near the present level about

35 000 years B.P., began to recede about 30 000 years B.P., fell slowly until 21 000 years B.P., then more rapidly until a low sea-level of about -130m was reached about 15 000 years B.P. This level ties in well with the 'best estimate' of Ollier (1981,p. 233).

The above evidence also correlates fairly well with that provided by Dingle & Rogers (1972,p. 155), which suggests that the Agulhas Bank was exposed some 20 000 years ago and covered in the Flandrian transgression over the next 10 000 years when the present sea-level was reached about 6 000 years ago. There is evidence to support the palaeogeographic reconstruction shown in Fig. 2.3 . du Toit (1922,p. 11) reports large water-worn boulders which were brought up in a trawl of the "Pieter Faure" some 64 km off the coast of Mossel Bay, thereby supporting his contention (See p. 58) that the coastline was extended during the Pleistocene.

In answer to the question why 26 000-year-old beachrock is found in the present inter-tidal zone, Siesser (1974,p. 1852) avers that Epeirogenesis during the Quaternary has uplifted this part of the coastal landmass (including the Cape Peninsula) in relation to sea-level. Siesser (1974) quoting Haughton (1969,p. 437) confirms what the writer has postulated thus far, namely, that ..."a process of intermittent and irregular uplift of the coastal belt ... began in the early Tertiary and continued intermittently into the Quaternary until the present day."

"Invasion" by the Sea

It is the contention of du Toit (1922,p. 12), that, at the end of the ice-age, "The waves of the invading ocean attacked the old land mass and soon the present coast-line became established in all but details."

If one accepts the evidence provided for the early transgressions during the Tertiary, the Miocene and the Pliocene,

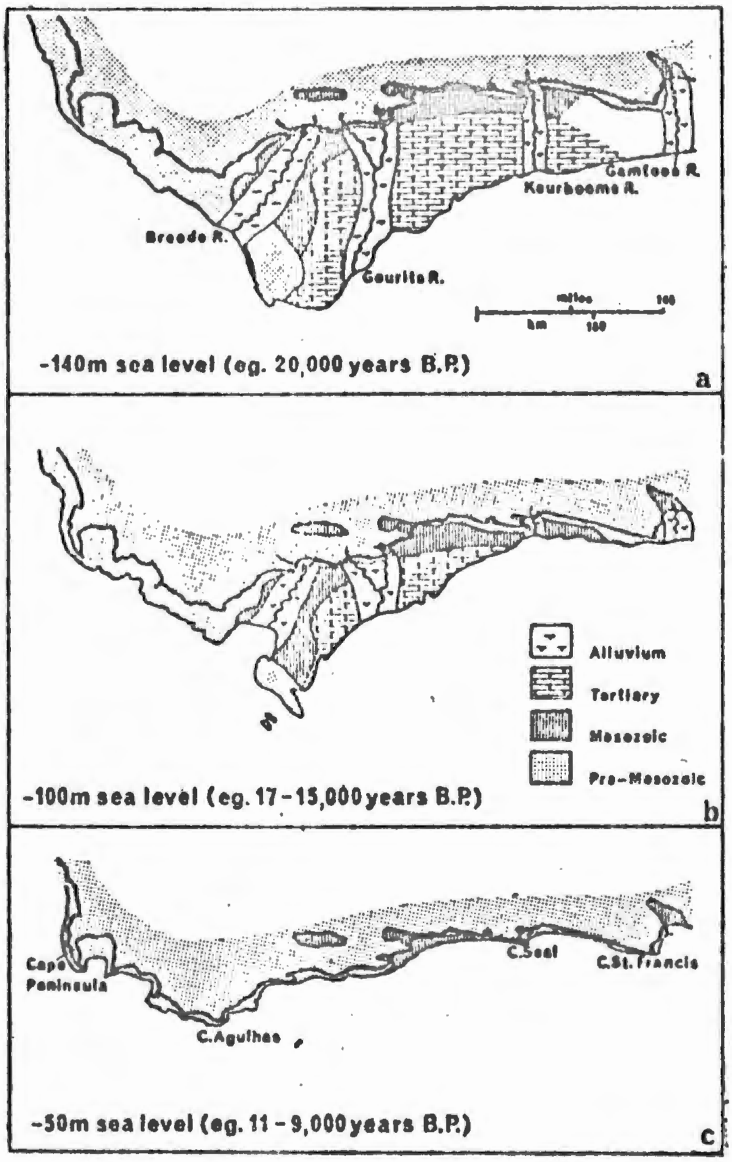

Fig. 2.3 Palaeogeography and the suggested ages applicable to the Flandrian transgression.

(Dingle and Rogers, 1972)

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Inclined rock strata of the Swartkop Mountains dipping towards the west suggest an anticline over False Bay.

and, provided one concurs with the postulate of Shand's (1913,p. 153) "Cape Strait" and, conditional upon the acceptance of Mabbutt's (1952,p. 25) contention that the watershed near the False Bay coast in the vicinity of the Swartkop mountains was breached by cliff retreat during ... "the slow shoreline retreat which followed upon the 400 - 200 ft. stage" (120 - 60m), (for where could the divide have been is not over the present False Bay ?), then Shand's (1913,p. 153) assertion, together with that of du Toit (1922, p. 12) referred to above, plus his claim that.... "False Bay was carved out by the invading sea" further supports the theory of a "False Bay anticline."

Fieldwork provides further evidence in support of this theory. In the Cape of Good Hope Nature Reserve in particular, the layers comprising the Swartkop mountains, Die Boer, Paul's Peak and others are seen to dip noticeably towards the west, suggesting an anticline over False Bay. (See Plate 5). The same phenomenon manifests itself on the eastern side of False Bay, where the layers comprising the Hottentots Holland mountains and particularly those in the vicinity of the Steenbras Dam and Kogel Bay dip sharply in an easterly direction this time, suggesting an anticline over the bay.

The above is supported by botanical evidence. Levyns (1952,p. 67) points out an interesting resemblance between the flora found in the southern half of the Peninsula and that found to the east of False Bay. It is significant to note, and it also seems to be more than a coincidence (as pointed out by Levyns) that certain rare plants such as Audouinia capitata, Mairia coriacea and others are confined to two localities, namely to the south of a line drawn from Kommetjie to Fish Hoek in the Peninsula, and south of an extension of this line across the bay on the eastern shores of False Bay. Does this not, as in the case of the primitive isopodus crustacean Phreatoicus suggest that these two localities were contiguous in the past, but that the sea has been responsible for the present separation?

Recent Events

The most recent event in the coastline history of the study area is that of slight emergence. The land has subsequently been elevated in two distinct stages. The first or "Major Emergence" of Krige (1927,p. 25) is indicated by wave-cut terraces about 15 - 18m above sea-level. These have been dated to the beginning of the Upper Pliocene - Pleistocene. The second or "Minor Emergence" is indicated by wave-cut terraces 6 - 9m above sea-level and took place towards the end of the Pleistocene epoch.

(G) THE "MAJOR EMERGENCE"

Higher Raised - Beaches

Remnants of a wave-cut terrace covered by boulders occur at a few points in the study area approximately 18 - 21m above sea-level.

(i) A good section referred to by Haughton (1933,p. 47) and subsequently by Gatehouse (1955,p. 257) occurs on the road through Oude Kraal south of Camps Bay. Here a storm-beach deposit of well-rounded granite boulders is exposed in a road cutting 19,5 - 24m above sea-level and rests on a weathered, almost planed surface of granite. The surface on which these boulders rests slopes gently seaward, and is interrupted on the seaward side of the road by an abrupt descent to the present beach, and is continued after interruption by the tops of the highest granite stacks which project above the sea. Landwards the slope steepens abruptly and rises to about 36m giving a relict cliff which is a replica of that existing behind the present beach.

Mabbutt (1955,p. 263) in his discussion on a paper by Gatehouse (1955) sees the "double beach" referred to by the latter as a deposit of quartz boulders among the granite blocks, the latter having subsequently weathered down completely.

(ii) A second remnant of the same wave-cut terrace occurs about 1,6km north of Miller's Point. The road is cut through a storm beach deposit cut at 18m above sea-level. The deposit rests in a gap of decomposed granite and is about 55m long from north to south and consists of well-rounded boulders which differ sharply from the angular material found in the talus which is exposed elsewhere along the road and which overlies the beach deposit.

(iii) At Oatlands Point about 1,6km south of Froggy Pond a remnant of this wave-cut terrace is to be found, and is exposed in a road cutting, and also about 180m further north in the playground of a children's camp. Well-preserved beaches are to be found here, the first extending for approximately 135m, with rounded beach stones embedded in weathered granite. Between these two beaches a more recently formed marshy section has brought down many beach stones to a lower level varying from 12 - 13,5m.

(iv) Taljaard (1949,p. 24) in his attempts to explain the origins of the Fish Hoek lowland, which extends from Fish Hoek Bay in the east to Chapman's Bay in the west, refers to the lowland surface which, throughout is less than 23m above sea-level.

He maintains that, provided the wind-blown dune elevations are subtracted, a general elevation of 18m would be obtained for the gap. Taljaard asserts that this lowland gap has clearly not been cut by streams, and no deposits are present to indicate weathering as the main activity. The only conclusion to which one can come is that the Fish Hoek lowland, having been cut by wave action must subsequently been elevated to a height of at least 18m, or else sea-level must have dropped by a similar amount. Evidence of a related kind from other parts of the study area leads one to conclude that the former contention is nearer the truth.

(v) Approximately eight hundred metres south of Sunny Cove a raised beach is to be found at an altitude of 19,5m above sea-level. It manifests itself as a vertical section of the beach lying on a T. M. S. base.

Krige (1927,p. 35), Haughton (1933, p. 49) and Mabbutt (1952,p. 21) all make mention of the well-known terrace which forms Green Point Common. There is a certain ambivalence observable regarding this wave-cut surface. It rises to a height of 18m on the slopes of Signal Hill from the 6 metre-mark above the present sea-level. Since this terrace has been planed on the Malmesbury Beds, which are not very resistant to abrasion, there is no observable break of slope between Higher and Lower raised beaches. The writer would venture to suggest that the falling sea planed the Green Point Common as the continuous sloping surface which we find today.

THE "MINOR EMERGENCE"

Widespread evidence remains of a shoreline 6m above the present one; indeed it is to this shore that much of the present cliff-line belongs.

(a) Along the west coast of the study area a low, emerged

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A raised beach of the Minor Emergence (5,7 metres) at Blouberg-strand within the Cape of Good Hope Nature Reserve. Note the well-rounded quartzitic boulders comprising the storm beach and the sudden descent to the true beach.

bench, running along the foot of the old sea-cliffs can be followed practically without break from Chapman's Bay to the Cape of Good Hope. It often attains its maximum height of 6m and has an average width of 90m.

(b) At Hout Bay, on the landward side of the road, just east of the harbour, a terrace comprised partly of sea shell is to be found at a height between 6 - 7,5m. The overhanging cliff of T. M. S. would suggest undercutting in the formation of the bench.

(c) A similar bench occurs below Paul's Peak on the west coast of False Bay in the vicinity of Venus Pool. The average height of the shelves varies from 2,5 - 3m above sea-level, whilst other shelves occur at 4,5 - 5,5m. Krige (1927,p. 66) has come to the conclusion that the emerged ledges below Paul's Peak indicate a negative shift in sea-level of approximately 6m.

(d) At Kommetjie the raised beach extends for approximately 450m, the entire surface being exposed including the storm beach, which rises to 12m above sea-level in places. The range of characteristics is remarkable. In one section the bench of smooth rock occurs; in another the true or present beach, and finally the storm beach. The smallest pebbles occur at the foot of the beach indicating that no major disturbance has occurred since its formation.

(e) On the west coast of the Cape of Good Hope Nature Reserve at Bloubergstrand, a good example of a wave-cut terrace covered by well-rounded quartzitic boulders occurs. The beach occurs at a height of 5,7m. The beach is fairly extensive and slopes gently seaward. There is an abrupt descent from the storm beach to the present one. (See Plate 6).

(f) An irregular ledge occurs at Simonstown, and also between Fish Hoek and Muizenberg. The railway line in this section has been constructed along this strip. The average height of this bench is approximately 4m, thus serving as a record of the pause at the 4-metre mark before the present sea-level was reached.

Cliffs and Abrasion Platforms

To the west of the area adjoining Cape Maclear, the base of the cliffs lies between 6 - 8 metres above sea-level, thus relating to the "Minor Emergence" of Krige (1927, p. 37). The abrasion platform extends seawards for 45m from the cliff base and descends to within 3 - 5 metres of present sea-level, where it is overlain by a shingle beach. The platform narrows to the rock ledges at Cape Maclear where it is almost continuous with those at Cape Point.

The abrasion platform and rock ledges together appear to embrace the gradual withdrawal from the 6 - 8 metre level, and the pause at 4 metres above present sea-level envisaged by Krige (1927,p. 66).

Caves

Other records of wave erosion during past years, reflecting differing land-sea relationships are to be found in the form of numerous caves along the coastline, both within the study area and without. Krige (1927,p. 46), for example, has found 42 caves and 4 funnel caves on the eastern and western shores of False Bay along. All these caves are well above present sea-level and, in terms of their altitude would fall within Krige's (1927,p. 37) "Minor Emergence."

Near Cape Point, for example, a large cave occurs with a length of 180 metres, a roof height of 12 metres and a maximum floor height of 9 metres above sea-level at the back. Other caves such as Trappiesgrotte, Blaasbalkgrot and others occur on the western flank of False Bay within the Cape of Good Hope Nature Reserve.

This evidence would tend to support the contention of a world-wide post-glacial lowering of sea-level of approximately 6 metres as envisaged by Daly (192o,p. 258). This assertion is strongly supported by Tjia (1968,p. 197) after he had investigated 200 raised stream levels in Java. Tjia concluded that the evidence strongly suggested that the stream levels and marine Daly terraces were genetically related in that both were caused by the sudden lowering of the sea-level during the Pleistocene.

Krige (1927,p. 49) after a study of the floor heights and field relationship concluded, ... "that the caves furnish dedided evidence of a total emergence of almost 20 feet in two distinct stages of about 7 and 13 feet respectively." In his summing-up of all the evidence which he had compiled in the field, Krige (1927,p. 66) concludes that if his evidence were taken in conjunction with similar evidence recorded and compiled by Daly (1920,p. 258) and others from widely separated coasts, such a eustatic negative shift as he and others, such as Daly (1920,p. 261) had postulated could perhaps be regarded as fact and no longer as an hypothesis.

That the land may even yet be slowly rising is pointed to by certain assertions made by Wybergh (1920,p. 63). He cites two examples from Hermanus to support such claims:

(a) a rocky channel which was previously navigable, of which the rocky ocean floor had always been visible, and which had not become silted up in the interim, had become so shallow that vessels could no longer use it;

(b) a certain rock, previously totally submerged was now visible above the ocean level.

This manifestation according to du Toit (1922,p. 12) would imply a rate of upheaval of perhaps 30 cm in 50 years.

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CHAPTER 3

STRUCTURE AND THE PHYSICAL LANDSCAPE

A. INTRODUCTION

In the Northern Peninsula, the base of the quartzitic sandstone liew mainly above sea-level, and the older rocks build the gentler lower slopes. The plateau is highest and most impressive in this section, attaining its greatest height of 1 064,7m at Maclear's Beacon on the northern face of Table Mountain. The plateau surface is often deeply dissected and in places the sandstone has been completely removed, leaving mountain outliers separated by low neks --- such as Kloof Nek and Hout Bay Nek --- from the main plateau.

In the south the basement rocks lie extensively below sea-level, and the plateau falls in steep cliffs to the shore. Here the plateau lies lower, but is less dissected, and the quartzitic sandstone everywhere remains intact. The watershed borders the False Bay coast to Smitswinkel Bay, south of which it has been breached by cliff retreat.

GEOLOGICAL FORMATIONS

The following geological formations have been identified within the study area:

Tertiary and Recent	Dune and beach sand Talus Alluvium Ironstone gravel Surface quartzites Raised beach deposits High level talus River terrace gravels
(Cape System) Table Mountain Series	Glacial band Main sandstone Lower shales
Pre-Cape	Malmesbury Series
Igneous Rocks	Dolerite intrusions Granite

Of the geological formations listed on the pre-preceding page, three make up the bulk of the study area. They are:

(iii) The Table Mountain Series

(ii) Granite

(i) The Malmesbury Series

In a reference to the South-Western Cape, Scholtz (1946,p. xli) makes the following observation: "The South-Western Area provides an excellent illustration of the simple yet powerful glyptogenic process of erosion and denudation unaccompanied by modifying factors so frequently encountered elsewhere, with the net result that the surface form is practically entirely dependent on the geological structure of the area."

Discussing landforms from the same genetic viewpoint, Taljaard (1949,p. 25) interprets the interaction between structure and weathering as a causal factor in the evolution of landforms as follows: "The difference in the mode of weathering of these rocks types therefore results in distinct scenic types of surface."

As this investigation has progressed, the truth of these assertions, particularly the specific reference of Scholtz (1946,p. xli) to the south-western Cape has become more evident to the writer. Within the framework of Scholtz's claim the writer has encountered numerous examples in the field where the surface forms have been largely determined by the underlying geological structure.

Prof. Trueman (1963,p. 11), whilst making basically the same points which have been outlined above, goes on to observe that, "A country is not just a jumble of hills and valleys; the features have a plan, a system underlying their distribution, and once this is understood the region is seen more clearly and its variety more readily appreciated." With reference to the Cape Peninsula, this plan is interpreted quite simply by Haughton (1933,p. 9) who says, "In contrast to the precipitous cliffs formed by the rocks of the Table Mountain Series, the older rocks form gentler slopes, often talus-covered; and it is upon these slopes that the city of Capetown and its suburbs are largely built."

B. THE MALMESBURY SERIES

Rocks of the Malmesbury Series are confined to the northern part of the study area. Thus, from Kirstenbosch to Sea Point dark-coloured, dense rocks are exposed at various places, especially in the stone quarries at Strand Street and on the slopes of Devil's Peak. Green Point Common is underlain by the Malmesbury Beds which are also visible on the shore section from Green Point to Sea Point.

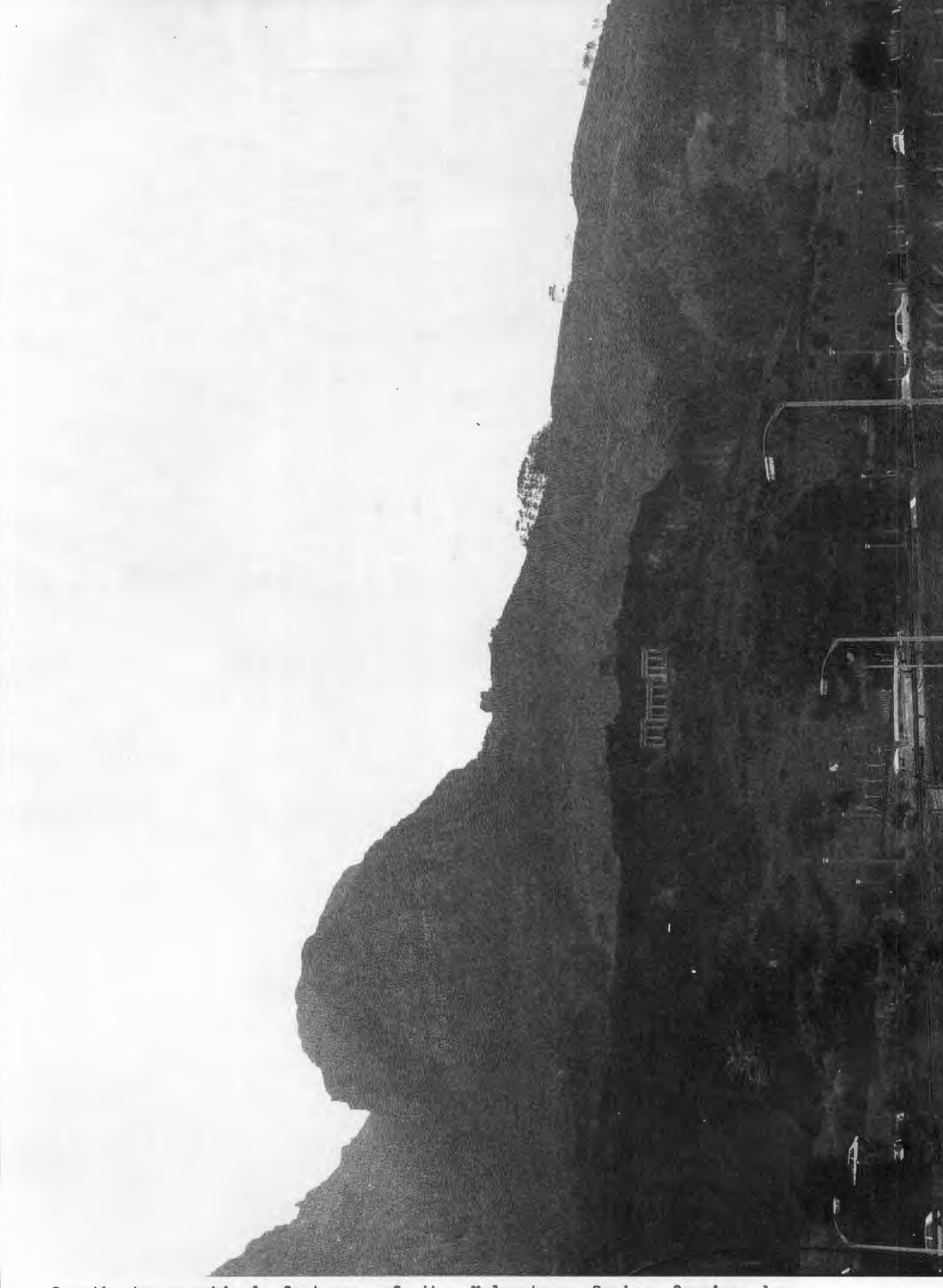
The steeply dipping slates of the Malmesbury Beds underlie Cape Town and the northern suburbs of the study area. Hatch and Corstorphine (1905,p. 34) point out that these beds in many places dip at an angle of 70 to 90 degrees, and that their upturned edges are covered unconformably by younger formations. They also point out that the true base and top of the formation are unknown and, as a result the thickness remains undetermined.

"The rocks consist of micaceous 'clayslates' and fine compact argillaceous quartzite interbedded with one another, the whole dipping at high angles and folded into a series of sharp anticlines and synclines. At the Strand Street quarry the strike is almost N.W. to S.E. and the dip is approximately 80° S.W." (Haughton 1933,p. 15).

On the beach at Mouille Point the writer has found the dip to be 90 degrees in at least two exposures.

PLATE

7



Smooth topographical features of the Malmesbury Series forming low, undulating terrain in the neighbourhood of Rhodes Memorial. Note the marked contrast between the rugged features of the T. M. S. above together with the steep gradients of the latter.

The unweathered rock is dark bluish-grey in colour and, according to Walker (1952,p. 7) is known locally as "Bluestone."

Over much of the study area the rocks are usually decomposed to a depth of many metres, giving rise to clayey or sandy material of white, yellow, red or brown colour, and are hidden over large tracts by thin clayey soil or other superficial deposits. Good exposures are to be seen along the slopes of De Waal Drive, between the intersections with Roeland Street in the north and the Eastern Boulevard in the south.

Referring to the type of landform which the Malmesbury Beds produce Lückhoff (1951,p. 27) makes the following observation: "It forms the mass of Signal Hill and the lower slopes of Devil's Peak giving rise to smooth topographical features in marked contrast to the rugged features of the Table Mountain sandstone." A combination of rapid weathering and high run-off does not favour strong relief. Thus the Malmesbury Beds usually form low, undulating country. (Plate 7).

Mabbutt (1952,p. 15) is of the opinion that Signal Hill exists as an exception which can be explained in one of two ways. Both explanations, however, have their protagonists. One explanation is that local hardening through contact with the invading granite has been responsible for the continued existence of Signal Hill as a feature of reasonably high relief. He is supported in this assertion by Hatch and Corstorphine (1905,p. 41) who state that, "Over the Lion's Rump this contact zone is covered by soil and vegetation." The other explanation is that the hill could have lost a protective capping of T. M. S. fairly recently. Corroboration for this viewpoint comes from Rogers and du Toit (1909,p. 21) who are of the opinion that "The Pre-Cape sedimentary rocks of the south-western coast belt give rise to but few conspicuous hills, and of these in the Peninsula, the highest is Lion's Rump near Cape Town. They owe their existence to former outliers of the Table Mountain Series, now removed by denudation." The writer suggests that the truth in all probability contains elements of both explanations.

The rocks comprising the Malmesbury Series tend to weather deeply and forms a clay soil, often with an ironstone layer. A large proportion of the rainwater runs off the surface of this clay soil to form a close, branching network of small streams with little evident directional control. Because of the great depth of softened rock, streams tend to grow into dongas wherever the vegetative cover has been removed or destroyed.

In his paper on the "Sea-Point Granite-Slate Contact" Prof. Schwarz (1913,p. 34) distinguishes five zones within the vicinity of the contact area on the beach at Sea Point. Here the Malmesbury Beds had been invaded by granite and metamorphosed to spotted rocks and hornfels. Prof. Schwarz (1913,p. 35) points out the following: "In between the places, in one of which there is more slate than granite, and in the other there is more granite than slate, there is an area in which the two are intimately mixed." After days spent in examining what he called .... "This fascinating section" Prof. Schwarz concluded .... "I am perfectly convinced from the evidence there afforded that the granite, in this particular case at any rate, advances by a process of solution and deposition through the agency of water." Rogers and du Toit (1909,p. 34) refer to the belt of "spotting" as being fully 2 km wide.

These metamorphosed rocks are much more resistant to weathering and erosion by the sea or running water. This aspect was referred to earlier in the section dealing with Signal Hill. (See p. 76).

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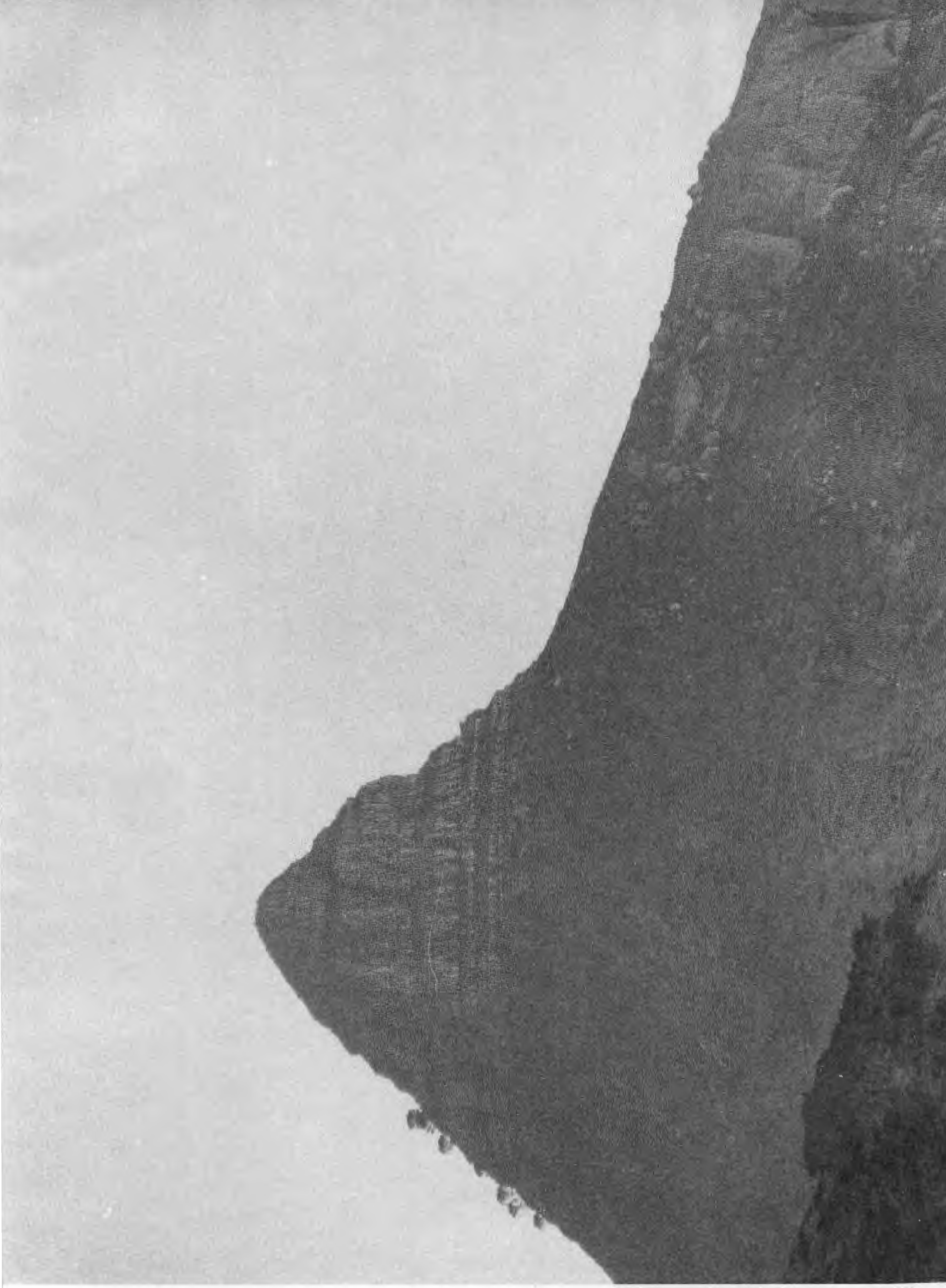

The granite dome at the base of Lion's Head with the remnant of the T. M. S. above. Note the rugged nature of the T. M. S. in marked contrast to the rounded outlines of the granite and the Malmesbury Series.

C. GRANITE

In a chapter devoted to the Pre-Cape Granite, Haughton (1933,p. 33) points out that the separate masses of exposed granite are almost certainly part of one large batholith. He classifies the different masses geographically purely for convenience into the Cape Peninsula Granite, the Stellenbosch and Paarl granite, and so on. Haughton makes it clear that his classification does not imply that the various masses differ from one another in age or composition.

In a subsequent comparative analytical study, Mathias (1940,p. 203) not only confirmed that the Peninsula and Paarl granites belonged to the same age of intrusion, but also concluded that the Aggenys granite could be correlated with the group of Cape Granites to which the Paarl and Cape Peninsula granites belong.

The Cape Town Granite extends the full length of the study area and is almost throughout a grey porphyritic biotite granite with twinned crystals of white microline-perthite up to 7,5cm across, with ubiquitous dark rectangular pseudomorphs in pinite after cordierite and a little muscovite.

Good exposures of granite can be observed at various places in the Peninsula, for example along the road leading from Hout Bay to Chapman's Peak, near Kloof Nek at the base of Lion's Head, the eastern sector of Signal Hill or Lion's Rump and along the Atlantic coast from Sea Point to Llandudno. Granite is also exposed at the base of Wynberg Hill and along the False Bay coast south of Simonstown up to Smitswinkel Bay.

Granite builds the lower slopes in most of the Northern Peninsula. (Plate 8). It is a massive, resistant rock when fresh, but the heat and moisture experienced within the study area appear to favour its fairly rapid chemical breakdown. In this regard, Taljaard (1949,p. 24) observes, "The coarse gritty sands in the rock gullies still display pieces of all these minerals, and it would seem that the granite tends to crumble away to grains rather than blocks, under the high rainfall and temperate weather conditions of the Cape."

During heavy rains, weathered granite may absorb much water and become plastic, so that steep slopes become unstable and the surface layers begin to move downhill. Mabbutt (1952,p. 15) states that this mass movement could range from an imperceptible soil creep to a catastrophic landslide. Crescentic yellow scars above the road south from Hout Bay mark where small landslips have occurred. Along the road from Simonstown to Smitswinkel Bay good exposures of decomposed granite are to be seen. It is in this section with its steep slopes that the tendency to mass movement is reflected in the convex outlines of many weathered granitic slopes.

On very steep slopes, or on the shore where the rocks are washed clean, cuboidal granite blocks may appear. These reveal modes of breakdown which are peculiar to this massive homogenous rock. A second process is the shedding of successive granitic layers which have expanded on weathering, and by means of exfoliation have separated in layers from the rock beneath.

The slope between Wynberg and Constantia is gentler and more stable, and the granite remains completely covered by a thick mantle of the weathered rock. The slopes are well-watered, and have been dissected by the still youthful headwaters of the Diep and Liesbeek Rivers into rounded spurs and deep, sheltered valleys. Taljaard (1949,p. 26) is struck by the concave profiles of these streams in the granite country.

The slopes between Wynberg and Constantia, and Wynberg and the Cape Flats, together with the slopes towards

Kenilworth and Newlands can be seen as being typical of hill country, transitional from mountain to plain. Examples of this type do not occur elsewhere within the study area.

D. THE TABLE MOUNTAIN SERIES

Rocks belonging to this series form nearly all the prominent features of the landscape within the study area. All owe their striking characteristics to the jointed quartzites of which the series is mainly composed.

Twidale (1971,p. 247) writes, "Sandstone, and especially quartzite, is consistently the most resistant of rocks." A sedimentary quartzite consists of quartz fragments cemented together by secondary silica. Quartz has a hardness of 7 on the Mohr scale, and is, moreover chemically almost inert. Though their porosity varies with the degree of cementation, sandstones are characteristically pervious by virtue of their well-developed bedding and jointing. Surface waters tend to percolate through the rock rather than run over and erode the surface. Thus, very little sub-surface solution or erosion, or surface abrasion, is effected. For these reasons, massive quartzites invariably give rise to uplands.

Prof. Talbot (1971,p. 7) explains the pre-eminence of the T. M. S. as makers of mountains in terms of the following: "Wherever they outcrop they rise abruptly to imposing heights; through their remarkable resistance to weathering they dominate the physical landscape."

In a reference to the study area, Prof. Schwarz (1906,p. 78) writes, "The Cape Peninsula extends from Cape Point to Table Bay, and is a precipitous mass of sandstone resting upon a basement of pre-Cape rocks and granite." Hatch and Corstorphine (1905,p. 61) refer to it as, ..."the Cape Peninsula, with its conspicuous northern escarpment forming the precipitous wall of Table Mountain."

The maximum thickness of the series elsewhere is estimated at 1 500m, but nowhere in the study area is it quite so thick. Lithologically it is divided as follows:-

5. Upper Sandstone
4. Upper Shale Band
3. Glacial Band
2. Main Sandstone
1. Lower Shale Band.

Haughton (1969,p. 331) maintains, "The full succession within the series is not displayed on Table Mountain nor within the Cape Peninsula." Only the lower three occur within the study area.

In the landscape the quartzitic sandstones comprising the T. M. S. are generally of a sombre grey, the colour of the lichens that usually cover the rock surface, although when freshly exposed they are a lighter grey, unless stained a rusty brown by ferruginous oxides or darkened by manganese compounds.

The T. M. S. is composed essentially of quartzites. Though the name sandstone is often applied to them, the rocks are rarely typical sandstones, being generally indurated by pressure, and frequently hardened by secondary silification. Weathering tends to change the colour of the quartzites.

Under the microscope the quartzites are seen to contain scales of mica and granules of tourmaline, magnetite and zircon in addition to the predominating quartz grains.

Since the component sand grains are chemically stable, and the silica binding the grains is especially hard and durable, these quartzites are highly resistant to weathering which proceeds but slowly. Thus erosion can accomplish little on the unaltered rock, and its resistance to the forces of destruction finds expression in the mountainous relief of the Peninsula.

At its northern end the base of the T. M. S. stands at about 420 - 450m above sea-level. The higher ground of the study area as a whole is composed of two main masses of the series, separated by an outcrop of granite at Constantia Nek. The northern mass comprises the plateau of Table Mountain; it dominates Hout Bay to the south and Table Bay to the north and north-west, whilst its eastern escarpment, above the Cape Flats faces the interior. In the extreme north of the study area there is a small outlier which forms the upper portion of Lion's Head (654m), which together with Table Mountain (Maclear's Beacon - 1 064,7m) and Devil's Peak (981m) stand in stark contrast to the smooth slopes leading up to them and the rounded outlines of Signal Hill (Lion's Rump - 344m). The north-western corner is occupied by another outlier which, together with Karbonkelberg (642,3m) form the hills separating Hout Bay from the Atlantic.

The general feature made by the T. M. S. right around the study area is a steep escarpment of bare rock, in many places over 300m high.

In the northern area the quartzitic sandstone is confined to the highest ground of the Peninsula, except on the western side of Hout Bay where it reaches sea-level in the vivinity of Leeugat, Duikerpunt, Brako and Duikereiland. The shape of the main mountain mass in the northern portion of the study area is broken by the broad valley of the Disa / Hout Bay river which has incised its way down into the older rocks.

The southern portion of the study area, from Constantia to Cape Point lies at a much lower elevation, averaging less than 300m above sea-level. The base of the Series also occurs at a lower level, so that on the False Bay coast it reaches sea-level at Muizenberg, although on the Atlantic side at the same latitude its base is still many metres above sea-level, that is, in the vicinity of Ratelklip and Chapman's Point.

South of the gap formed by the Fish Hoek valley, the study area is composed almost wholly of rocks of the T. M. S. On the coast near Simonstown, beds of quartzite outcrop on the beach, dipping at high angles of between 70 to 90 degrees. This has probably been caused by local faulting. South of Simonstown the T. M. S. becomes much thinner, and the basement bed rests directly on the granite. The highest point in this southern half occurs on the ridge directly above the False Bay coast -- Swartkop (666,6m). On the western side of this ridge the topography is that of an elevated tableland with seaward cliffs as at Oompiesgat, Gifkommetjie, Bloubergstrand, and so on.

The Lower Shales occur at the base of the T. M. S. Du Toit (1954,p. 241) states that the maximum thickness of these beds in the Peninsula is 45m. Haughton (1933,p. 30) differs slightly from du Toit (1954) and contends that the thickness of the shale band in the Cape Peninsula varies from 45 - 60m. Haughton (1933,p. 30) refers to exposures of the Lower Shales at several points along the Pipe Track between Kasteels Poort and Slangolie Ravine on the western side of Table Mountain, and also on the path leading up Kasteels Poort where the thickness of the shales is about 60m.

These beds consist of red and maroon micaceous shales and flagstones, and exhibit sun-cracked surfaces and worm castings. These beds, being softer than the sandstone or quartzites have frequently been undercut by erosion resulting in the formation of hollows and caves. A fine example of such a cave can be seen in the Woodstock Cave, high up on the north-western side of Devil's Peak. A good exposure of these shales can be seen near the top of Chapman's Peak Drive where the Lower Shale Beds rest unconformably on the underlying granite.

Both horizontal bedding-planes and vertical joints are conspicuous features of the T. M. S., and as such impart a distinctive character to the mass.

The block form of the T. M. S. portion of the northern masses of the Peninsula is largely determined by two sets of prevalent vertical joints which are approximately at right angles. Walker (1952,p. 5) states that these joints are due principally to contraction. The more prominent of these joints as determined by Haughton (1933,p. 10) is one which lies in a direction between W. 25° N. to E. 25° S. and W. 35° N. to E. 35° S. This is well displayed, for example, in the trend of the northern front of the Western Table, in the escarpment on the north side of the Waai Vlei, in the buttresses at the north end of Orange Kloof, in the axis of Karbonkelberg and that of Skildegat Ridge, also in the south face of Kalk Bay mountain, and in the upper reaches of Silvermine Valley. The complementary transverse set of joints is not so apparent at first sight on account of the number of kloofs that cut into the eastern and western sides of the mountain.

The T. M. S. is also traversed by widely-spaced horizontal bedding-planes. These two structures control the form of the mountain faces. Luckhoff (1951,p. 29), whilst discussing the evolution of Table Mountain points out how joint-fracturing parallel to the face has resulted in great blocks breaking off along these "clefts" in the T. M. S., and how these have tumbled down the mountain-side and strewn the slopes with debris, often in huge piles. Above, on the mountain-side, the fresh cliff-face would remain vertical. Joints running into the mountain often form narrow kloofs, such as separate the projecting buttresses of the Twelve Apostles. In this regard Taljaard (1949,p. 26) comments, "The joint planes seem to exercise a marked control on the manner of disintegration of the rocks."

Other noteworthy geological features of the T. M. S. are the horizontal ledges occurring on the buttresses, but almost completely absent on the vertical rock walls such as occur particularly on the Western Table.

Haughton (1933,p. 10) maintains that, "Throughout the Peninsula tectonic control of the topographic features by joints or faults is obvious where these features are imposed upon the Table Mountain Sandstone." (Fig. 3.1). He goes on to assert that the topographic forms displayed by the pre-Cape rocks are dependent upon a combination of weathering and the deposition of Talus.

On the top of the plateua, either on Table Mountain itself or on the southern portion of the study area, weathering is produced by the influence of rain-water dissolving the soluble constituents of the rock, and the wind blowing away the loosened granules. The effects produced are fantastic, often grotesque, and sometimes of peculiar artistic beauty when decorated with iron or manganese stains and mantled by numerous species of lichen.

E. THE ROLE OF WATER

(a) SURFACE WATER

In such a narrow tract of elevated land as the Cape Peninsula, it is apparent that there can be no important rivers, but such streams as do exist are of considerable interest.

The upland drainage of the northern section of the study area is older than that of the southern portion, with the result that the streams have had more time to dissect the landscape and, as in the case of the Disa / Hout Bay river has been enabled to carve a wide valley in its lower reaches, and has also cut into the older rocks below.

The aspects touched upon very briefly in the preceding will be dealt with in greater detail in Chap. 5.

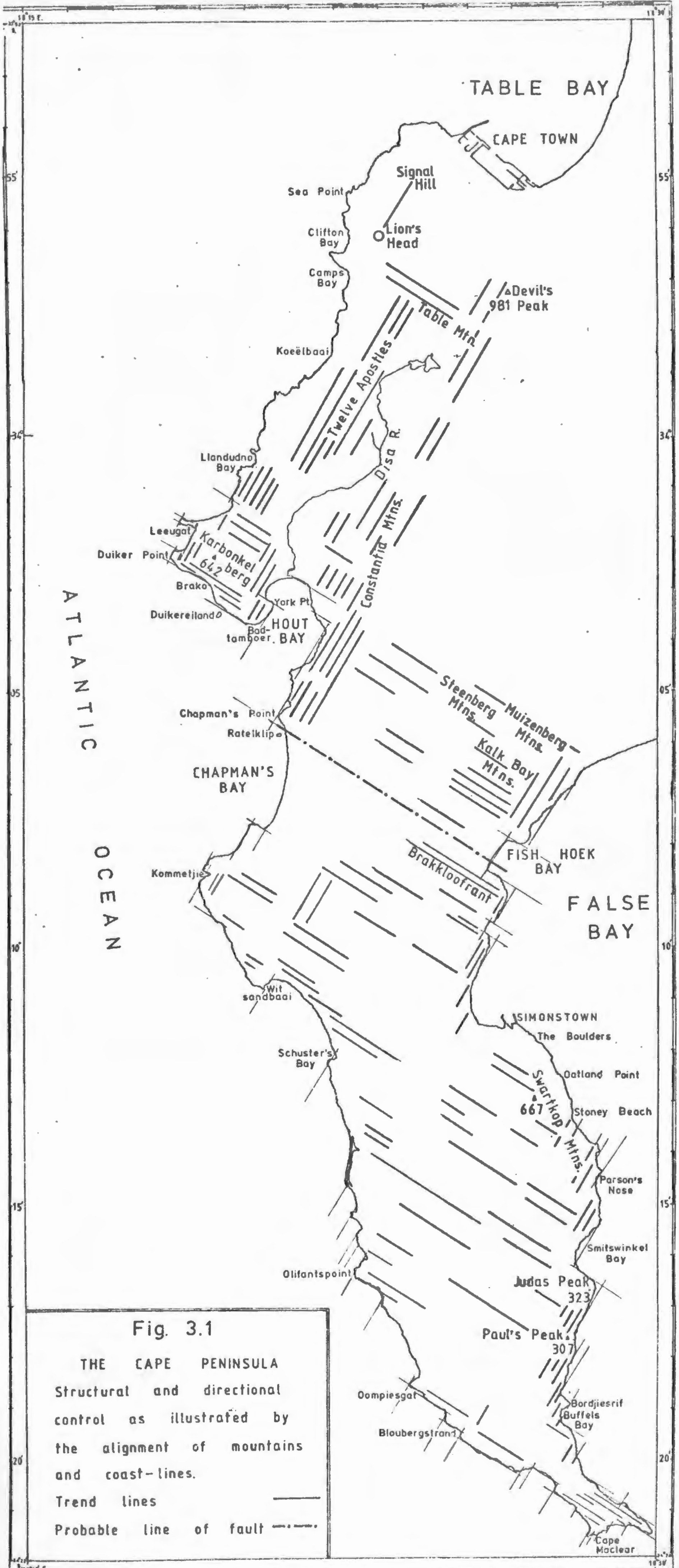

Fig. 3.1

THE CAPE PENINSULA

Structural and directional control as illustrated by the alignment of mountains and coast-lines.

Trend lines ———

Probable line of fault —·—·—

(b) UNDERGROUND WATER

In his paper "Underground Water Resources" Frommurze (1933,p. 70), whilst dealing with the springs which originate from the T. M. S. within the study area points out that the T. M. S. stands high above the surrounding country, "They form platforms upon which the greatest precipitation of this area takes place, giving rise to many perennial and intermittent streams." Frommurze stresses the role played by, and the importance of the vertical joints, together with the folds and faults in the T. M. S. along which rain-water percolates to issue as springs of considerable size in different parts of the study area. "These springs," he states, "provide an excellent illustration of how the circulation of underground water takes place in the T. M. S."

Thinking along the same lines, Mabbutt (1952,p. 14) points out how .... "the widening of joints and bedding-planes may proceed to some depth below the surface, especially where these provide channels for the escape of water underground." Taljaard (1949,p. 26) underlines this point by declaring that, "These joint planes become seepage planes for water, frost action and the solvent action of seepage waters."

Thus, whilst the face of the Peninsula is being visibly changed from without by the observable onslaught of the sea and by the action of running water, it is also being altered imperceptibly and inexorably from within as pointed out by Prof. Talbot (1971,p. 7) in his reference to the part played by percolating water in the destruction of the "False Bay anticline." He writes, "Along such joint-planes percolating waters would promote the slow disintegration of the rocks and even the Table Mountain sandstones yielded to the timeless attrition of such weathering."

F. THE PENINSULAR COASTS

No one who has sat upon the rocks of the shore and watched the ceaseless action of the breakers and witnessed their relentless pounding action, can doubt that the ocean is a powerful agent in the modification of existing shore-lines, and that it has played a considerable part in shaping them in the past.

Davies (1977,p. 25) is of the opinion that waves are by far the most important agents of coastal modification. In this regard it must be pointed out that wave parameters of geomorphic significance are energy, height, length, steepness and direction.

It is generally accepted that the ocean, like running water is best able to modify the landscape during periods when unusual conditions prevail. Thus, during times of flooding for example, running water is able, within a relatively short period of time to effect considerable changes within the physical environment. The same holds true for the work performed by waves when, during times of high energy input, such as when gale force winds lash the coastline that considerable modification of coastal landforms results. King (1963,p. 104) gives his impressions of marine action in the following lines: "Gales of great severity are not infrequently experienced in the neighbourhood of Capetown, and the magnificient coast of the Cape Peninsula is a monument to the marine energy manifested in these storms."

Thus, as pointed out by King (1963,p. 104) there is a fairly high input of energy by the north-westerly winds, which sometimes blow with gale force during the winter months. This is counter-balanced to a certain extent by another energy input during the summer months by the south-easterly winds. As a result there is a reasonable input of energy around the shores of the Cape Peninsula throughout the year, thus enabling the waves to continue the process of coastal modification.

Sufficient evidence exists of the destruction already achieved. The many reefs off the west coast, and the numerous stacks off the False Bay coast of the study area are relicts of the land surface destroyed during coastal retreat. On the False Bay side the watershed has been breached south of Smitswinkel Bay.

Noordhoekstrand, on the other hand is a good example of a prograded coastline where the shore is being extended seaward. Prograded and retrograded coasts are really two sides of the same coin, since erosion not only implies destruction and transportation, but deposition as well

In the previous section it was pointed out how the different rock types vary in their composition and resistance to weathering and erosion to produce landforms that are characteristic of each rock type. This is equally true with regard to marine action, where each type of rock reacts in a distinctive manner to marine attack to produce its own type of shore scenery.

(i) THE MALMESBURY SERIES

This rock type is the least resistant to marine attack, and extensive wave-cut platforms tend to be formed. The sea penetrates along joints between long arms of dark-coloured rock which extend seaward with the north-westerly strike of the formation. This type of shore extends from Sea Point through Mouille Point to Table Bay in the northern sector of the study area.

(ii) GRANITE

This type of coastal scenery is best developed between Sea Point and Llandudno. The base of the T. M. S.

here lies about 300m above sea-level, and a fairly steep talus slope of weathered granite runs down to the small bays and blunt granite headlands. The latter are continued in lines of flat-topped rocks which run out to sea with a W. N. W. trend, following a master-joint direction of the Peninsula granite. In this respect de Villiers (1944,p. 185) has noted what he terms "the remarkable parallelism" between the pre-Cape rocks in the western and south-western Cape with that of the younger Cape system in both strike and position. This makes it clear that the joint-patterns of the T. M. S. and the Granite tend to coincide. The intervening bays are aligned in the same general direction i.e. W. N. W., square to the constructional waves, so that the coast-line here, too, is slowly being prograded in places.

The granite coast south of Simonstown is similar, except that the talus slope is steeper and less dissected. As a result the coast-line is less indented and bay beaches are lacking, but the same granite blocks occur as at Windmill Beach, Oatland Point, Stoney Beach, the Boulders and so on along this section of the coast.

True granite cliffs occur only on the exposed coast below Chapman's Peak. The base of the T. M. S. here is only 120m above sea-level and has been so undermined by wave attack that the granite base falls almost vertically to the sea. The granite columns exhibit signs of vertical jointing, and, together with the usual smooth rock faces, form the cliff. Below Cape Point the waves have tunneled along the joint planes and have formed sea caves more than 30m deep in the granite. Divers tell me that there are spectacular caves also below Chapman's Peak.

(iii) THE TABLE MOUNTAIN SERIES

Mabbutt (1952,p. 19) puts it rather aptly when he declares that, "The spectacular cliffs formed by the

T. M. S. and the bold youthful state of the terrain now undergoing destruction by the sea owe their form to the massiveness of the Series." The vertical jointing and horizontal stratification of the T. M. S. allow the cliff face to become and remain perpendicular under wave attack. This is similar to the manner in which the precipitour wall of Table Mountain has been developed above Cape Town. In this latter instance, however, the causal factors are somewhat different, namely, weathering (frost action, the solvent action of seepage water) as opposed to wave attack.

In the Southern Peninsula the Malmesbury Beds and Cape Peninsula Granite occur mainly below sea-level, bringing the T. M. S. down to the shore, and here the finest cliffs occur, particularly along the False Bay coast. The cliffs at Smitswinkel Bay rear up perpendicularly to 322m above sea-level at Judas Peak, whilst those at Cape Point rise in a vertical cliff face to 150m above sea-level.

The waves penetrate along the horizontal bedding planes of the T. M. S., forming rocky platforms in the inter-tidal zone as between Muizenberg and Clovelly. Wave-cut ledges also occur at the base of the cliff between Cape Maclear and Cape Point, where the softer, more thinly bedded Lower Shales at the base of the T. M. S. are being eroded.

The T. M. S. exerts a strong structural control over the directional pattern exhibited by the shore-line as a result of the set of master joints within the Series itself. Thus marine action is given alignment by such lines of weakness, and the numerous linear gullies attest to this fact. Jointing, it seems, had much to contribute to the present-day form of the peninsular coast.

This structural control is particularly observable in the southern sector of the study area, even though evidence is present in the northern portion as well. For example, from Duikerpunt to Badtamboer at the base of the Karbonkelberg, the coastline, in keeping with the alignment of the set of prevalent vertical joints trends from W. N. W. to E. S. A., whilst from Badtamboer to York Point (on the western side of Hout Bay) and from Die Perd to Leeugat (west of Karbonkelberg) the coast-line follows the complementary set of right-angled master joints from E. S. E. to W. S. W.

On the False Bay coast from Muizenberg to Simonstown the coast-line too follows the complementary right-angled master joint pattern, trending from E. N. E. to W. S. W. On the Atlantic coast from Kommetjie to Cape Point, the coast-line trends from W. N. W. to E. S. E. again. (Fig. 3.1).

It has been observed that where small bays occur, the shore-line of the bay itself will tend to follow the general directional pattern outlined above. The bay heads will exhibit the tendency to follow lines of weakness afforded by the transverse set of joints at right angles to that of the bay itself. Fish Hoek Bay and Elsies Bay are two examples along the False Bay coast, whilst Witsandbaai -- Schuster's Bay, together with Platboombaai further south exemplify this alignment along the Atlantic coast.

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CHAPTER 4

CLIMATIC DEVELOPMENT AND CHANGES IN VEGETATION

A. APPROACH TO BE UTILISED

There is general agreement on the part of Ewing and Donn (1956,p. 1066), van Zinderen Bakker (1967, p. 126), Twidale (1976,p. 5), Lancaster (1979,p. 64) and Budyko (1982,p. 123) that ... "the present is the key to the past." Twidale (1976,p. 5) is of the opinion that the Principle of Uniformitarianism should be utilised as a reasonable and necessary basis for geomorphological investigation. Grindley (1979,p. 20) asserts that, "Until the mechanisms controlling present rainfall patterns are established, it is not possible to understand how they might have varied in the past." Coetzee (1967,p. 2) places a high priority rating upon understanding present climatic conditions when declaring that, "Unless the present climatic regime is understood, attempts at explaining past climates cannot be made."

Kraus (1958,p. 666) is of the opinion that climate is nowhere invariant, and that the existence of a never-ending change is most apparent along the shifting boundaries of the various climatic provinces. This viewpoint is shared by Tyson (1977,p. 77) who observes, "That climates have changed radically many times in the past is indisputable; that they are likely to do the same in the future is an entirely reasonable assumption." With this in mind, it is the intention of the writer to utilize what van Zinderen Bakker (1967,p. 126) terms the "principle of ecological actuality" and Budyko (1982,p. 123) refers to as ... "the assumption that in the past, relationships between the climate and other natural phenomena were the same as at present" in an attempt to reconstruct the climatic history of the study area.

In the following pages it will be shown that the climate of the study area has been warmer, wetter and more humid for long periods in the past than at present. For other periods in its geologic history the climate of the Cape Peninsula has been colder and drier than that currently experienced. These changes in climatic regime, coupled with parallel changes in the vegetation have left distinct morphogenic imprints upon the physical landscape. This latter point will be developed at a later stage.

B. PRESENT CLIMATIC CONDITIONS

Current theory holds that most of Africa south of 20° S. latitude is dominated by the sub-tropical anti-cyclones of the general circulation, namely by the South African anticyclone off the Namib coast and the South Indian anticyclone off Durban.

Jackson and Tyson (1971,p. 1), however, point out that over Southern Africa the circulation pattern is not as simple as stated above.

Schulze (1965,p. 6), together with Tyson and Jackson (1971,p. 2) indicate that South Africa is almost entirely under the influence of the westerly circulation --- to a lesser extent in summer than in winter. They further emphasize the fact that the weather changes in South Africa as a whole and the Cape Peninsula in particular are largely dominated by the perturbations in the southern hemisphere's westerly circulation which, on the surface appears as a succession of cyclones and anticyclones moving around the coast or across South Africa from some westerly point of the compass.

Schulze (1965,p. 313) has the following to say about the climate of the study area:

"The region enjoys a climate similar to Mediterranean countries, receiving the bulk of its rainfall in winter from about May to September, and having a warm to hot dry summer. The rainfall is profoundly influenced by the very pronounced orographical features, resulting in annual amounts of the order of 3 000mm in some mountain kloofs, as against 400 - 500mm on the Cape Flats."

During the season of maximum rainfall one may normally expect 12 - 15 rain days per month, whilst in the dry season Cape Town and environs experience 4 - 5 rain days per month.

The rainfall is mainly cyclonic and orographic, but very occasionally thunderstorms do occur, namely on nearly five occasions per year. Hail is a rare phenomenon. The mountains such as the Hottentots Holland, to the east of the study area are occasionally snow-capped, but the snow layer never persists for more than a few days. Snow has been known to fall on Table Mountain on very rare occasions.

Table 4.1 provides further details regarding the rainfall within the study area.

***** RAINFALL NORMALS (1921 - 1950)

S T A T I O N	LAT.	LONG.	HEIGHT	RAINFALL
	S.	E.	M.	mm
Cape Town (Fire Stn.)	33^{o} 56'	18^{o} 26'	53	545,6
Cape Town (Roy. Obs.)	33^{o} 56'	18^{o} 29'	12	576,9
Table Mountain	33^{o} 59'	18^{o} 23'	686	1 242,3
Kirstenbosch	33^{o} 59'	18^{o} 26'	89	1 342,5
Tokai	34^{o} 03'	18^{o} 25'	56	914,6

***** Source : Climate of S.A. : Rainfall Statistics : W. B. 20, p. 2. Schumann, T.E.W., 1950 (Director)

The above data for the various stations are comparable since they extend over the same 30-year period. The stations are arranged in order from north to south. It is regretted that the data only covers the northern half of the study area, and is therefore not representative of the study area as a whole.

(a) The latitudinal extent is too limited and does not result in any observable pattern of precipitation;

(b) the effect of relief is pronounced in the case of the station on Table Mountain which reflects the combined effects of both cyclonic and orographic rain;

(c) Kirstenbosch, despite the lack of altitude reflects the increased precipitation brought about by the alignment of the adjacent mountain to the rain-bearing winds.

Table 4.2

***** STATIONS REFLECTING AVERAGE RAINFALL

S T A T I O N	LAT.	LONG.	HEIGHT	PERIOD	RAINFALL
	S.	E.	M.	YRS.	mm
Sea Point	33° 55'	18° 23'	23	29	586,5
Camps Bay	33° 56'	18° 23'	15	17	618,0
Royal Obs.(C.T.)	33° 56'	18° 29'	12	109	627,4
Tbl. Mtn.(McL's.B.)	33° 58'	18° 26'	1 092	43	1 972,0
Newlands (Monte B.)	33° 58'	18° 28'	23	16	1 662,4
Kirstenbosch	33° 59'	18° 26'	89	36	1 364,5
Claremont (Bis.Crt.)	33° 59'	18° 28'	30	34	1 424,2
Kenilworth	34° 00'	18° 29'	27	25	1 207,0
Wynberg (B. Vista)	34° 00'	18° 28'	61	7	1 303,0
Muizenberg (Pav.)	34° 06'	18° 28'	15	8	481,8
Simonstown (Wood)	34° 12	18° 26'	30	23	809,8
Klawer Camp	34° 12'	18° 25'	293	7	739,9
Smitswinkel Bay	34° 16'	18° 28'	15	31	698,2
Cape Point	34° 21'	18° 30'	217	47	333,0

***** Source : Climate of S. A. : Rainfall Statistics : W. B. 20, p. 21 - 22. Schumann, T.E.W., 1950 (Director)

These are average figures. They are not as reliable for purposes of comparison as the Rainfall Normals of Table 4.1 since they extend over different periods of time --- not necessarily coeval. The figures do, however, give an idea of the amount and distribution of the rainfall within the Peninsula.

Note:

(a) At the Royal Observatory the statistics have been compiled over the past 142 years (i.e. 109 + 33 yrs. up to and including 1983), the longest period for which statistics of this nature have been compiled in South Africa.

(b) The benefits of altitude is seen at Maclear's Beacon which receives both orographic and cyclonic rainfall. This constitutes the highest rainfall for the study area. Cape Point at sea-level on the other hand records the lowest rainfall for the study area.

(c) The contiguous areas between Newlands and Wynberg record the heaviest precipitation.

The Sea Fisheries Institute Survey (reported in the Cape Times, p.3, 26 January, 1981) points out that the winds over the Peninsula are governed by the synoptic weather cycles of the high and low pressure cells which pass over the south of the area.

The summer months are dominated by a subtropical high pressure system centred at about 30^{o} S. and winds blow anticyclonically around this high pressure system. Schulze (1965,p. 314) asserts that the winds during summer blow almost exclusively from the south-east and are a prerequisite for the formation of the beautiful 'tablecloth' (orographic cloud) on Table Mountain. What is less well known is that Steenberg Mountain to the south of Cape Town -- and which has the identical north-west - south-east alignment too is mantled in summer by its own cloudy cover similar to the 'table-cloth' of Table Mountain.

The circulation over the study area in summer is distinctive. The season tends to be windy and dry. South and south-east winds prevail for 60% of the time, with force and direction being modified to some extend by the alignment of the mountains. Thus, according to the research officer responsible for the aerial surveys of the Sea Fisheries Institute --- as reported in the Cape Times (op. cit.) --- one finds that superimposed on the fields of the prevailing winds are areas of strong and weak winds due to the blocking effect by Table Mountain and the Hottentots Holland Mountain range. This explains why there can be a 40-knot south-easter blowing at Cape Point and no wind at all at Clifton.

At times the anticyclonic Cape south-easters are notoriously strong and gusty, and in the vicinity of Cape Town for example may blow at gale force for two or three days at a time. This causes great inconvenience to and disruption of shipping in Table Bay harbour.

The winter circulation is also distinctive. Jackson and Tyson (1971,p. 2) are of the opinion that the winter circulation of the areal matrix is associated with disturbances in the circumpolar westerly winds which take the form of a succession of eastward-moving cyclones or depressions and anticyclones. They state that these disturbances originate in the areas of cyclogenesis far to the south and west of Southern Africa and bring rain to the Cape Peninsula, the south-western Cape Province and south and south-eastern coasts, and may even extend far inland.

The winter rains are the result of the north-ward shift in the trajectories of the depressions during the northern summer, which brings the study area into the path of these perturbations. According to Schulze (1965), the planetary wind system of anticyclones, cyclones and westerlies is subjected to a seasonal meridional displacement of about 4^0 of latitude. The seasonal displacement southward during summer in the southern hemisphere results in the system migrating southward with the cyclones passing eastward to the south of the Peninsula. This explains why the study area does not receive much rain in summer.

Fronts are usually associated with depressions or cyclones: warm fronts are diffuse, difficult to recognise and almost impossible to follow. Cold fronts on the other hand are more common, are sharper and more easily recognised.

Once an eastward-moving trough of low pressure, together with its associated cold front moves over the study area, the north-westerly area becomes progressively more continental and stable in character and more typical pre-frontal conditions result. Entrainment of air from the continental anticyclone together with horizontal divergence may produce excessively hot weather prior to the passage of a front over the Peninsula, thus producing the well known "Berg wind conditions." Tyson (1969,p. 15) points out that pre-frontal conditions are characterized by warm, reasonably moist, stable conditions. Pressure falls, visibility is usually poor and little cloud cover is visible. What generally happens is that, following the passage of a coastal low to the south-east of Cape Town the weather deteriorates rapidly and north-westerly winds replace Berg wind conditions in a typical weather cycle over the study area.

Sunshine duration over the study area varies from about 60% of the possible duration in July to well over 70% in January. (See Table 4.3).

Table 4.3

***** MAXIMUM AND MINIMUM MONTHLY MEAN SUNSHINE DURATION

S T A T I O N	DEC.	MAR.	JUN.	SEP.
C A P E T O W N (23 yrs.)				
Possible duration (hrs./day)	14,4	12,3	9,9	11,9
Maximum (%)	82	82	75	73
Minimum (%)	70	65	46	53
Range (%)	12	17	29	20

*****

Source : Schulze, B.R., 1965 : Climate of South Africa Part 8 : General Survey, p. 27

It will be noted that:

(i) the range is greatest during the Winter months (Jun.);

(ii) the range during the Autumn and Spring months is comparable (Mar. & Sept.);

(iii) the range is smallest during the Summer months (Dec).

C. PRESENT VEGETATION OF THE CAPE PENINSULA

Prof. Adamson (1945,p. 18) points out that the vegetation of the south-western Cape, of which the study area forms part, has for a long time been recognised as one with distinctive characteristics both geographically and floristically.

The vegetation as distinct from the flora can be divided into two kinds comprising, on the one hand forest, which is limited in extent and for the most part confined to the deeper and more protected kloofs on the mountains and to river banks, and on the other the widespread vegetation made up of shrubs which cover most of the area.

Taylor (1972) prefers the term 'fynbos' to describe the vegetation, which he states has now replaced older, ambiguous terms such as Sclerophyll Bush or Scrub, Maqui or Macchia. He points out that the word fynbos implies both the fine-leaved form of many of the shrubs and the bushy structure of the vegetation and, at the same time delimits a definite phytogeographical unit.

The shrub vegetation is wholly evergreen and characteristically of a brown or greenish-brown colour, which shows little change in tone through the year. The shrubs have leaves of rather small size and are rarely polished. The leaves are hard and in many plants either rolled or pressed against the stem. These leaf characteristics have come to be known as "sclerophyll."

The vegetation is characterized by very great diversity. Not only is the flora exceedingly rich and markedly varied from place to place, but also the vegetation itself is composed of large numbers of species growing in association without any definite dominance of one or two species.

The fynbos flora is noted for its richness in species, both in small areas and over its whole range. According to Adamson and Salter (1950), no less than 2 600 species were known to occur in the Cape Peninsula alone --- with an area of 435km^2 . This is a little larger than the Isle of Wight, and compares more than favourably with the 2 000-odd species found in the whole of Great Britain.

In those parts of the study area with a precipitation of 450 - 625 mm per annum or more, the fully developed or climax community is dense and definitely stratified. The uppermost stratum which is most often not continuous, is composed of tall shrubs with relatively large leaves; species of Protea, Leucospermum, Leucadendron, Gymnosporia and others are prominent, varying between 1 to 5 metres in height. Below and between these large shrubs is a dense stratum of smaller bushes, many of which have small or heath-like leaves. This layer has great diversity in floristic composition. In it are associated tall reed-like monocotyledons belonging to Restionaceae, Cyperaceae and less often Gramineae.

Goldblatt (1972) is of the opinion that the dominant elements comprising fynbos are Proteacea, Ericaceae, Restionaceae and Iridaceae.

The forests belong to a different kind of vegetation, distinct in physiognomy and in floristic features. Forest is usually confined to kloofs and especially sheltered slopes or riversides. The fully developed forest is composed of evergreen trees of a considerable variety of species but with very uniform leaves of medium size and usually highly polished.

A few species of woody climbers or monkey ropes are abundant. Epiphytes are frequent in the moister parts, but rare in the drier sections. The ground layer is herbaceous and shade-loving, with ferns often forming a large part of its composition.

The Cape Peninsula, with its Mediterranean type of climate is particularly suitable for geophytic plants such as Tulipa, Hyacinthus and Cyclamen. Here part of the stem or leaves is modified to form an underground perennating organ designed to enable the plant to withstand and survive, in a resting-stage, the unfavourable dry summer season in the study area.

"One general characteristic of the vegetation of the Peninsula is that it re-develops in a remarkable manner, and has maintained itself in spite of frequent burning." (Wicht, 1945 p. 23). Taylor (1972) asserts that burning is good and essential to preserve the vegetation. Controversy still surrounds this issue. Pest-plants such as Hakea and wattles are stimulated by fire to reproduce at an alarming rate.

PHYTOGEOGEOGRAPHY

In a reference to the pattern of distribution in the southern hemisphere of Irideae, Goldblatt (1972,p. 5) finds that the explanation which fits the facts best is that of a common origin in Chile, New Zealand, Africa and Australia at a time when the southern continents were in contact with one another as part of the then super-continent of Gondwanaland. He concludes that the Theory of Continental Drift explains this type of distribution best. Goldblatt (1972) is of the opinion that other explanations of the present southern distribution such as independent origin of three similar groups of plants in the three southern continents, or migration from a common northern hemisphere to be unacceptable.

Coetzee (1978a, p. 19), however, does not share the conviction held by Goldblatt. She records that it might be possible that palynological investigations currently in progress could throw more light on the origin of the phytogeography and diversification of the typical Cape elements.

D. CLIMATE AND VEGETATION DURING THE LATE CRETACEOUS AND TERTIARY ERAS

(i) THE LATE CRETACEOUS

It has been postulated earlier that the surface manifestation of the study area dates from the end of the Cretaceous - Early Tertiary, approximately 70 m.y. B.P.

In the following pages an attempt will be made to reconstruct the climatic and vegetal history of the area under consideration during Tertiary and Quaternary times.

According to Budyko (1982,p. 127), the Mesozoic climate (230 - 65 m.y. B.P.) was equable. He is of the opinion that over most of the globe the climatic conditions were similar to the contemporary tropics, although the climate was cooler in the high latitudes. Budyko (1982) further maintains that at the end of the Cretaceous the hot climatic zone decreased in size and that during the Tertiary the process of cooling commenced. Flohn (1978,p. 8) shares this viewpoint and writes, "The climate of the early Tertiary (and probably also of the greater part of the Mesozoic era) was characterized by an ice-free climate over the whole globe."

(ii) TERTIARY CLIMATES AND VEGETATION

Basing his conclusions upon faunal remains at Langebaanweg, approximately 100km outside the study area, Hendey (1973,p. 14) finds that during the Late Pliocene the vegetation in the area was much more luxuriant than at present and was characterized by trees and grasslands. He envisaged an environment of riverine woodland flanked by grassland. It can reasonably be inferred that this was due to heavier precipitation and warmer conditions which prevailed then. Haughton (1929, 1933 & 1969) points to changes in the ecological environment as reflected by the fossilised remains of fauna from the beaches around Saldanha Bay, Blaauberg Strand and Milnerton. The fossils, according to Haughton could only have existed in water considerably warmer than the present. Tankard (1974,p. 281) found that the molluscs of the Varswater Formation at Saldanha Bay suggested water temperatures 3^{o} - 5^{o}C warmer than today.

Lancaster (1979,p. 12) points out that during most of the Tertiary, temperatures were generally warmer than today, but with a number of cooler episodes. This conviction is shared by Budyko (1982,p. 127) who maintains that, "At the end of the Pliocene the climate was warmer than at present, yet it resembled present climatic conditions more than the climates of the Mesozoic and Early Tertiary."

Our understanding of the palaeoenvironmental history of the study area biome has been elucidated by recent studies of fossil pollen assemblages of Late Cainozoic Age carried out by Coetzee (1978a). This was based upon a number of borings from Noordhoek (within the study area), the adjacent Cape Flats, Mamre and Saldanha. (See Fig. 4.1).

Coetzee (1978a,p. 15) points to the fact that the pollen spectra of the Noordhoek core have so far provided the best evidence for a number of vegetation changes which have occurred within the Cape Peninsula. According to Coetzee (1978a,p. 15) two distinct pollen zones can be distinguished. The lower Zone (Pollen Zone L) represents Tertiary microfloral assemblages of which many types have become extinct. The Upper Zone (Pollen Zone M) contains pollen of the present macchia vegetation, and is considered

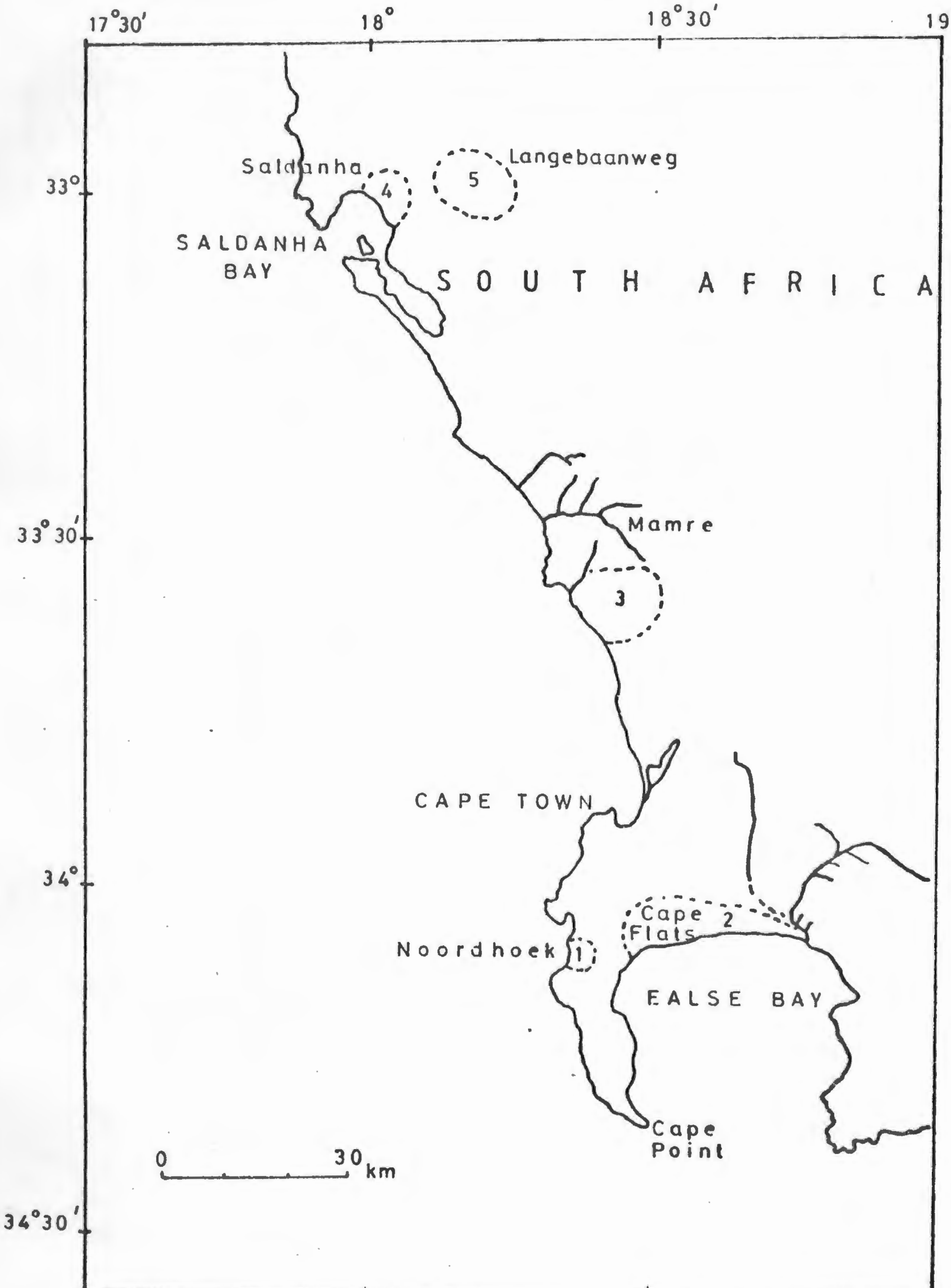

Fig. 4.1 Location Map: S.W. Cape borehole zones 1 - 5
(Coetzee, 1978b, p. 117)

to be of Quaternary Age. Coetzee (1978a,p. 16) identifies seven Tertiary pollen zones which `indicate that until the Pliocene the vegetation of the study area was dominated by forests. (See Table 4.4). Coetzee (1978a,p. 19 - 20) finds that the dominance of the Palm pollen, together with higher pollen percentages than at other times in the Late Tertiary of such forms such as Croton, Boscia, Alchornea, Trema and others such as Cycadopites could testify to a sub-tropical - tropical vegetation and climate during these two periods. Coetzee (1978a) comments, that despite the diversity of sporomorphs present in the cores, which is characteristic of the study area during the Tertiary (and incidentally for the South-West Cape as well), relatively high percentages of certain dominant palynomorphs do occur and these, together with certain associated forms could be an indication, in general terms, of the type of vegetation and probable climate during different periods.

Lancaster (1979,p. 12) is of the opinion that the mid-Miocene forest may be contemporaneous with the Arrisdrift fauna and relates it to the work done by Corvinus (1978) in that area.

All the evidence presented thus far suggests warmer climates and, together with the sub-tropical molluscs referred to by Haughton (1929, 1933 & 1969), Tankard (1974) and the work done by Hendey (1973) could be correlated with warmer periods on the Palaeo - temperature Curve of the Southern Ocean. (See Fig. 4.2).

From the Late Miocene onward temperatures dropped sharply. The palm forests of the Peninsula became extinct and were replaced by cool temperate forests reflecting a move toward cooler and drier conditions within the study area. Coetzee (1978a,p. 20) is of the opinion that the vegetation changes during the Tertiary within the Cape Peninsula referred to above, and the final elimination of many of the species more sensitive to temperature and humidity changes must

POLLEN ZONE	VEGETATION	CLIMATE	SUGGESTED STRATIGRAPHY	
M	Present Macchia	Present	Quaternary	
Lvii	First Strong Development of Macchia	Colder Drier	Tertiary	Pliocene
Lvi	Forest: Coniferae, Casuarinaceae, Cupaniedites	Cool Wet	Tertiary	Late Miocene
Lv	Palmae	Sub-Tropical Tropical	Tertiary	
Liv	Restionaceous Swamp	Temperate Locally Wet	Tertiary	
Liii	Forest: Coniferae, First Compositae	Cool Wet	Tertiary	
Lii	Palmae	Sub-Tropical Tropical	Tertiary	Late Oligocene
Li	Forest: Coniferae	Cool Wet	Tertiary	Late Oligocene

Table 4.4 Pollen zones of Late Cainozoic deposits in the S.W. Cape.

(Coetzee, 1978b, p. 118)

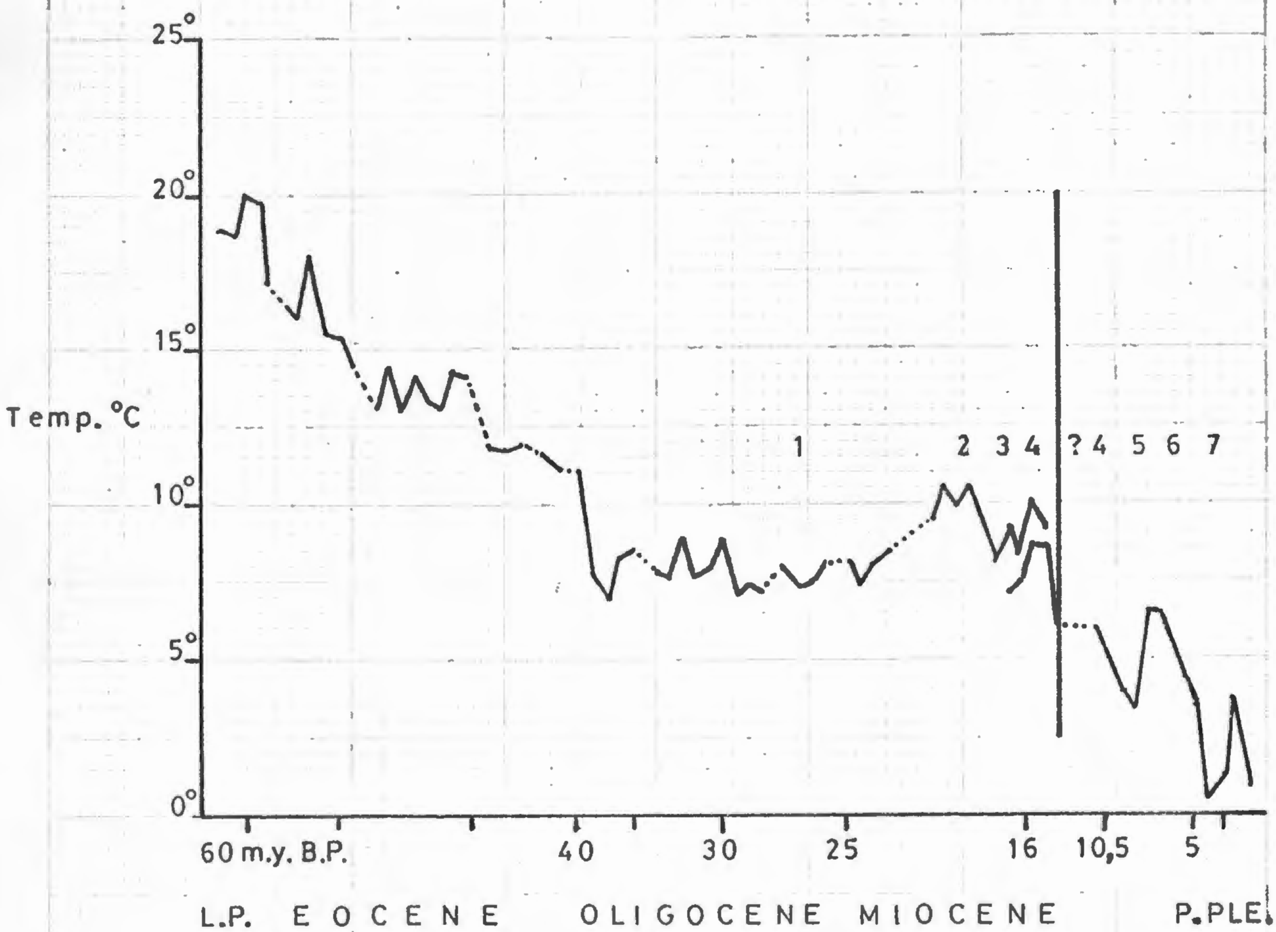

Fig. 4.2

Palaeotemperature curve of the Southern Ocean with correlations of palaeoenvironments of the south - western Cape. (After Coetzee 1978a, p. 26)

(1) Conifer forest, Late Oligocene. Benguela current originated. (2) Palmae, Early Miocene. Fossil fauna Luderitz? (3) Conifer forest, Early Miocene. Upwelling Walvis Ridge. (4) Palmae, Early / Middle Miocene. Fossil fauna Arrisdrift. (5) Origin of Namib Desert? Antarctic ice-sheet build-up. Middle / Late Miocene. (6) "Conifer" forest with sub-tropical elements, Late Miocene. (7) First strong development of macchia, Namib Desert, Pliocene.

certainly be related to profound climatic episodes outside the study area.

(a) CHANGES IN ANTARCTICA

Major events occurred in the Antarctic regions from the Eocene onward which saw :

(i) Further developments in Continental Drift coupled with the continued fragmentation of the once super-continent of Gondwanaland. This involved major geological changes.

(ii) Developments in oceanographic circulation which resulted in a mighty new ocean current coming into existence, the lowering of ocean temperatures in the Southern Ocean and the initiation of a new global pattern of oceanographic circulation;

(iii) the growth of continental glaciers in East and West Antarctica.

(iv) The major events referred to above were to have a profound effect upon the planetary atmospheric and oceanographic circulation, world climates and vegetation in general, and the study area in particular.

Approximately 55 m.y. B. P. Australia detached from Antarctica and commenced drifting towards its present position. Although the spreading commenced during the Early Eocene, a complete deep ocean passageway between the two continents did not develop until well after the initiation of spreading because the South Tasman Rise remained in close connection with Victoria Land Antarctica, forming a shallow-water barrier to circum-Antarctic flow.

Kennet (1978,p. 51) points out that by the Middle and Late Oligocene (30 - 25 m.y. B. P.) a substantial ocean had formed between Australia and Antarctica, while equatorial circulation north of Australia had become rather restricted.

At this time major changes occurred in oceanic circulation in the Southern Hemisphere as deep circum-Antarctic flow developed south of the South Tasman Rise which, by this time had sufficiently cleared Victoria Land, Antarctica. Mercer (1978,p. 74) is of the opinion that by the Early Miocene (± 22m.y. B.P.) a deep channel had opened between South America and West Antarctica. This event marks the opening of the Drake Passage. Mercer (1978,p. 74) states that the result was the initiation of the powerful Circum-Antarctic Current, which led to the enhanced thermal isolation of Antarctica leading to increasing land and sea ice-cover.

Kennett (1974,p. 144) sees the Circum-Antarctic Current as being of great oceanographic and climatic importance because it transports more than 200 X 10^6 M^3 of water per second, probably the largest volume transport of any ocean. It circulates completely around Antarctica mixing waters of all oceans. Kennett (1974,p. 147) writes : "The separation of Australia from Antarctica led to a fundamental change in the world's oceanic circulation and its climate that marks the onset of the modern climatic regime." This important event brought about fundamental changes in the oceanic and climatic circulation patterns of the world which were intensified by the drop in ocean temperatures resulting from the glaciation of Antarctica.

Siesser (1978,p. 108 - 109) has presented evidence from Deep Sea Drilling Project (D. S. D. P.) core 361 raised from the sea floor approximately 300km south-west of Cape Town, which indicates that significant changes in the character of the Benguela Current occurred progressively from Late Miocene - Pliocene times onward. Siesser deduced this from the increased amount of diatom fustules which were present in the core. Abundant diatom production is a feature of cold upwelling water.

Thus, at a time when temperatures in the study area were beginning to drop markedly, coincident with the period when palm forests of the Peninsula became extinct to be replaced by cool temperate forests, Siesser (1978) records the replacement of sub-tropical by cold-water Foraminifera and calcareous nanno-fossils in cores from the Walvis Ridge. (D. S. D. P. Core 362 A). By Pliocene times Siesser (1978) finds that the assemblages are decidedly cold-water ones.

In summary therefore, despite minor differences there appears to be broad agreement between the onshore evidence of Haughton (1929, 1933 & 1969), Hendey (1973), Tankard (1974), Corvinus (1978), Coetzee (1978a) and the offshore evidence provided by Siesser (1978). It is thus reasonable to assume that within the study area during Tertiary times the climate was generally warmer, that it was more humid, and that the precipitation was probably heavier than it is today. This has left its imprint upon the physical landscape.

(b) FURTHER CORRELATIONS AND DEDUCTIONS

The tertiary vegetation at the Cape, recorded by recent palynological studies could substantiate the above oceanographic and off-shore evidence for warmer and more humid conditions than those prevailing at present within the study area from Late Oligocene until Early Miocene. Coetzee (1978b, p. 120) is of the opinion that the final extermination of the Palmae, together with other forms sensitive to temperature and humidity changes must certainly have been related to the intense cooling of the coastal waters, and the final establishment of the cold Benguela Current and its far-reaching effects.

E. CLIMATE OF THE QUATERNARY AGE

The entire Quaternary period, except for the Holocene can be said to correspond to the Pleistocene. During the Pleistocene, climatic conditions differed markedly from the preceding Mesozoic and Tertiary when thermal zones were relatively indistinct. A cooling trend became more pronounced in middle and high latitudes and great continental glaciers developed. They advanced repeatedly, reaching the middle latitudes and retreated again to the high latitudinal belt. During the advance of continental glaciers sea ice expanded over vast areas. Coetzee (1978b,p. 123) considers the last four Quaternary glaciations to have been more severe than any of the previous cold periods which have been recorded since the Pliocene.

During the glacial episodes the pressure gradient between the Antarctic Convergence and the equator was steepened with the result that the oceanic and oceanic circulation was activated. Cold polar air could penetrate the interior up to about 24^{o} S. latitude, and the cold Benguela Current had more energy and moved further north. In the study area and adjacent parts of Southern Africa the winters must have been very cold, wet and very windy.

Tyson (1977,p. 78) claims that at least three major ice ages lasting several million years must have occurred at roughly 300m.y. intervals during the earth's history, and that between these ice ages warmer ice-free conditions prevailed. Evidence of these ice ages is to be found within the study area today.

CLIMATE OF THE STUDY AREA DURING THE LAST GLACIAL PERIOD

The development of the Antarctic ice sheets, according to van Zinderen Bakker (1976,p. 168) caused dramatic changes in the palaeoenvironment of Southern Africa as the sub-continent has, since late Miocene times been dominated by a different atmospheric and oceanic circulation system. Lancaster (1979, p. 12) subscribes to the same viewpoint and postulates that the present climatic regime over the South-Western Cape (icluding the study area) was not established until the Pliocene and Early Pleistocene. In general, this new climatic system with minor modifications has persisted till the present.

van Zinderen Bakker (1967, 1968, 1976) has postulated a northward displacement of the Antarctic Polar Front at the time of the last glaciation of Würmian Age of Marion Island (46° 50' S., 37° 40' E). This hypothesis has subsequently been confirmed by palaeotemperature assessments of 34 sediment cores from the sub-Antarctic region. (See Fig. 4.3). It has been shown that in the western South Atlantic the northward shift of the Polar Front was of the order of approximately 10° of latitude, while in the South Atlantic and Indian Oceans the shift traversed about 6° of latitude. South of South Africa this Polar Front remained almost stationary. The apparent reason why the Front remained almost stationary in this section is ascribed to the oceanic ridge which runs from west to east, thus forming a zonal barrier.

The considerable northward expansion of the pack ice and cold water must have brought about a northward shift of the westerlies and sub-tropical pressure system. This northward shift of the pressure systems is subscribed to by van Zinderen Bakker,p. 136 & 1976,p. 166), Damuth and Fairbridge (1970,p. 189), Tyson (1977,p. 100), Lancaster (1979, p. 33) and Budyko (1982,p. 144). Damuth and Fairbridge (1970) are of the opinion that the South Atlantic High Pressure Cell was displaced by as much as 1 500 km northward during the glacial phases and by the same margin southward during the interglacial phases.

This northward shift is supported by evidence provided by Vincent (1972,p. 45). She analysed two ocean sediment cores from the southern end of the Mozambique Channel at about 25° S. The analysis showed that during the last glacial period the oceanic boundaries of the south-east coast had shifted northward considerably. Radiocarbon dating of the planktonic foraminifera in the sediment cores indicated that before 11 000 years B. P. the surface water of the channel was 5° C colder than at present.

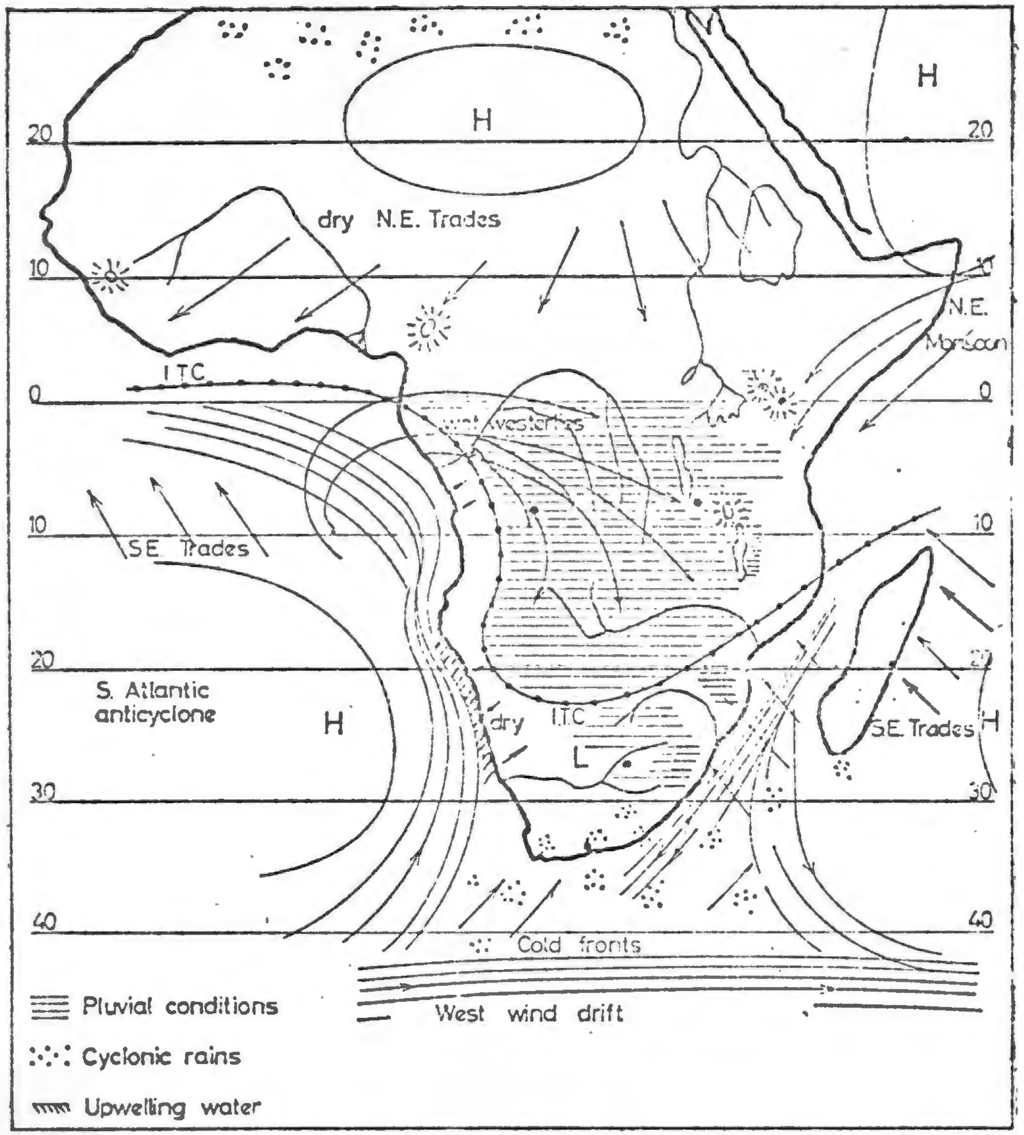

Fig. 4.3 (a) Schematic reconstruction of conditions during a hypothermal minimum (glaciation): southern summer

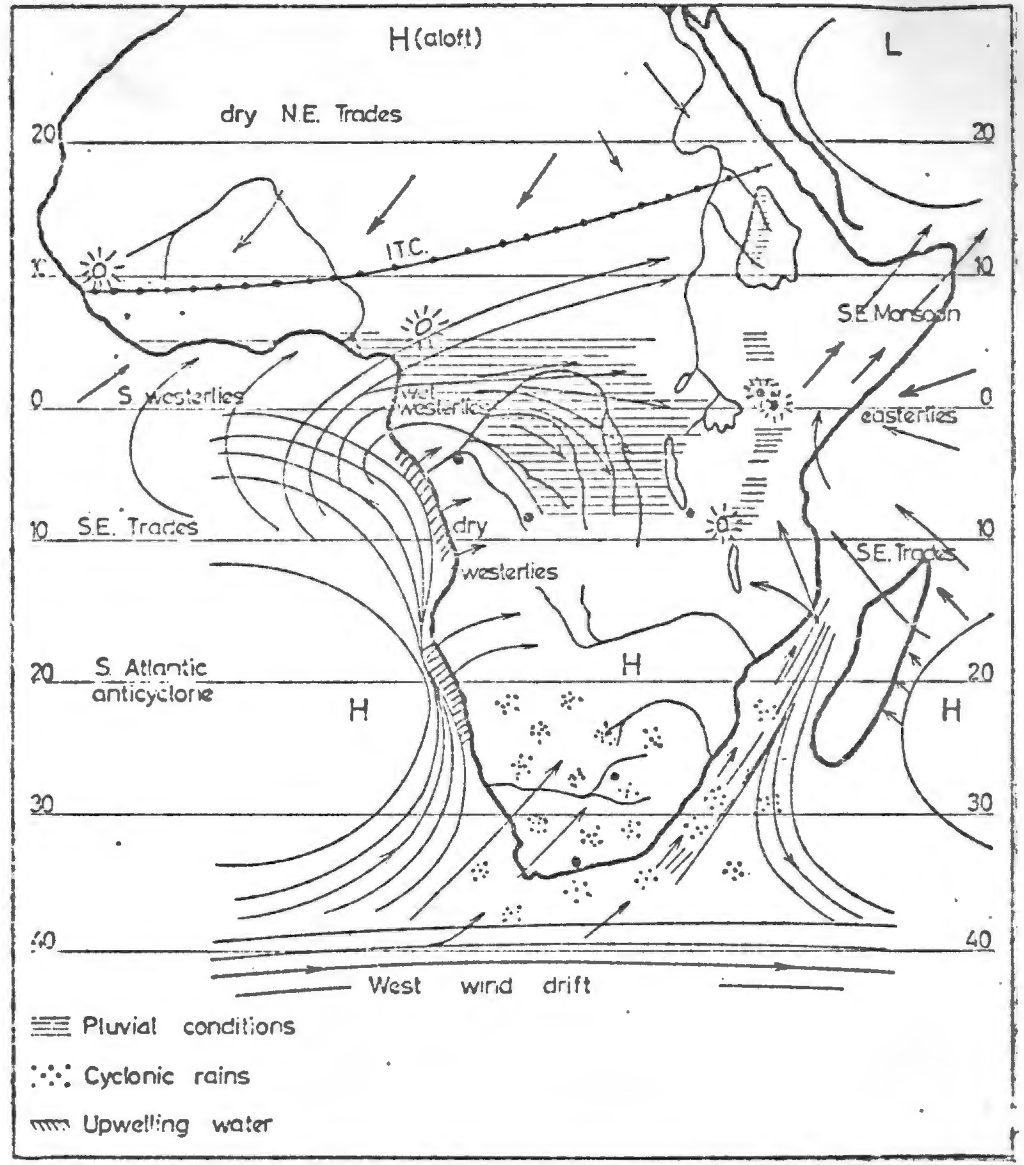

Fig. 4.3 (b) Schematic reconstruction of conditions during a hypothermal minimum (glaciation): southern winter.

(van Zinderen Bakker, 1967)

One of the very important changes in climate during the last glacial period was a considerable decrease in temperature which resulted in sub-zero temperatures in winter and caused frost-shattering and other forms of cryoturbation. The Peninsula today is practically frost-free even in winter. van Zinderen Bakker (1976,p. 169) refers to a drop in average temperature of approximately 10°C during the ice-ages. It is perhaps reasonable to infer that at least 100 depressions from the cold south-west must have reached the study area annually causing extremely cold spells in winter.

Another important facet of the cold climate during a glacial maximum would have been the strong winds. The great temperature differences which existed between the polar and equatorial regions intensified the strength of the zonal winds and caused more violent weather in the mid-latitudes. If stormy conditions during winter within the study area at present are to be used as a yardstick, then conditions during the glacial maxima must have been stormy indeed. Street and Grove (1976,p. 388) refer to the ... "increased rigour of the trade wind circulation during glacial periods." These winds too played a role in shaping the landscape.

F. VEGETATION DURING GLACIAL AND INTERGLACIAL PERIODS

Schalke (1973) studied the area of the South-Western Cape using four cores from the Rietvlei area just north of Cape Town and one boring each from the adjacent Cape Flats and Cape Hangklip. His work resulted in the chronology provided in Table 4.5 which follows.

It will be noted from a study of the table that Schalke (1973) reflects that Podocarpus forest existed in the south-western Cape during the warm Kalambo interstadial and the cold last glacial maximum. Both van Zinderen Bakker (1976, p. 183) and Coetzee (1978b,p. 124), however, disagree with his findings. Both find that the evidence upon which his con-

-clusions were based is unconvincing since the percentages of Podocarpus pollen used was far too low to be utilised as reliable evidence.

Table 4.5

	SUB - DIVISIONS	BIOTIC ENVIRONMENT	CLIMATE
H O L O C E N E	SUB-ATLANTIC SUB-BOREAL ATLANTIC	dune and macchia vegetation	slightly wetter slightly drier drier-wetter-drier
LATE GLACIAL	11 140 B.P. -	peat wind blown sands?	
UPPER PLENIGLACIAL		Podocarp Forest vleis + dunes	
MIDDLE PLENIGLACIAL (5 Intervals)	± 28 000 B. P.	prob. macchia marine influence	drier
	33.000 B. P.		
	DEEP RIVER	Podocarp Forest dunes marine infl.	wetter (colder?)
	36 500 B. P.		
	KILLARNEY	dunes macchia	drier
	40 500 B. P.		
	SALT RIVER	forest vleis + swamps	wetter (colder?)
	45 000 B. P.		
	MILNERTON ? 51 000	macchia vlei + brackish	drier

Stratigraphy of pollen profile in the South-Western Cape

(Schalke, 1973)

G. GEOMORPHOLOGICAL IMPLICATIONS OF THE DIFFERENT CLIMATIC REGIMES

From the preceding account of climatic development it would have become apparent that the study area has, during geological times been subjected to two major types of climatic regime. They are:

(i) Tertiary climates and

(ii) climate/s during the Pleistocene ice-ages with glacial and inter-glacial periods.

Visher (1945,p. 714) points out that the important role played by climate in morphogenic processes has been recognized for a long time. It is thus proposed to look at each of the climatic regimes listed above in an attempt to trace the geomorphological effects which each has had upon the physical landscape of the study area.

Ollier (1969,p. 252) is of the opinion that the style and intensity of weathering has changed through geological time in all parts of the earth.

It is generally accepted that a particular climate will produce its own peculiar assemblage of geomorphic processes. Consequently each type of climate will therefore have its own type of geomorphic manifestations.

Peltier (1950,p. 216) maintains that lands which fall within the zone of climatic fluctuations may have the peculiar characteristics of one climatic cycle superimposed upon those of another, where the effects of previous geographical cycles would not have been obliterated. He avers that a composite product of the different climatic regimes, which he terms ...."a polygenetic topography" would then result. Bradshaw et al (1979,p. 95) refer to ... "the complexities of changing climates over time," and assert that "landforms produced by weathering in different climatic environments may occur in the same area. This is particularly true of the Cape Peninsula where relict features from previous regimes occur within the same areal matrix.

Bradshaw et al (1979,p. 89), whilst referring to the important roles of water and temperature change suggest that they can be related to climatic zones. The distribution of particular processes has been compared. (See Fig. 4.4).

Right at the outset the important role of water in the morphogenic process must be emphasized. Ollier (1969,p. 103) writes as follows: "Water is the most important reactant in almost all forms of weathering and clearly its supply is a great factor in the amount and style of weathering." Water also plays an important role in supporting the living organisms which are sometimes bound up with weathering processes.

The different morphogenic elements consist of the process of rock weathering and the transportation of these products. Weathering processes have been divided traditionally into those which cause the break-up of rocks by mechanical means and those which involve chemical reactions. It is becoming increasingly clear, however, that plants, animals and bacteria are closely involved with many of the processes and may, in some instances be the controlling influences.

MORPHOGENESIS DURING TERTIARY TIMES

It has been stated earlier that during Tertiary times the climate of the study area was warmer, more humid, and the precipitation heavier than today. The climate could be classified as ranging from Tropical to sub-Tropical as evidenced by the pollen spores of plant growth

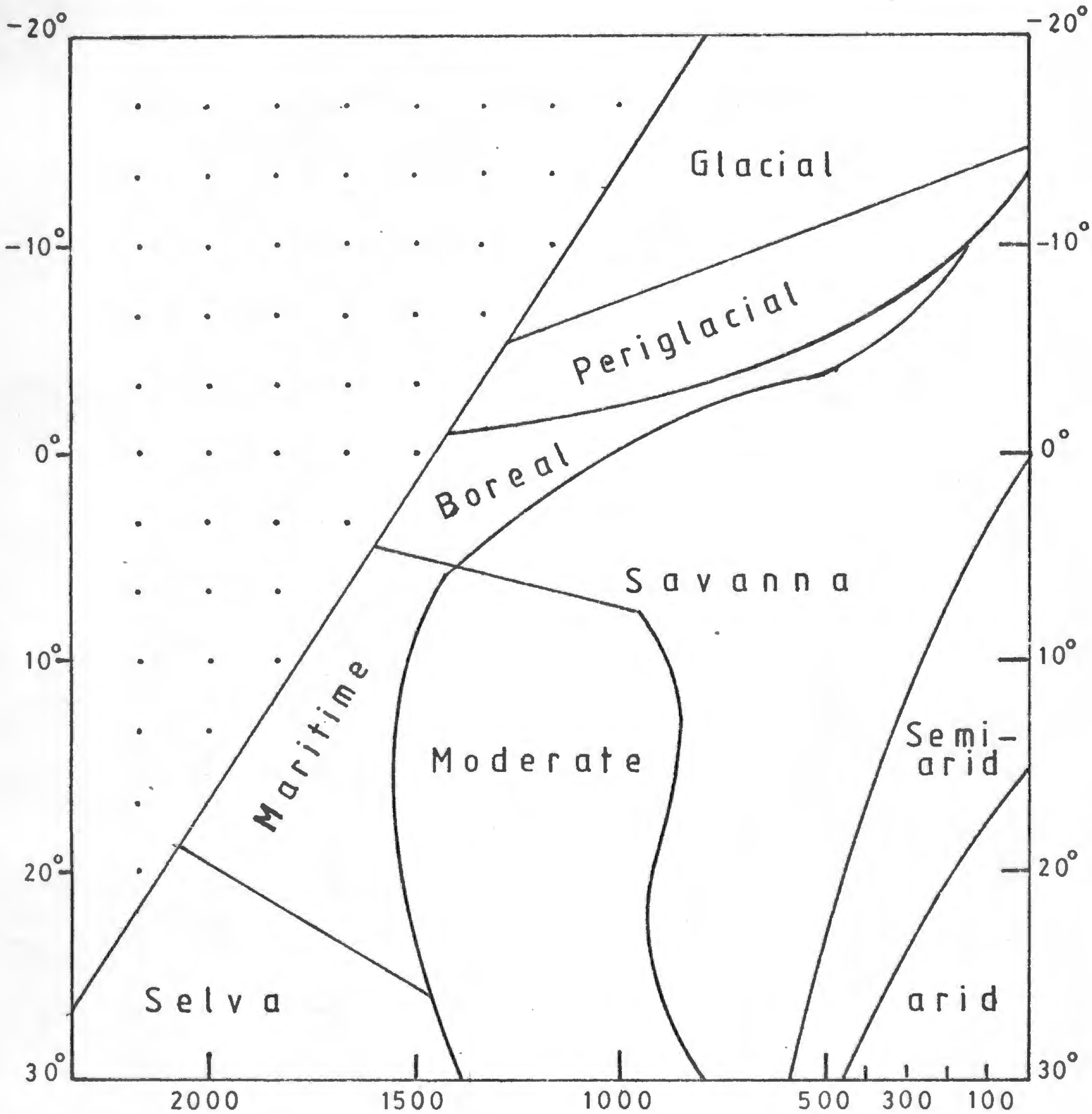

Fig. 4.4

Climatic boundaries of regions giving rise to distinctive groups of landforms. Conditions of temperature affect weathering processes: chemical weathering increases in importance from the top right to the bottom left of this diagram, whilst frost weathering increases towards the top centre. Places in the centre thus receive moderate chemical weathering and moderate frost action.

(After Peltier, 1950, in Ollier, 1969 p. 112) at that time.

Under such climatic conditions chemical activity would have been dominant as a result of the high temperatures, very humid conditions and the high rainfall. Peltier (1950,p. 217) maintains that chemical decomposition, which consists primarily of the oxidation, hydrolysis, hydration and carbonation of the various mineral constituents of the rocks, may be theoretically related to the climate. The essential elements are rainfall, insofar as it determines the availability of water for chemical reactions, and temperature, since it determines the speed of the chemical reactions. This tendency toward direct variation of chemical weathering with temperature would be augmented within the study area by the dense vegetation found under such conditions. The heavy rainfall and high temperatures would produce thick regolith, and the rapidly decaying vegetation would also have led to an increased production of organic acids in the soil. As a result chemical reactions, which are related to organic wastes would have been rapid during Tertiary times within the Cape Peninsula.

EFFECT OF THESE CONDITIONS UPON THE DIFFERENT ROCK TYPES

(a) GRANITE: The chemical weathering of granite is both marked and variable. Thus, although granite contains some quartz, the feldspars are more important in terms of volume occupied and are susceptible to chemical reaction, making the rock as a whole liable to crumbling. Taljaard (1949,p. 24) has commented upon this manifestation, where the granite tends to crumble away to grains rather than blocks under present climatic conditions experienced within the Cape Peninsula. This process would, no doubt, have been accelerated during the climatic conditions of Tertiary times. Since weathering often follows the joint blocks, and isolated joint blocks weather spheroidally, 'core-stones' of unaltered granite are often left in the centre. The heavy rainfall would have ensured that the regolith formed on granitic slopes would have been washed away regularly, thus exposing the fresh rock underneath to renewed processes of weathering.

It is generally accepted that extreme weathering leads to chnia clay deposits being formed. These deposits would consist of almost pure kaolin and quartz grains. The writer tentatively suggests that the deposits of high grade china clay in the Noordhoek area could have been formed during the Tertiary period.

The weathered granite also absorbs much water during rainy periods and tends to become plastic so that steep slopes become unstable. Thus crescentic yellow scars on the slopes above the road from Simonstown to Smitswinkel Bay, and the same type of scars above the road south from Hout Bay indicate where such landslips have occurred. Many of these landslips are masked by vegetation today. It is probable that these landslips could date from Tertiary times.

(b) MALMESBURY SERIES: It is reasonable to assume that under consitions where precipitation was heavier than today, that the water table would have been higher than it is at present. Consequently these rocks would have been weathered to great depths.

It is probable that the slumping of the Malmesbury Series, which is evident on the slopes above the Rhodes Memorial, in the vicinity of King's Blockhouse could date from this period. (This point will be taken up at a later stage.

(c) EFFECT UPON THE TABLE MOUNTAIN SERIES: The jointed quartzites of the T. M. S. have lost the porosity of sandstone and as such is not weatherable. Douglas (1977,p. 45) points out that the materials of which clastic sedimentary rocks are composed have undergone phases of weathering, erosion and transportation before being included in the formations in which they are presently found, and that it is almost inert chemically. Thus, under humid conditions, where chemical weathering is dominant, sandstones (according to Douglas) form relatively resistant rocks. Bradshaw et al (1979,p. 86) refer to a quartzite as being one of the most resistant rocks under any climate. It would therefore be safe to conclude that the T. M. S. would have been relatively unaffected by morphogenic processes during Tertiary times.

What would have happened to the T. M. S. is that the cement holding the quartz together would have been removed. The jointed quartzites would have been broken up primarily along the joints, giving slabs of rock which weather slowly.

EFFECTS UPON THE DRAINAGE

Because of the heavier precipitation during the Tertiary period, the rivers of the Peninsula would have carried a greater volume of water than today. Their load-carrying capacity would also have increased plus an increased capacity to erode their channels. Coupled with sporadic and intermittent uplift the rivers would have extended their courses by means of headward growth. Streams such as the Disa River, for example, would also, as a result of primary rejuvenation following upon uplift have been able to abrade its channel into the solid bedrock of the T. M. S. on Table Mountain. In this way the preliminary incision of the present Disa Gorge could have commenced during Tertiary times.

Bradshaw et al (1979,p. 94) point out that rivers in humid tropical and sub-Tropical areas carry up to ten times the solute load of rivers in temperate latitudes.

This would, in all probability have been the case with the rivers of the study area during Tertiary times.

In conclusion, it would be reasonable to assume that during Tertiary times, for the reasons outlined above that the rivers of the Cape Peninsula would have been enabled to modify the physical landscape to a considerable degree.

EFFECTS OF PAST GLACIATIONS

(a) The Winterhoek Glaciation

Rust (1967,p. 99) points out that the Winterhoek glacial epoch consisted of two transgressive glacial pulses and one intraglacial period of regression followed by the final deglaciation phase. He is of the opinion that this occurred about 431 m.y. B.P.

Three ice sheets passed over the Cape Basin at different times. The first pulse saw the Sneeukop ice sheet enter the basin to be followed by the Winterhoek and Kobe ice sheets. These ice sheets entered the basin from the east and north-east and flowed from north to south down the slight palaeoslope of the basin floor.

Direct Effects of the Glaciers

Direct evidence regarding the presence of these glaciers during the glacial maxima exists on Table Mountain. It consists of glacial deposits on the plateau surface of the mountain stretching between Platteklip Gorge and the knob on which Maclear's Beacon stands. The other evidence comprises an example of intra-formational folding on a small scale in the vicinity of the glacial band.

The glacial bed consists of a gritty quartzite, and the pebbles together with the boulders are mostly found weathered out from the intractable matrix which is found strewn over the surface of the plateau. Many of the pebbles are from 2 - 3cm in length and are made of white quartz. Larger "pebbles" are up to 30cm long and are beautifully striated. du Toit (1954,p. 242) points out that many of the smaller ones were "well water-worn before they were striated."

Rennie (1925,p. 79) has described ..."a peculiarly folded stratum in the neighbourhood of the glacial band." The ridge occurs on the edge of the plateau between Silver-stream Gorge and Maclear's Beacon. The ridge has a maximum height of 4 metres and consists of an upper horizontal stratum, a central stratum thrown into a series of folds and an underlying ill-defined stratum. The folded stratum consists of a hard, resistant grey quartzite with a thickness of approximately 1,5 metres thrown into a series of gently-curved anticlines and synclines.

In their explanation regarding the intra-formational folding connected with the glacial bed in the T. M. S. Haughton, Krige and Krige (1925,p. 23), who based their conclusions upon field evidence are convinced that the folding of the rocks below the tillite is intimately connected with the glaciation of the area. They are of the opinion that the ice-sheet must have passed over the still-unconsolidated glacial material and the sand below, and rucked them up into folds.

(b) MORPHOGENESIS DURING THE PLEISTOCENE

Sub-zero temperatures during the Pleistocene witnessed the entry of glaciers into the study area and resulted in frost-shattering and other forms of cryoturbation

PLATE

9

Evidence of Pleistocene cryonival and cryoturbation phenomena exposed in a road cutting between Castle Rocks and Partridge Point on the western shores of the False Bay coast. Note the marked angularity of the constituent fragments.

Effects of Frost Action

Whereas chemical weathering was the dominant morphogenic process during Tertiary times, it would be true to state that during the different climatic regime of the Pleistocene --- which was characterized by sub-zero temperatures --- that mechanical weathering was the chief morphogenic agent. Peltier (1950,p. 227) is convinced that the over-riding agents of planation which are active in a periglacial cycle are frost action and wind action. Visher (1945,p. 728) refers to frost action as being .... "of profound geologic importance." Ollier (1969,p. 11) goes a little further in his convictions and sees frost-shattering as one of the greatest if not the greatest mechanical agent in weathering.

Prof. Linton visited the study area in July and August 1967 and in his paper of 1969,p. 72 stated that his observations led him to believe that ....."evidence of Pleistocene cryonival and cryoturbation phenomena are quite widespread in South Africa, descending to low levels in the south. He referred to examples of "young-looking geliflual accumulations of the Cape Peninsula at Llandudno and Camps Bay."

Prof. Verhoef (1969,p. 96), after considering various slope deposits in areas around Cape Town has tentatively suggested that some measure of "periglacial cryergic action" had also played a role in their formation.

The writer has found what he tentatively considers to be evidence of cryoclastic frost-fracturing which could have occurred during the Pleistocene. The evidence is to be seen along a road cutting between Castle Rocks and Partridge Point just north of Smitswinkel Bay. (See Plate 9).

Other evidence of frost-shattering occurs in the vicinity of the contour path north of Kirstenbosch at the base of Window Buttress, Fernwood Buttress and Hiddingh Buttress. The angular spalled fragments are masked by the vegetation. Other evidence of preiglacial frost action is to be seen on the bare upper reaches of the Steenberg and Muizenberg Mountains. It consists of boulder-strewn slopes and rubble drift. The rubble deposits on the mountain-sides referred to exhibit the typical lack of sorting and characteristic angularity of the fragments.

Characteristic features of Pleistocene cryonival and geliflual activity within the study area are:

(a) marked angularity of the constituent fragments; their corners are not rounded;

(b) an abundance of small chips in the matrix and frost-scarred stones or fragments;

(a) a rough zonation by calibre of the constituent fragments. This can be attributed to the derivation of the material at different levels in the deposit from various levels of the parent slope;

(d) the colluvial deposits tend to be unsorted.

The writer has also found evidence of what he considers to be periglacial slumping on the lower slopes of Devil's Peak above the Rhodes Memorial and in the vicinity of King's Blockhouse. This slumping could, however, date from Tertiary times.

It would appear that the Malmesbury Beds had become over-saturated during the warmer and wetter interglacial periods coupled with thawing of the surface layers. This must have caused the slopes to become unstable. As a result the surface layers slid downhill. This tends to be borne out by the odd angles of repose of the fragments of the T. M. S. resting upon the slumped Malmesbury Series. It appears that the boulders could not have reached their present angles of repose as a result of rolling downslope, but only if they had been rafted down as part of the slumped Malmesbury Beds.

During the Pleistocene a new base level resulted due to a negative shift in sea-level of approximately -130m. The rivers of the Peninsula would, as a result of primary rejuvenation have had to adjust to this new level, bringing about acceleration in the rate of landform modification. Visher (1945,p. 731) points out that freezing and thawing are important in aiding sheet erosion as it often renders the top of the soil fluffy --- and easily carried away by even a small runoff. It would thus be a reasonable assumption to see the rivers of the study area transporting a greater load during the inter-glacials whilst extending their courses through headward erosion, and abrading their channels in response to the lower base level.

It has been pointed out at an earlier stage that very strong winds would have formed a very important facet of the cold climate during the glacial maxima of the Pleistocene. It could thus be inferred that gale force winds, coupled with the destructive waves which they produced would have been very active as a morphogenic agent during this period in shaping the coastline of the study area. It has helped to produce the present shoreline of the Cape Peninsula which King (1963,p. 104) sees as ..... "a monument to the marine energy manifested in these storms."

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CHAPTER 5

DRAINAGE OF THE CAPE PENINSULA

This attempt at tracing the development of the drainage systems within the study area can be related to those clear and cogent words of W.M. Davis (1909,p. 268) in which he writes, "To look upon a landscape without any recognition of the labour expended in producing it, or of the extraordinary adjustments of streams to structures and of waste to weather, is like visiting Rome in the ignorant belief that the Romans of today had no ancestors."

The development of the drainage systems within the Peninsula must, therefore, be seen against the background of the following :

(a) the sub-surface formation of the Cape Peninsula as part of the Cape Basin;

(b) the tectonic forces responsible for the Cape orogeny;

(c) sporadic or intermittent uplift of the study area during Tertiary and Quaternary times, coupled with

(d) the formation of various denudational levels (marine benches and terraces), which were formed by the sea during stillstands of the land in relation to the sea at present elevations of 450, 300, 165, 120 and 60m above sea-level, as well as at lower elevations. There is evidence for a denudational level at 700m, but this point will be developed in the next chapter.

(e) the elimination of the False Bay anticline as a result of weathering, the work of running water and the destructive action of the sea;

(f) this has produced the present plateau-and-scarp topography which characterizes the present physical landscape of the Cape Peninsula.

DRAINAGE DEVELOPMENT

As early as 1937 Wooldridge and Morgan (p. 189), whilst attempting to trace a systematic cycle of development within a drainage system came to the conclusion, that during the earlier stages a process of extension prevails, involving lengthening of the streams by headward erosion and subsequently by the multiplication of tributaries. They stated that integration would begin at a later stage, whereby the drainage system would be simplified. This would involve the absorption of minor by major valleys.

Their assertions have subsequently been corroborated by an experimental study of drainage basin evolution which was carried out by Parker (1977,p. 157).

A 9 X 15m facility was built and filled with a homogenous mixture of sand, silt and clay. The material provided sufficient resistance to erosion to maintain channels and to allow valley sidewalls to develop. A sprinkling system was established along the sides of the container, and it provided four intensities of rainfall to the nearly $140m^2$ drainage system.

Two experiments were performed, each of which documented the development of the drainage system on an initially flat, gently-sloping surface. In the first experiment the network grew headward, developing fully as it extended into the basin. This is termed "headward" growth. In the second experiment an initial skeletal network blocked out much of the watershed, and later internal growth and re-arrangement of the channels occurred just as previously asserted by Wooldridge and Morgan (1937,p. 189). This is termed "Hortonian" growth.

Parker (1977,p. 157) found that sediment yields from the basin undergoing erosional evolution show an exponential decline with time. This overall trend was found to be characterized by high variability. Parker (1977) points out that in nature the long term variability would be compounded by changes in climate and land use. It would appear that periods of high variability appear to be related to times of high sediment production in the basin. Alluvial material is periodically stored and flushed in the main channel aggravating sediment-yield variability. Parker (1977) is of the opinion that base level changes produce degradation which leads to aggradation in the main channel as sediment production upstream continues. This phenomenon is termed "the complex response of the basin."

The findings of Parker (1977) have value as a mental standard of comparison (when related to theoretical knowledge or fieldwork), but its full development presupposes simple and uniform conditions both of structure and climate such as appertains within the study area as a whole. It would also be reasonable to assume that drainage development within the Peninsula would have occurred in the manner outlined above.

THE CLASSIFICATION OF STREAMS

Johnson (1932,p. 482) maintains that it is possible to classify streams according to a variety of different principles. Depending on the purpose in view, the classification may be according to :

(a) method of origin or genesis;

(b) stage of development in the cycle;

(c) relation to genetically associated structures,

(d) relation to foreign structures, and

(e) pattern of drainage lines.

(a) THE GENESIS OF STREAMS

An analysis of stream development shows that the various causes of valley location may be expressed as follows, viz. that the position of every valley is determined by inequalities of surface slope or by the inequalities of rock resistance. Valleys falling into the first group might be termed consequent, whilst those of the second group might all be termed subsequent.

Thus the present position of rivers within the study area such as the trunk streams of the Disa river, the Kromrivier, the Klaasjagers river and others have all had their courses determined by or are "consequent" upon the initial slope, the original slope or the constructional slope of the land.

Of great general importance in the growth of drainage systems within the study area has been the development of subsequent tributaries. Such streams, starting as gullies on the sides of the primary consequent valleys, discover and explore belts of structural weakness due to softer strata, fault- or joint-planes and shatter zones. By virtue of their chance-found advantage, subsequent tributaries establish a long start in both headward growth and vertical erosion, and pick out the natural structural lineaments or master joints of the landscape. Thus the growth of subsequent streams within the Peninsula has been largely determined by the crushed zones along faults or the weathered zones bordering joint planes.

The preceding developments relate to the drainage of the plateau itself, whereas the steep slopes of the escarpment have witnessed the growth of swiftly-flowing consequent streams.

(b) STAGES OF STREAM DEVELOPMENT

Johnson (1932,p. 482) points out that the, "Classification of streams according to stages of development into young, sub-mature, late-mature and old streams is a common procedure."

In the following the terms "young valley" and "young stream" will be used interchangeably. This is because any stream, which consists of both water and waste streaming toward the sea, cannot profitably be treated as independent of the depression or channel caused by the streaming water and waste.

In the northern sector of the study area remnants of mature, broad valleys are to be found draining the plateau such as the Waai Vlei valley, the valley between Kasteels Poort and Skeleton Ravine and a valley north of Groot Kop. They are characterized by broad and flat valleys with gentle gradients and carry sluggish, more or less meandering streams. Some of these valleys are presently

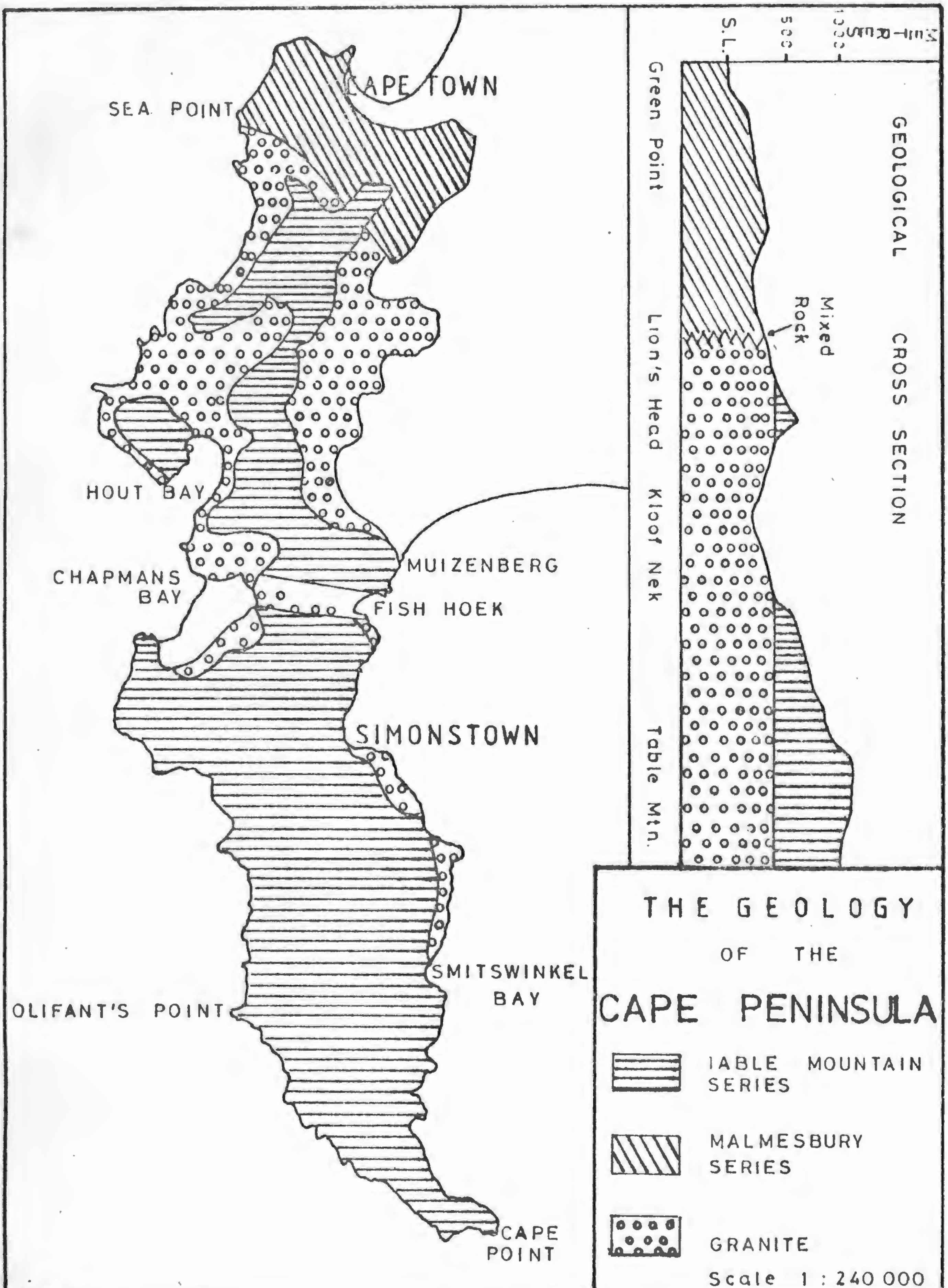


FIG. 5.1. Geology of the Cape Peninsula

[After Walker, 1952]

occupied by the Holy Hutchinson, Woodhed, Victoria and Alexandria resevoirs.

In the southern half of the Peninsula, mature streams are to be found draining the plateau such as the Klaasjagers river, the Klawersvlei river to the west of Simonstown, together with the Schusters river.

The escarpment by way of contrast is drained by young streams. The valleys are narrow, steep-sided with steep gradients and follow direct courses to the sea. Because of their greater energy, they have cut rocky gorges into the T. M. S. The numerous buttresses projecting between the various gorges on the slopes of Table Mountain, the Twelve Apostles and elsewhere attest to the great erosive powers of these youthful streams.

These youthful streams are busy dissecting the edge of the escarpment as well. The edge has been notched at long intervals by narrow gorges. It has also been fretted and rendered sinuous in places by numerous closely-spaced streams. Abstraction of the escarpment is also occurring. These streams are actively eroding their beds and are encroaching on the older upland drainage. Blocks of stones littering the slopes beneath the escarpment in various places provide proof that the face of the escarpment is disintegrating and that it is in a state of active retreat.

(c) RELATION TO UNDERLYING STRUCTURES

It has previously been stated that the greatest part of the surficial layers of the study area consists of the jointed quartzites of the Table Mountain Series. The point merits re-statement now, but for a different reason.

The T. M. S. everywhere forms the high ground

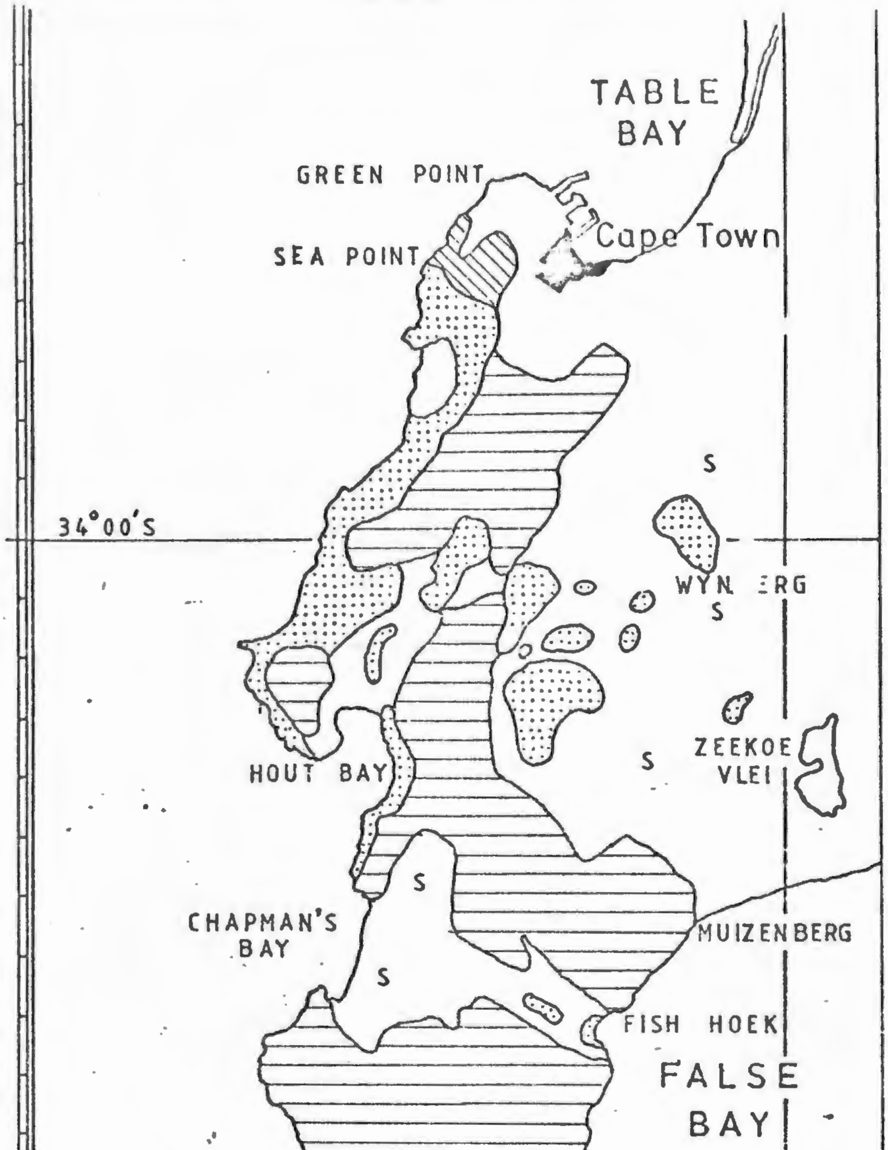


Fig. 5.2 Geological outcrop-map

(After Scholtz, 1945)

of the Peninsula. (See Fig. 5.1). The horizontal layers of the T. M. S. rest upon the older basement rocks consisting of the Younger or Cape Granite and the Malmesbury Series which together form the lower ground within the study area. Outcrops of these two rock types are, however, visible in scattered parts of the study area. (See Fig. 5.2).

The structures of the T. M. S. together with its form is largely determined by two sets of vertical joints or master joints which run approximately at right angles to each other. The joint planes are aligned from approximately W. N. W. to E. S. E. whilst the complementary set of joints is aligned approximately from N. N. E. to S. S. W.

The influence of the structural, directional or guidance control upon the primary consequents and secondary subsequents within the Peninsula is remarkable. Streams of the study area rise mainly on the jointed quartzites of the T. M. S., and their courses follow lines of weakness offered by joints or faults within the series. As a result, their courses run either in a general W. N. W. to E. S. E. direction or one at right angles to it, namely N.N.E. to S. S. W. This directional control is evident from the diagram illustrating the courses of the Silvermine, Schusters and Elsies rivers. (See Fig. 5.3). This structural control is what Wooldridge and Morgan (1937,p. 190), Twidale (1971,p. 214) and Small (1972,p. 250) refer to as "adjustment to structure."

(d) RELATION TO FOREIGN STRUCTURES

THE DISA RIVER ---- A CASE STUDY

It is generally accepted that the oldest features forming part of the landscape of the Peninsula are the mature plateau valleys of Table Mountain. Their age has

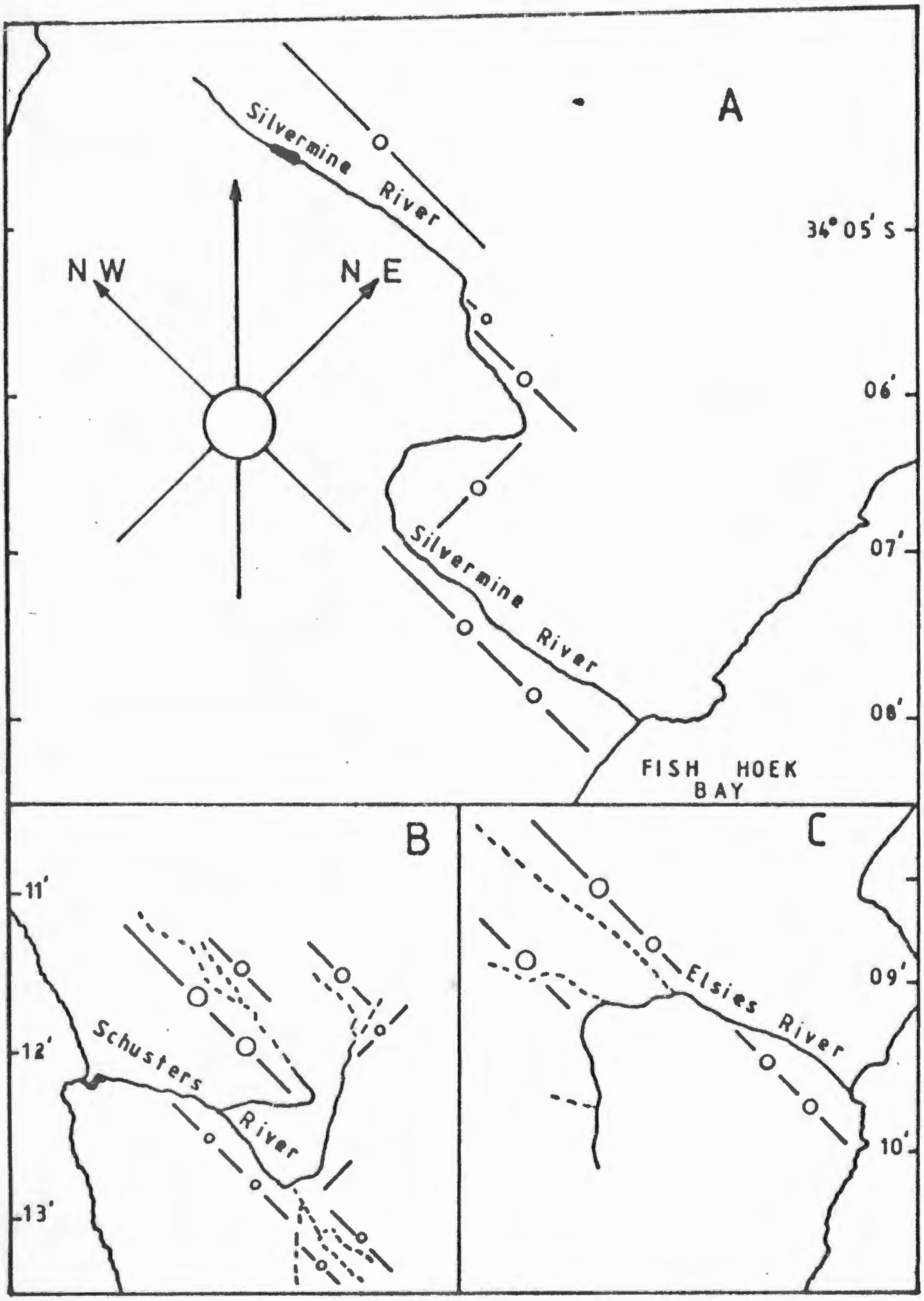


Fig. 5.3 Directional Control of Drainage Lines. A: Silvermine R. B: Schusters R. C: Elsies R.
—o— : Structural lines

been estimated at approximately 70 m.y. ---- thus dating back to Late Cretaceous times.

The decision to trace the development of the Disa river very briefly has been taken for the following reasons:

(a) It is one of the oldest rivers draining the surface of the study area, and as such can be related to the rather apt observation by Zernitz (1932,p. 498) in which she states: "Moreover as streams are long-lived, comprising among physiographic features some of the oldest survivors or surviving remnants and also some of the youngest developments in response to earth movements, they may embody a long record of the geologic history of a region."

(b) The river has contributed a significant part to modifying the physical landscape of a section of the study area. (See Fig. 5.4). Here the Disa River and its sculptural work is hypothetically represented over a long period of time. This role of modifying the landscape is in keeping with the injunction of Crickmay (1974,p. 240), that, "There is still a paramount need to see the work of the river as part of a round of geomorphic development."

(c) Furthermore, the river provides evidence of being a superposed consequent in its lower course.

(i) EARLY DEVELOPMENT OF THE DISA RIVER

The very slight gradients of the Disa River and the "Original Disa River" in their upper courses seem to

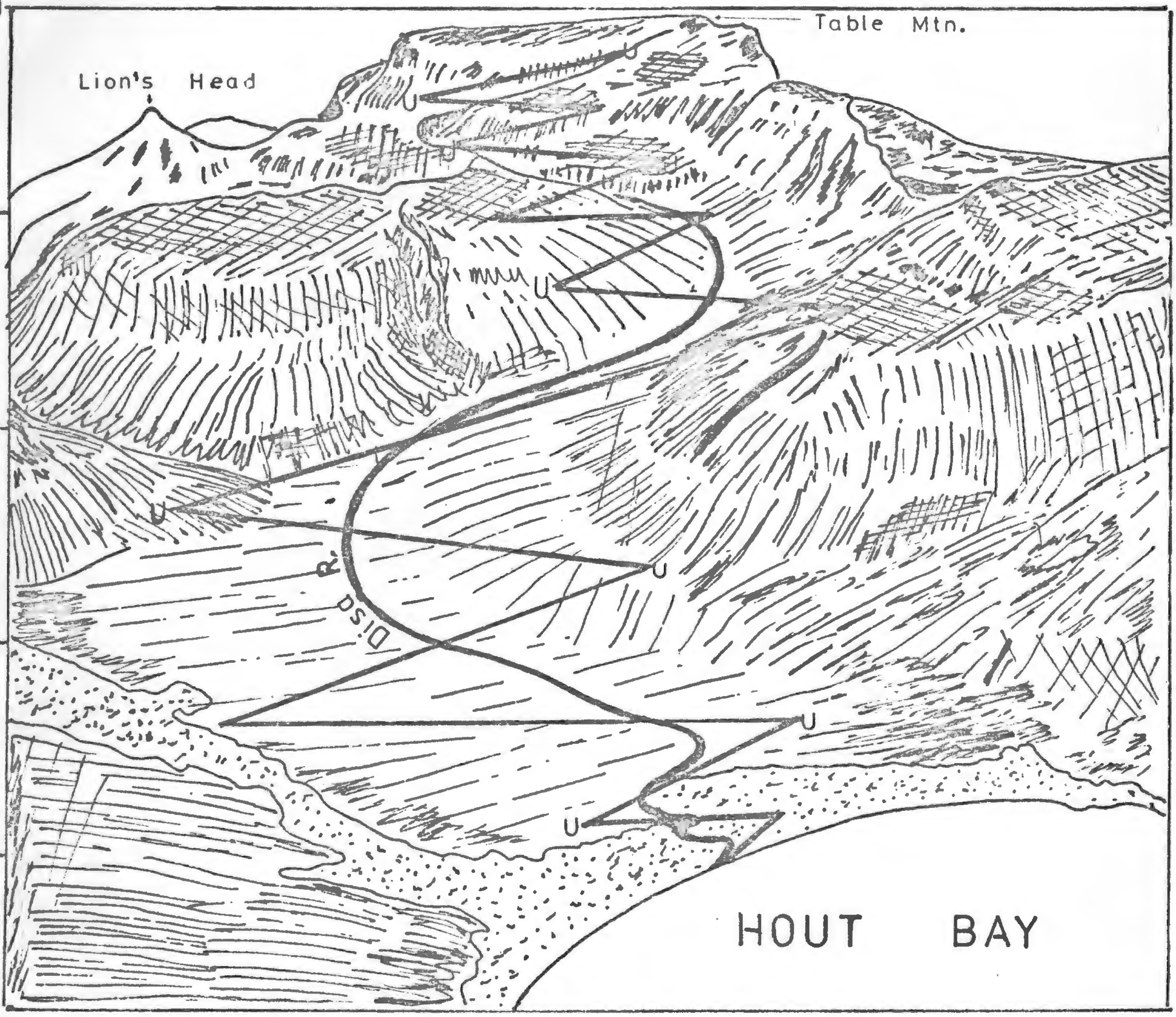


Fig. 5.4. Hypothetical Erosion History. The Disa river and its sculptural work.

U Hypothetical stream positions in the geological past.

—— Hypothetical routes of stream migration laterally and downward through oblique erosion.

indicate that these rivers were formed close to sea-level. (See Fig. 5.5). The following figure represents the moderate gradient of the original landscape (Fig. 5.6). In this regard Crickmay (1974,p. 241) observes that, "During stillstand, such streams as exist continue to work as they did to begin with, flowing at grade across broad flat lands near to base level and carrying the finest of detritus from the central headwaters areas."

Evidence has previously been provided with reference to sporadic and intermittent uplift of the study area during geologic times. This would have enlarged the surface area, increased the gradient and initiated new cycles of denudation by the Disa and other rivers with the emphasis initially upon vertical erosion.

The primary consequents and secondary subsequents would have adjusted their courses to the initial slope of the land, and to the master jointing of the T. M. S. It will be observed that the major direction of the river (apart from the meanders) trends from approximately E. N. E. to S. S. W.

(ii) LATER DEVELOPMENTS

With the passage of time, following repeated uplift, the Disa river had incised its course to such an extent that it abraded into the underlying basement rocks consisting of the Younger or Cape Granites. In the Hout Bay valley the height of the granite varies from approximately 300m in the north to about 90m in the south. The granite consists of older rocks which comprise components of an altogether different sequence and of a substantially different structure to that of the overlying T. M. S.

By the time the Disa river had cut through

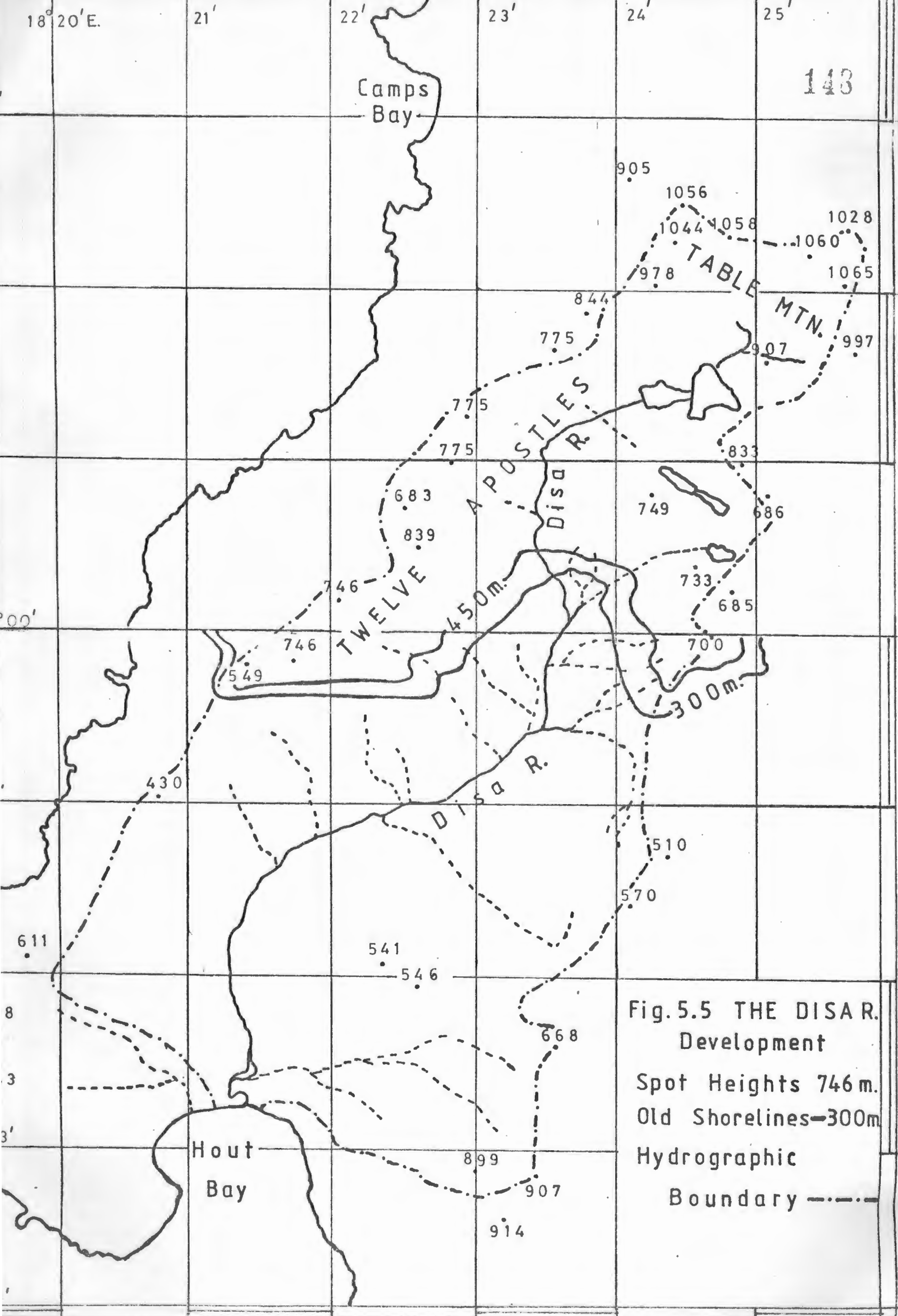


Fig. 5.5 THE DISA R. Development

Spot Heights 746 m.

Old Shorelines — 300m

Hydrographic Boundary -·-·-

the unconformity it was firmly established in its course, since adjustment to the overlying T. M. S. would have occurred by that time. The river has since been able to maintain its course independently of the structural features of the underlying Cape Granite. The Disa river together with its tributaries has cut back into the T. M. S. and has formed steep-sided ravines and gorges such as the step-like waterfalls and deep rock pools at "Hell's Gates" which mark the descent from the T. M. S. to the granite. With the passage of time the river has been able to widen its valley considerably, particulatly in the lower reaches. Here it has also succeeded in removing the whole of the younger sedimentary cover of the valley, while its course has been deeply incised into the underlying basement rock.

The Disa river in its lower course thus provides evidence of what Twidale (1971,p. 216) refers to as an example of "local superimposition" or drainage discordance. It can also be said to be superposed or superimposed upon the Younger or Cape Granite. Wooldridge and Morgan (1937, p. 205) refer to this type of drainage as being "Epigenetic."

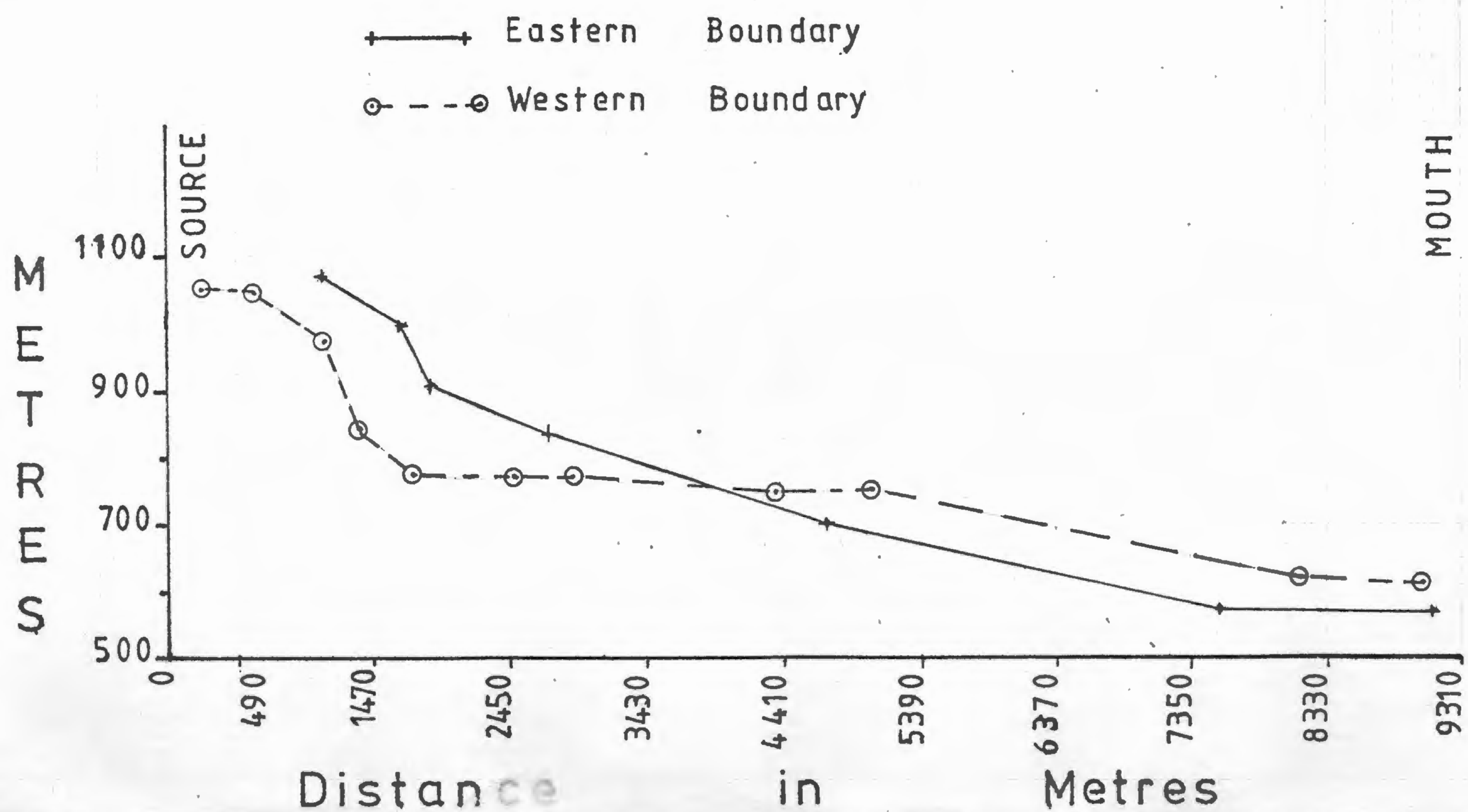
Bailey Willis (1929,p. 310) sums up as follows: "The direction of flow and the angles in the course of streams thus register older and younger controls which were inherent in the structure of the rocks."

(e) PATTERN OF DRAINAGE LINES

Zernitz (1939,p. 521) is of the opinion that the importance of drainage patterns far exceeds the attention that has thus far been devoted to them. She asserts that they have fittingly been called " ... the key to the landscape." Cooks (1972,p. 1073) develops this idea and takes

Fig. 5.6 The Disa River

Section showing Hydrographic Boundaries



it a bit further when he writes that, "Drainage patterns form very useful and important expedients in the interpretation of the landscape." He goes on to state that this is a fact which is very often overlooked by students and research workers in geomorphology. Small (1972,p. 225) maintains that a drainage system forms a major feature of the physical landscape, and that the form of that system and especially the orientation and spacing of its component streams does much to determine the essential character of the landscape. This is particularly true of the study area where:

(i) the streams are mainly aligned in the specific directions referred to earlier;

(ii) it is also notable that the steepest gradients in many cases parallel the stream courses i.e. paterally.

It must be stated at the outset that Strahler (1972,p. 84), Small (1972,p. 226) and Cooks (1972,p. 1073) all emphasize the fact that in reality drainage patterns are often not perfectly developed and therefore only approximate to the models which have been devised.

The following drainage patterns are to be found within the Peninsula:

(a) Rectangular patterns;

(b) subparallel patterns;

(c) semi-dendritic patterns, and

(d) radial patterns.

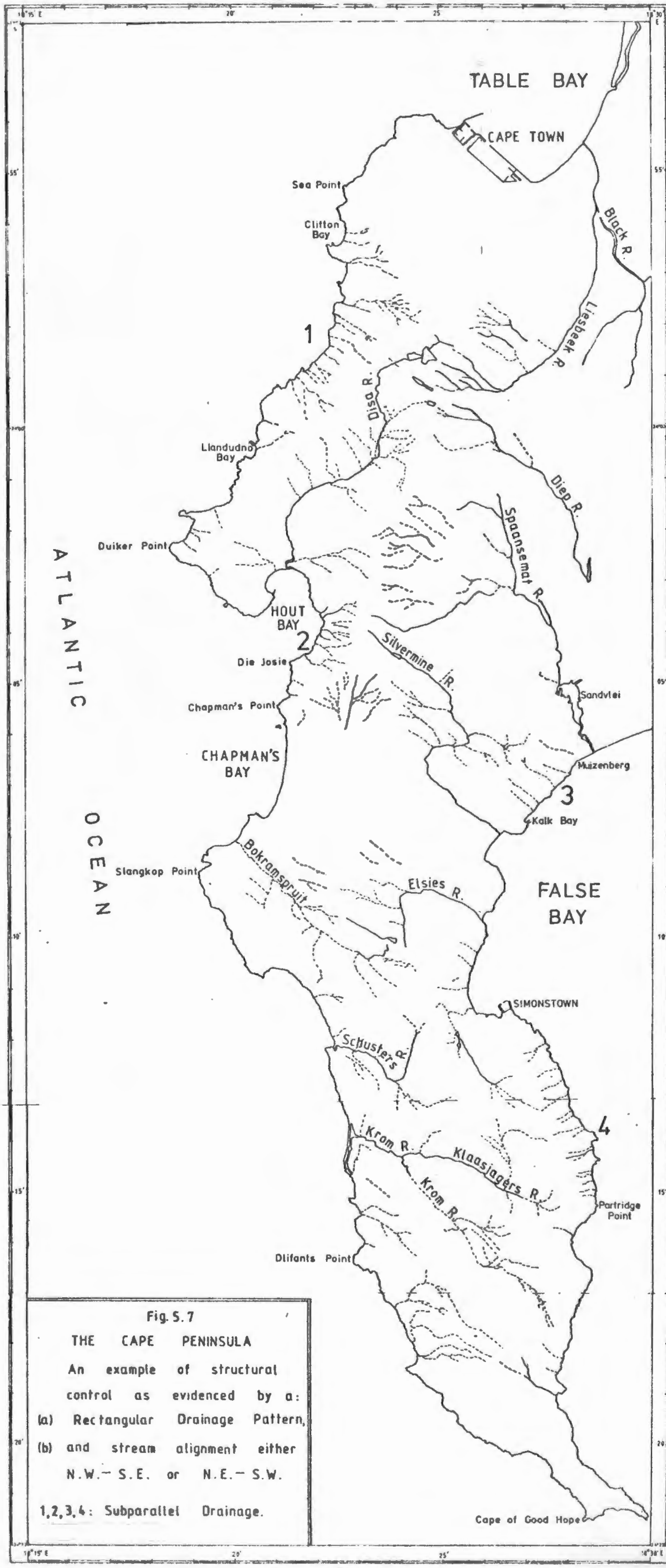


Fig. 5.7
THE CAPE PENINSULA
An example of structural control as evidenced by a:
(a) Rectangular Drainage Pattern,
(b) and stream alignment either N.W. – S.E. or N.E. – S.W.
1, 2, 3, 4 : Subparallel Drainage.

(a) RECTANGULAR DRAINAGE

The major drainage pattern of the Peninsula is notably rectangular, consisting of parallel consequent streams with subsequent tributaries. The influence of master jointing on valley plan is evident throughout the study area. Consequently, this pattern is the direct result of geological controls, and thus the primary consequents follow well-marked lines of structural weakness.

Within the framework of this parallel planimetric arrangement the individual streams may themselves show marked angularities of course such as that exhibited by the Silvermine river, for example. Structural control is prominent as the pattern is directly determined by the right-angled jointing or faulting of the underlying T. M. S. It is observable that the streams of the study area have thus extended their courses along well-defined lines of weakness and thus provide evidence of adjustment to the underlying structure.

Most of the streams within the Peninsula thus flow from approximately W. N. W. to E. S. E. Rivers such as the Silvermine, Schusters, Elsies, Bokramspruit, Krom, Klaasjagers and others exhibit this planimetric arrangement of their stream courses. The Disa and Liesbeek rivers are two notable exceptions however, since their courses are aligned to follow the complementary set of master joints and are thus orientated from approximately N. N. E. to S. S. W. (See Fig. 5.7). The effects of this joint control are also apparent upon the streams draining the plateau region of Table Mountain which exhibit a marked angularity. (See Fig. 5.8).

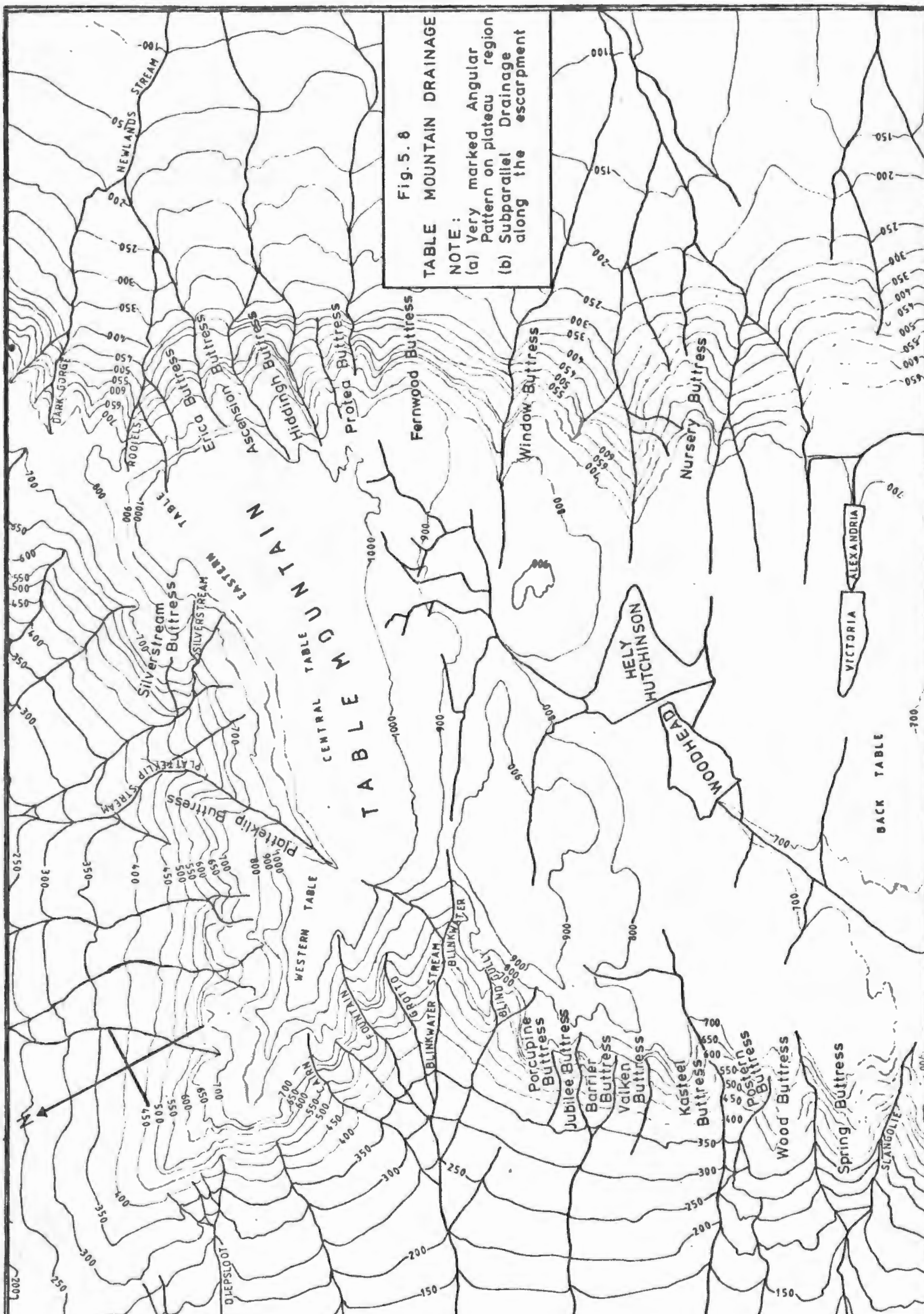


Fig. 5.8

TABLE MOUNTAIN DRAINAGE

NOTE:
(a) Very marked Angular Pattern on plateau region
(b) Subparallel Drainage along the escarpment

(b) SUBPARALLEL PATTERNS

These comprise a series of streams which run approximately parallel to each other. The younger streams flowing down the slopes of the escarpment normall conform to this pattern and can be classified as primary consequents.

This pattern is clearly evident in those parts of the Peninsula where the edge of the escarpment tends to run parallel to the present coastline where the latter is fairly straight in plan. It also occurs where the edge of the escarpment is fairly close to the coastline with a considerable difference in altitude between the two, thus providing a fairly steep gradient. Good examples are to be found on the Atlantic coastline between Clifton Bay and Llandudno Bay (1), and also between Koeëlbaai and Die Josie (2) on the eastern seaboard of Hout Bay. Other examples are to be found on the False Bay coast between Muizenberg and Kalk Bay (3), and on the stretch of the escarpment between Simonstown and Partridge Point (4). (See sections marked 1,2,3,4 on Fig. 5.7).

(c) SEMI - DENDRITIC PATTERNS

This pattern would appear to be anomalous and out-of-phase with the very marked joint- or structural control manifested by the two drainage patterns referred to previously. This phenomenon also appears inexplicable if it is borne in mind that the streams concerned also originate on the jointed quartzites of the T. M. S.

This apparently anomalous feature can, however, be explained with reference to one of the basic postulates which has been posited thus far, namely that of sporadic

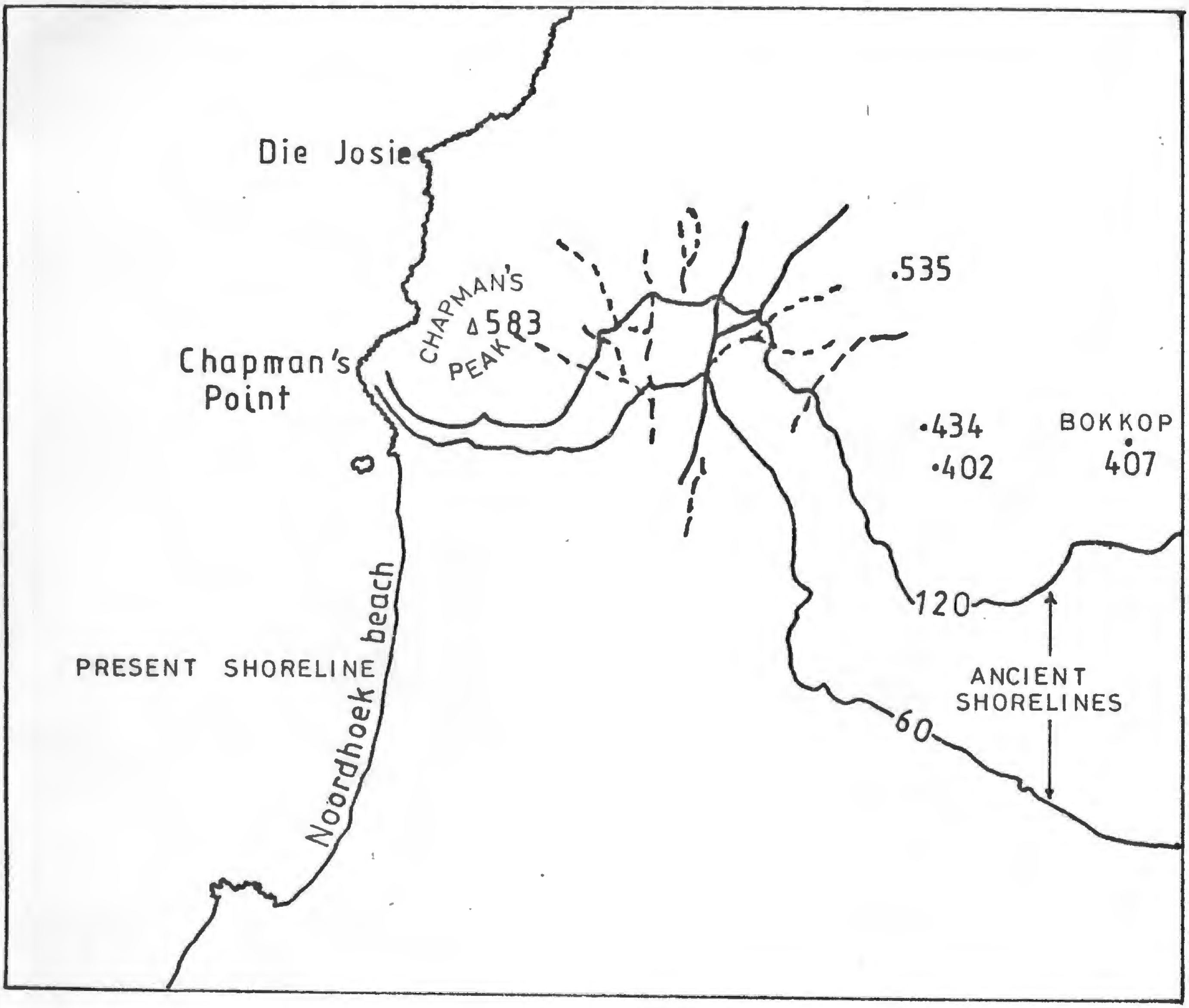


Fig. 5.9.(a) Semi-dendritic Pattern. Good Hope stream and tributaries.

Ancient coastlines inserted at 60 and 120m respectively.

Scale 1 : 50 000

and intermittent uplift of the Peninsula during geologic times involving stillstands at different levels, coupled with the changing relationship between the land and the surrounding sea.

In the case of the drainage of the Good Hope river and its tributaries, if the old coastline were to be inserted at 60m and 120m respectively for different stillstands, then the present pattern becomes explicable. (See Fig. 5.9 (a). If, in the case of the Blinkwater stream and its tributaries such as the Cairn, Fountain, Grotto, Blue Gully and others the old coastline is inserted at the present 450m contour (representing a stillstand as postulated earlier), then seemingly out-of-phase pattern too becomes explicable. (See Fig. 5.9 (b).

It is generally accepted that a semi-dendritic pattern results where the shorelines are irregular with pronounced headlands and embayments and a fairly steep gradient close to the shore. The reason is that marine platforms normally possess gradients approximately at right angles to the shore-line, and in the embayments there will be a tendency for convergence or confluence of drainage lines to occur as in the case of the two examples cited above.

(d) RADIAL DRAINAGE PATTERNS

In the case of Lion's Head, where a structural dome of Cape Granite underlies a remnant of the T. M. S. a radial consequent drainage pattern has resulted. Here the drainage lines radiate outward from the central high part and flow down the flanks of Lion's Head. (See Fig. 5.10). Because of its conical shape Klein Leeukop too exhibits the same pattern of drainage lines.

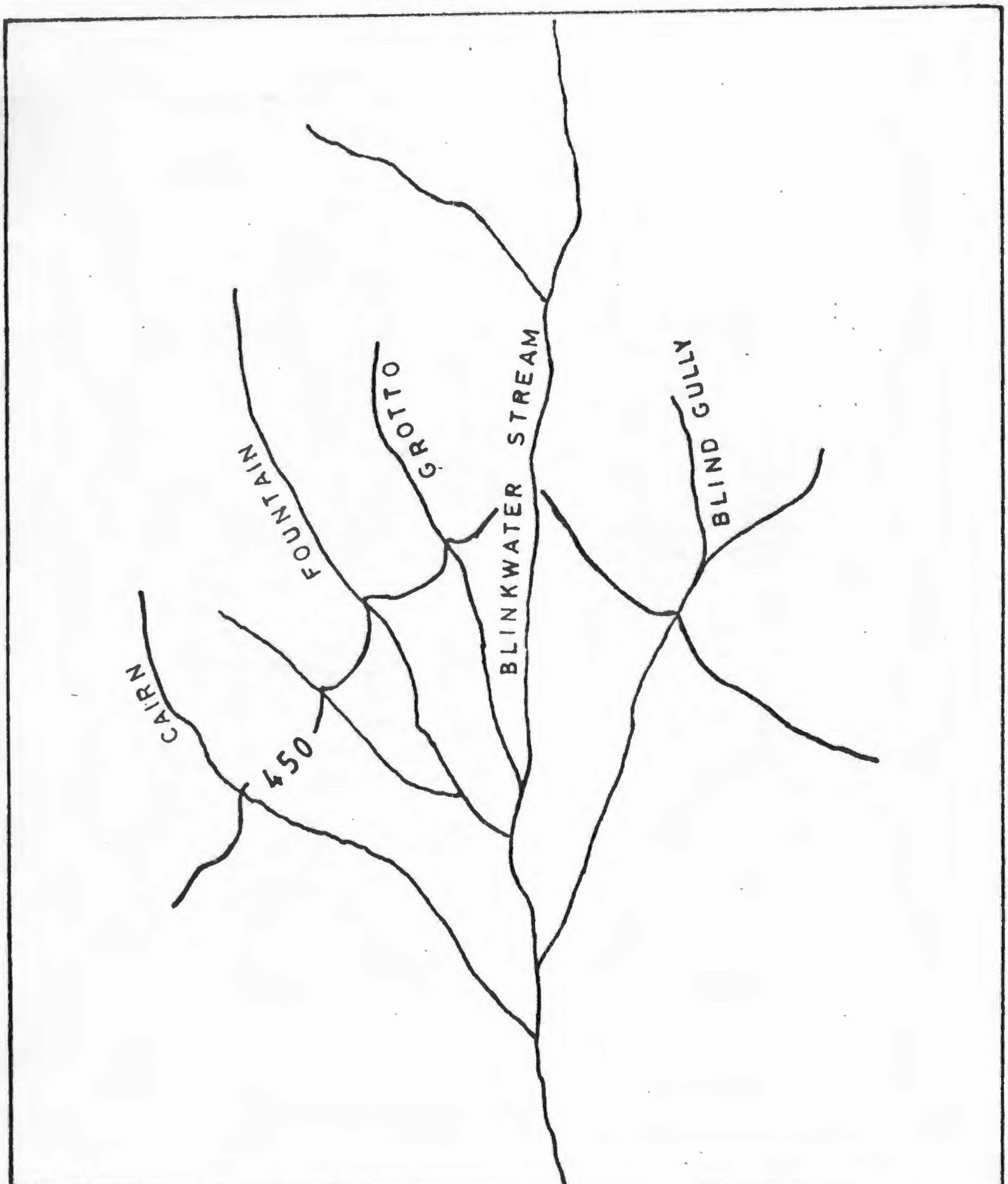


Fig. 5.9(b) Semi-dendritic Pattern

Blinkwater Stream and tributaries

Ancient coastline inserted at 450m

Scale 1 : 10 000

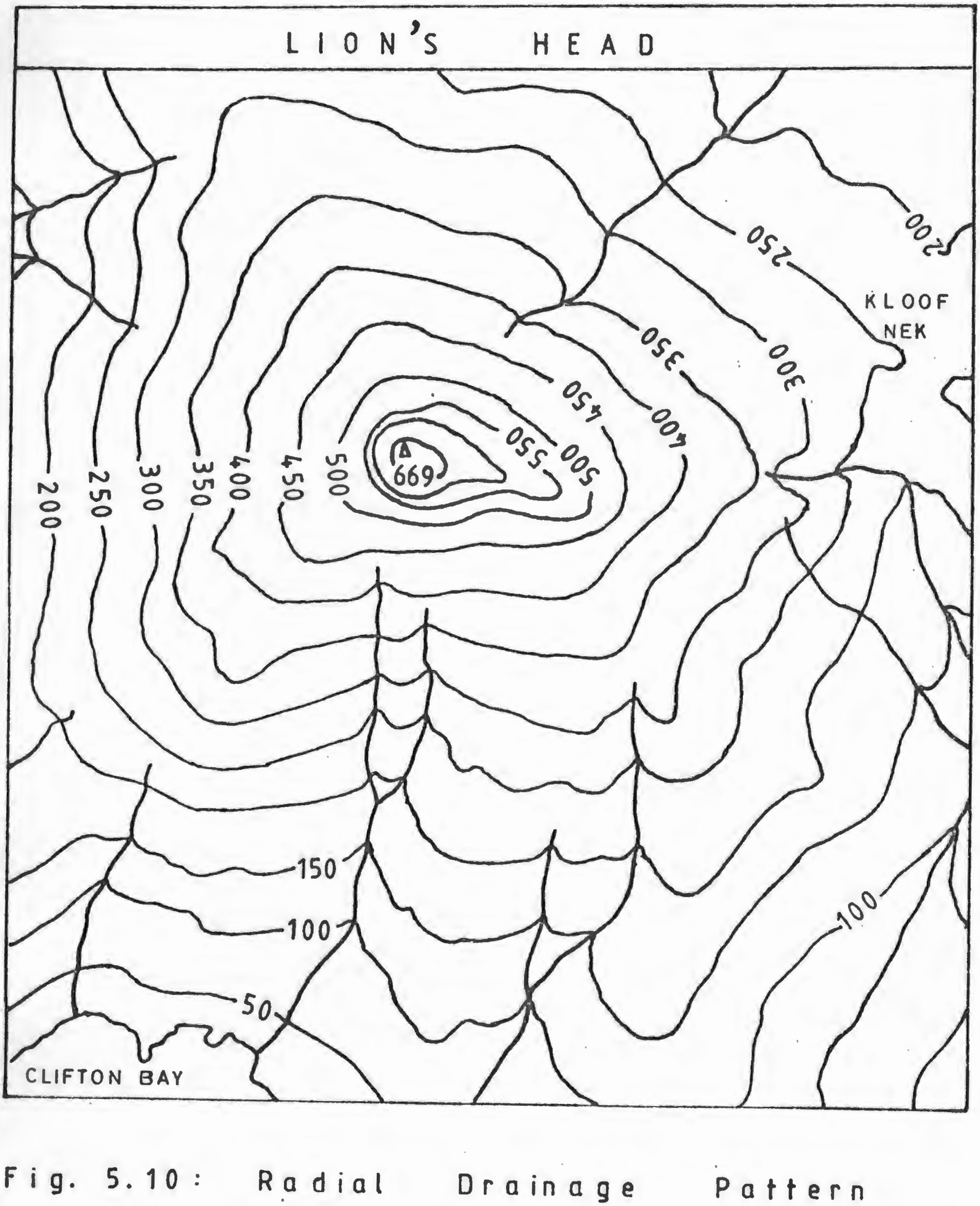


Fig. 5.10: Radial Drainage Pattern

Scale 1 : 10 000

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CHAPTER 6

AN EXAMPLE OF RIVER CAPTURE ON TABLE MOUNTAIN

A. THE PROBLEM STATED

There is general agreement on the part of Wooldridge and Morgan (1937,p. 195), King (1963,p. 62), Holmes (1965,p. 558), Sawyer (1970,p. 41), Small (1972,p. 238), Cain (1980,p. 75) and others, that for river capture to occur one stream must obtain a very great erosional advantage over its neighbour.

This advantage can be derived from geological conditions, from particular relief or from climatic factors which favour capture. Sawyer (1970,p. 41) points out that these factors may also occur in combination. To this must be added sporadic and intermittent uplift which has affected the study area since Tertiary times and resulted in differing land-sea relationships in the past. Reference will also be made to the highly complex interventions of the Pleistocene glaciations and concomitant changes of sea-level in an attempt to trace its contribution to river capture within the study area.

The structure and form of the Cape Peninsula promote, and are conducive to river capture occurring within its confines.

It has been pointed out in the previous chapter that the trunk streams within the areal matrix are orientated along lines of geological weakness, that is, along joint planes or along fault-lines.

Thus the two streams involved in the process of capture are orientated in keeping with the structural joints, and consequently flow either in a north-westerly direction (bearing 330°) or in a south-easterly direction (bearing 150°). (Plates 10 & 11). The writer has checked this orientation repeatedly at different exposures on Table Mountain and has found the alignment of the joint planes of the T. M. S. to be fairly constant and to be in agreement with that of the joint planes of the T. M. S. exposed on the beach at St. James, for example.

Two examples will serve to illustrate this point:

(i) The Blinkwater stream drains the escarpment of the Twelve Apostles and flows in a north-westerly direction. The stream draining Echo Valley follows the same joint plane system, but flows in the opposite direction, constituting a tributary of the Disa River on Table Mountain. As an extension of these two streams another stream flows in a north-westerly direction between the Waaikoppie (934m) and Junction Peak (921m) on Table Mountain, forming one of the headwater streams of the Disa River, whilst the stream draining Window Gorge descends the escarpment along the identical joint plane and flows in a south-easterly direction.

(ii) The stream flowing down the escarpment whilst draining Wood Ravine flows in a north-westerly direction. On the opposite side of the divide, along an extension of the same joint plane, a stream flows in a south-easterly direction across the plateau surface of Table Mountain to join the Disa River. Following the same alignment, but this time on the opposite side of the gorge, a tributary of the Disa River flows in a north-westerly direction once again. In a straight line, but this time draining the slopes of the escarpment, the stream flowing down Rooikatkloof descends in a south-easterly direction with only the divide separating their head-waters. (Fig. 6.1).

This paired nature of the streams flowing across the plateau and descending the escarpment constitutes one of the significant features of the drainage on Table Mountain, where the mountain mass has been bisected by the Disa Gorge. Thus a stream joining the Disa River from the north-west will have its counterpart on the opposite side of the gorge which flows into the "canyon" from the south-east. This serves to accentuate the influence of joint-control over the drainage within the study area and its contribution towards river capture within the Cape Peninsula.

The plateau and scarp nature of the study area also constitutes one of the factors responsible for the inequalities which help to set in motion the changes leading to river capture. Consequently the streams draining the escarpment, for example, possess steeper gradients and greater erosional energy than those flowing across the plateau itself.

The Nature of the Actual Mechanism of Diversion

This investigation attempts to explain the capture of the headwaters of Slangolie Ravine, a consequent stream draining the north-western slopes of the Twelve Apostles by a subsequent stream of the Disa River flowing in the opposite direction. These opposing streams are once again aligned along the same structural joint plane, bearing either 150^o or 330^o.

What has occurred in this capture has been that part of the drainage basin of the Slangolie Ravine has been incorporated inte that of a tributary of the Disa River without any surface diversion as such occurring. The Slangolie Ravine has thus been beheaded by its opposite number. Consequently, none of the classical symptoms of capture such as elbows or misfits are to be seen. This has been accomplished through the migration of the divide separating the two streams in the direction of the victim stream.

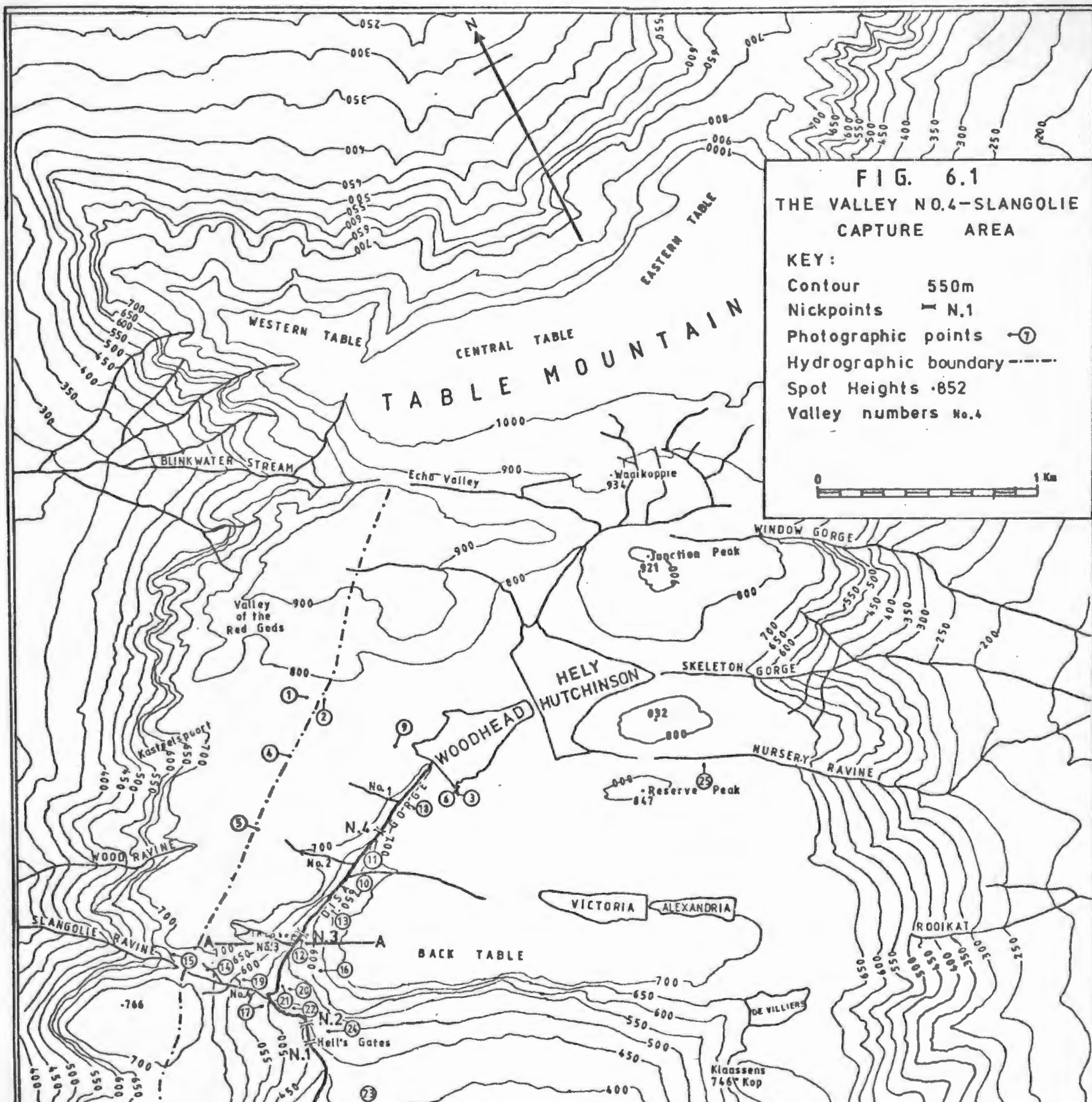


FIG. 6.1
THE VALLEY NO.4–SLANGOLIE CAPTURE AREA

KEY:
Contour 550m
Nickpoints N.1
Photographic points (7)
Hydrographic boundary
Spot Heights ·852
Valley numbers No.4

0 — 1 Km

B. APPROACH TO THE PROBLEM

Nicol (1965,p. 6) points out that, "In geomorphic research there can be no substitute for field investigation, however much reference material may be available." With this directive in mind, the writer has made field observation, the measurement of slopes and distances, the completion of field sketches, the taking of photographs and the recording of other relevant data the practical basis of his approach. The investigation required five field trips in all to the research area.

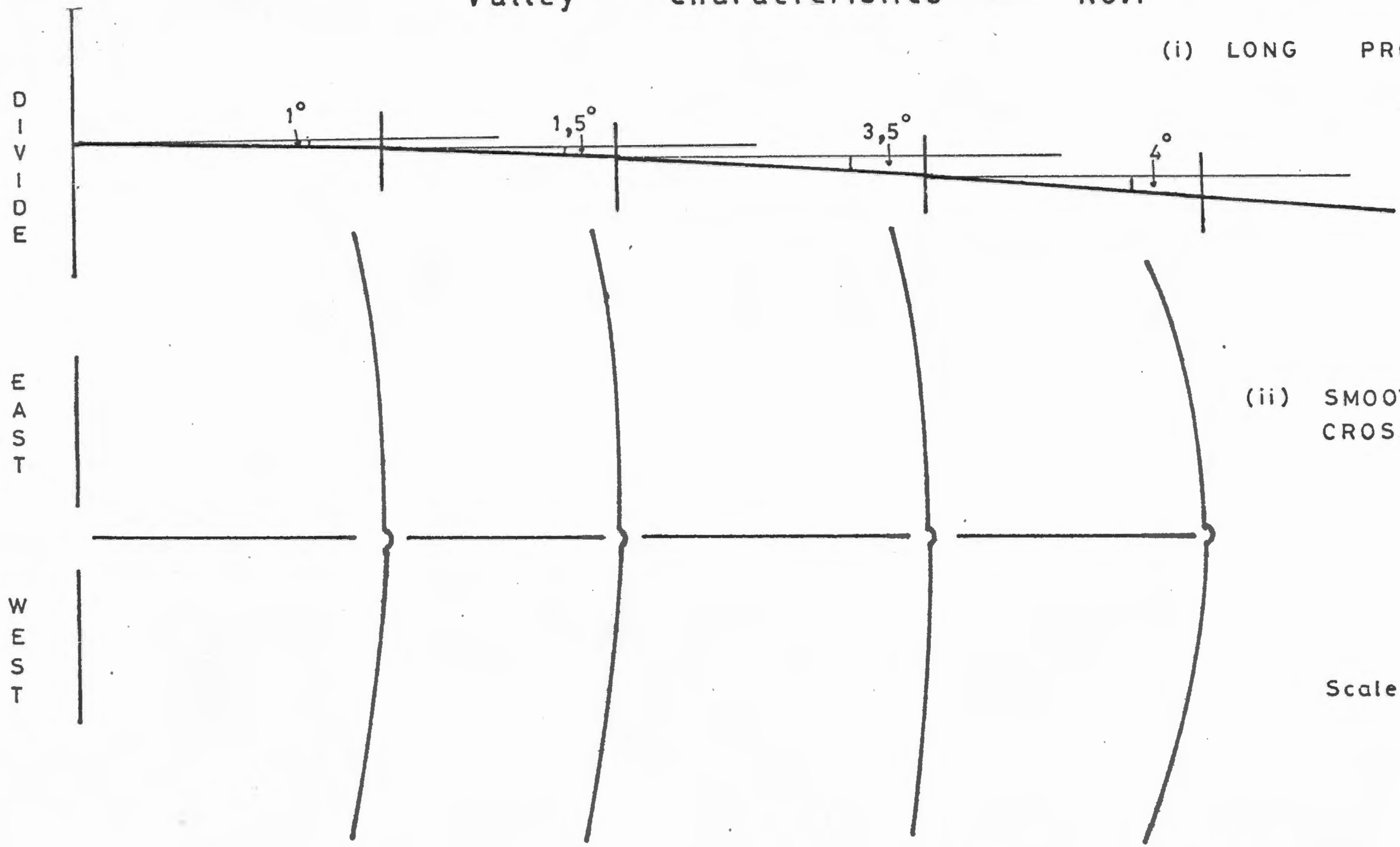
On each field trip most of the following equipment was used:-

(i) Prismatic Compass
(ii) Abney Level
(iii) Two Surveying Aneroids
(iv) Steel measuring tape (100m)
(v) Camera : 35mm
(vi) Drawing instruments
(vii) Field Notebook
(viii) Binoculars: 10 X 50
(ix) Relevant Air Photographs of the research area
(x) Orthophotos of part of the research area
(xi) Geological Survey Sheet (1933) No. 247 : 3318 C & D, 3418 A & B. The Geology of Captwoen and Adjoining Country

The writer's field observations were tabulated as set out on the following page, and the relevant data filled in at each observation / photographic point. Since all the recorded information is tabulated with each photograph or field sketch, only five representative examples will be given at this stage.

Fig. 6.2 [a]

Valley Characteristics — No.1



(i) LONG PROFILE

(ii) SMOOTHED CROSS-SECTIONS

Scale: 1 : 2 000

OBS/PHOTO POINT NO.	GRID BEARING	SUBJECT	FIELD DATA
1	150°	Outcrop of T. M. S. between two joint planes on Table Mountain.	ORIENTATION: VERY pronounced parallel nature of joint planes orientated approx. N.N.W. to E.S.E. These planes well exposed due to sparse vegetation over the greater part of the plateau surface.
2	60°	Transverse set of joint planes.	Occur approximately at right angles to joint planes in No. 1 above. Planes deeply weathered in places. Very rugged terrain. Part of Buttress projecting southwards. Towers over the terrain. Horizontal layering of T. M. S. well delineated by way of contrast
6	113°	Mature valleys occpied by Woodhead & Hely Hutchinson Reservoirs	Very gradual slope of valley exposed to the south of the Woodhead Res. Must have been formed when the mountain mass was close to sea-level. Contrasts strongly with the Central Table to the north towering over it. Col formed by Skeleton Gorge separating peaks on either side.
7	76°	Central Table and Junction Peak	Headwaters of the Disa River have their source in the distance. Valley formation as a result of erosion clearly evident.
9	190°	Disa Gorge	Impressive chasm incised by Disa R. in resistant T. M. S. Bisects plateau landscape. Eastern and western sectors. Groot Kop (852m) broods in the distance.

Whilst recording observations at each point of importance in the research area, a ground photograph was taken, coupled with a compass bearing along the optical axis of the camera.

The position from which the ground photographs were taken is shown on the map. (Fig. 6.1), whilst an arrow indicates the direction of the optical axis.

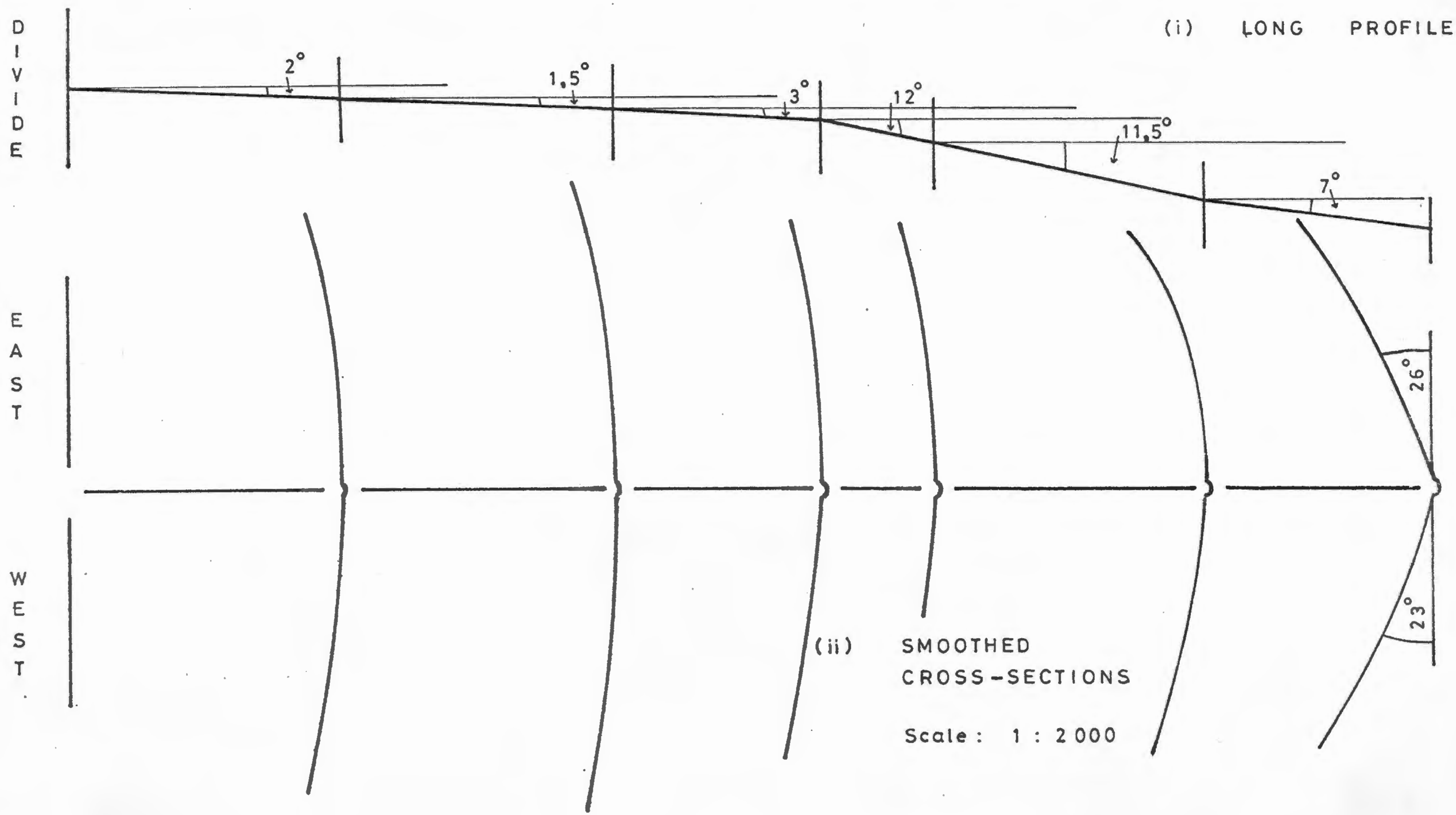
A Question of Interpretation

The contention of Holmes (1965,p. 563) that, "Tracing the ancestry of rivers, and their competition for drainage has always had a special fascination for geomorphologists" would appear to be inapplicable to South African geomorphologists in general and the study area in particular. The writer knows of no other detailed investigations of stream capture apart from those carried out by Nicol (1965) and Willemse and Frick (1970). As far as the Cape Peninsula is concerned reference to river capture has only been made in passing by Mabbutt (1952,p. 17) and Rimer (1958,p. 11), who probably got it from Mabbutt. This last point will be elaborated upon at a later stage.

Conflicting viewpoints exist regarding the "normality" or "abnormality" of river capture. Wooldridge and Morgan (1937,p. 195), for example, consider river piracy to be.... "a normal incident in a veritable struggle for existence between rivers." Small (1972,p. 234 & 240) on the other hand, whilst conceding that river captures are amongst the most important events in drainage history, considers it to be "a decidedly freak occurrence." The writer tends to support the viewpoint of Wooldridge and Morgan (1937,p. 195) and views river capture against the background of what Umbgrove (1947,p. 15) writes when he refers to one of the most

Fig. 6.2 [b]

Valley Characteristics — No.2



important features of history as being ...."the ceaseless flow of alterations" and that ...."nothing remains constant in geological time." Perhaps the most balanced comment in this regard is that provided by Cotton (1941,p. 1), who observes that though certain commonly observed processes are termed "normal" it is not implied that others are "abnormal."

C. INITIAL SURVEY AND OBSERVATIONS

When carrying out the initial survey of the area as a whole on Table Mountain, the writer was struck by the varying nature of the characteristics exhibited by the streams in the immediate vicinity of the capture area.

The upper sector of the Disa River, for example exhibits mature characteristics with broad, open valleys having gentle slopes.

A brief survey of Valleys No.1 and 2 en route to the capture area was carried out to reflect the striking contrast in valley characteristics which occurs over a short distance of approximately 2 kilometres from the dam wall of the Woodhead Reservoir to the capture area itself. (Fig. 6.2).

Bearing in mind that the streams concerned share a homogenous structural base and probably had a similar initial slope as well, it was striking to observe how:-

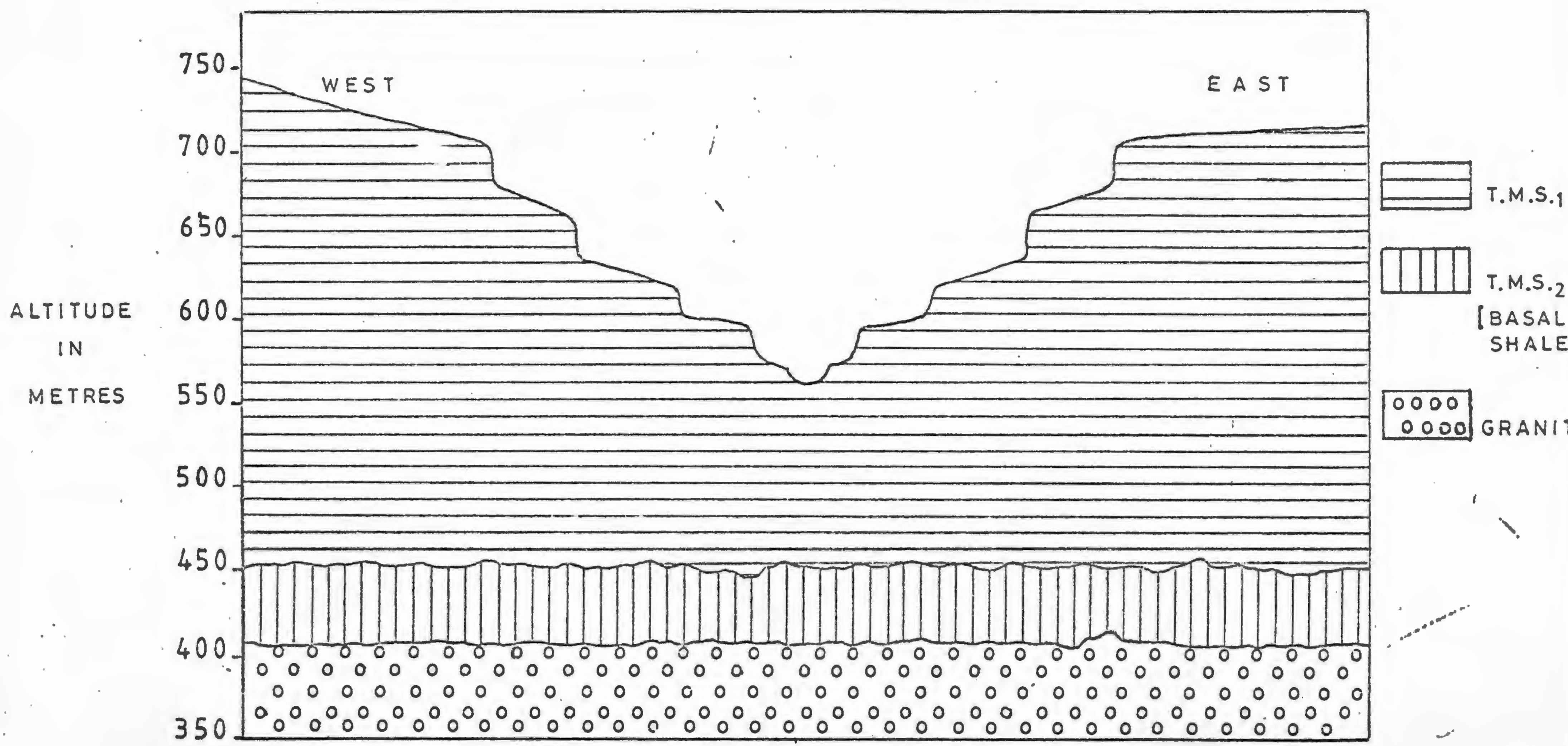
(a) valley characteristics of Nos. 1 and 2 which display mature characteristics contrasted with the youthful characteristics of the pirate stream; (Plates 12,13 & 14).

(b) the length of the stream courses themselves increased;

(c) the divides were lowered to an increasing extent whilst moving in a southerly direction past Valleys 1 & 2 one encounters the pirate stream which, for want of a name will be designated as Valley No. 4. Lack of time precluded that a survey of Valley No. 3 be carried out as

Fig. 6.3

Geological Section along Line A—A



well. Its characteristics are, however, essentially those of Valleys No. 1 and 2.

An index of the observed changes is reflected by the following data. Use of the two surveying aneroids indicated that Valley No. 1 had lowered its divide by 5,4m, Valley No. 2 by 13,5m and the pirate stream by 63,3m.

The questions which these contrasting characteristics raised were:

(i) which factors were responsible for valley characteristics changing so radically over such a short distance?

(ii) How did this relate to the capture which has occurred?

(iii) What special advantage(s) does Valley No. 4 enjoy over the neighbouring streams in the immediate vicinity?

D. FACTORS CONTRIBUTING TO THE CAPTURE

(i) Geology of the Capture Area

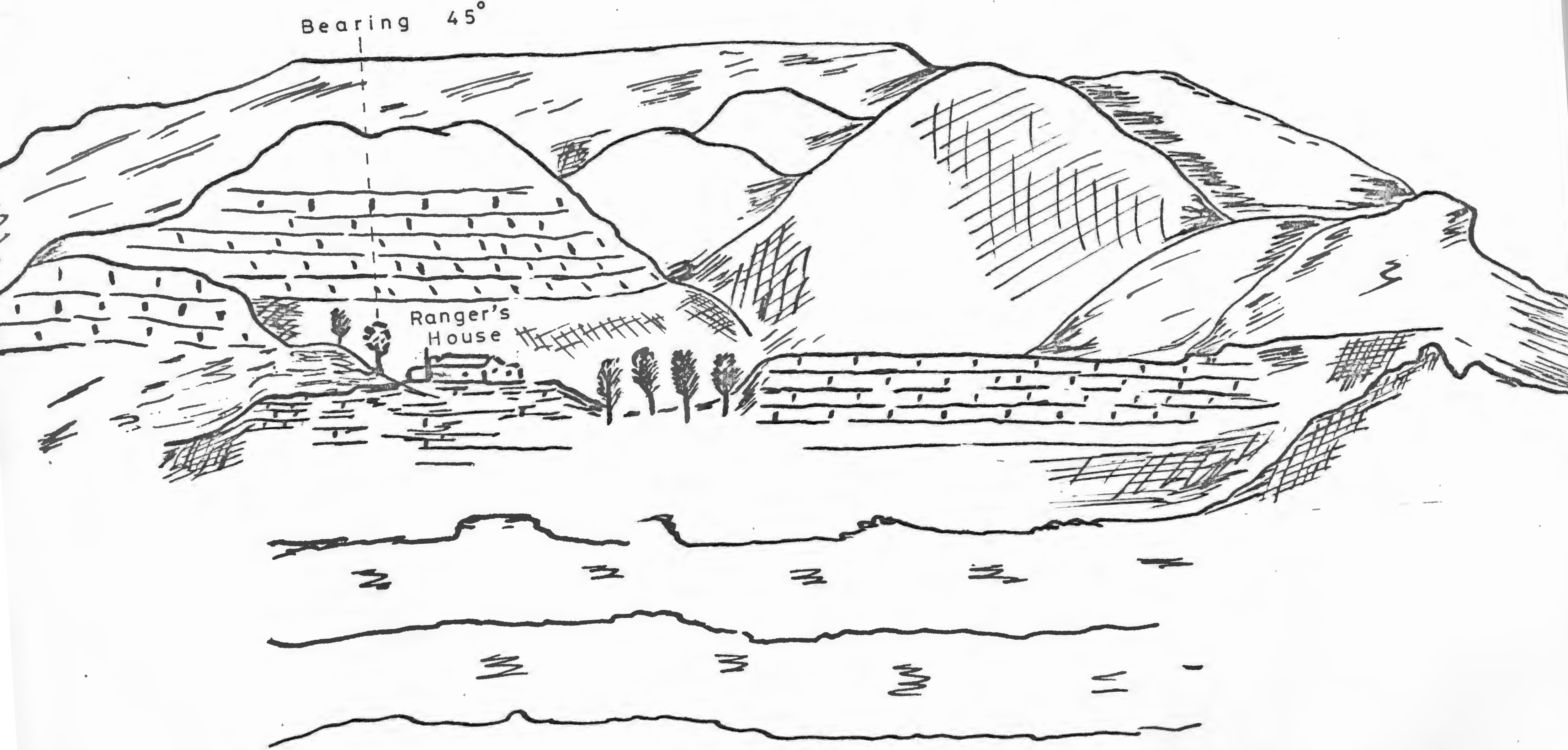
Both streams, that is pirate and victim together with those referred to earlier arise on the jointed quartzites of the T. M. S. which, on the whole are horizontally bedded and forms the bulk of the synclinal Cape Peninsula block. (This aspect has been dealt with in detail in Chap. 3).

Both stream No. 4 and that draining Slangolie Ravine thus flow over rocks which are homogenous in composition and geological structure, with no particular advantage being enjoyed by the pirate stream in this regard.

The basal shales of the T. M. S. rest unconformably upon a basement consisting of Younger or Cape Granite. This is reflected by the cross-section marked A - A on the map. (Fig. 6.3).

Fig. 6.4

Table Mountain looking N.N.E.
[AS SEEN FROM THE BACK TABLE]



(ii) The Physical Landscape - Particular Relief

The broad physical landscape within which cpature has occurred is characterized by the following features:

(a) The catchment area of the headwaters of the Disa River to the north, north-west and east of the Woodhead Reservoir stretches through at least 240°. This arc embraces the southern slopes of the Central and Eastern Tables, Junction Peak (921m) and Reserve Peak (847m). These features together form a huge amphitheatre whilst the Central and Eastern Tables tower approximately 300m above the plateau surface to the south. (See Fig. 5.6).

(b) The mature valleys of Table Mountain are occupied by the Hely Hutchinson and Woodhead Reservoirs. Since the first-named dam has a larger surface area and impounds much more water than the Woodhead dam, it fills the entire valley. The water-level is fairly high and rises against the base of the vertical cliffs which surround it, with the result that it was difficult to measure the adjoining slopes. This was different, however, with the Woodhead Reservoir. It was thus possible to measure the exposed slopes of the valley on either side of the impounded water in a few places. They were found to be on average 5° on the northern slopes and 6,5° on the southern side. (Plates 15, 16 & 17).

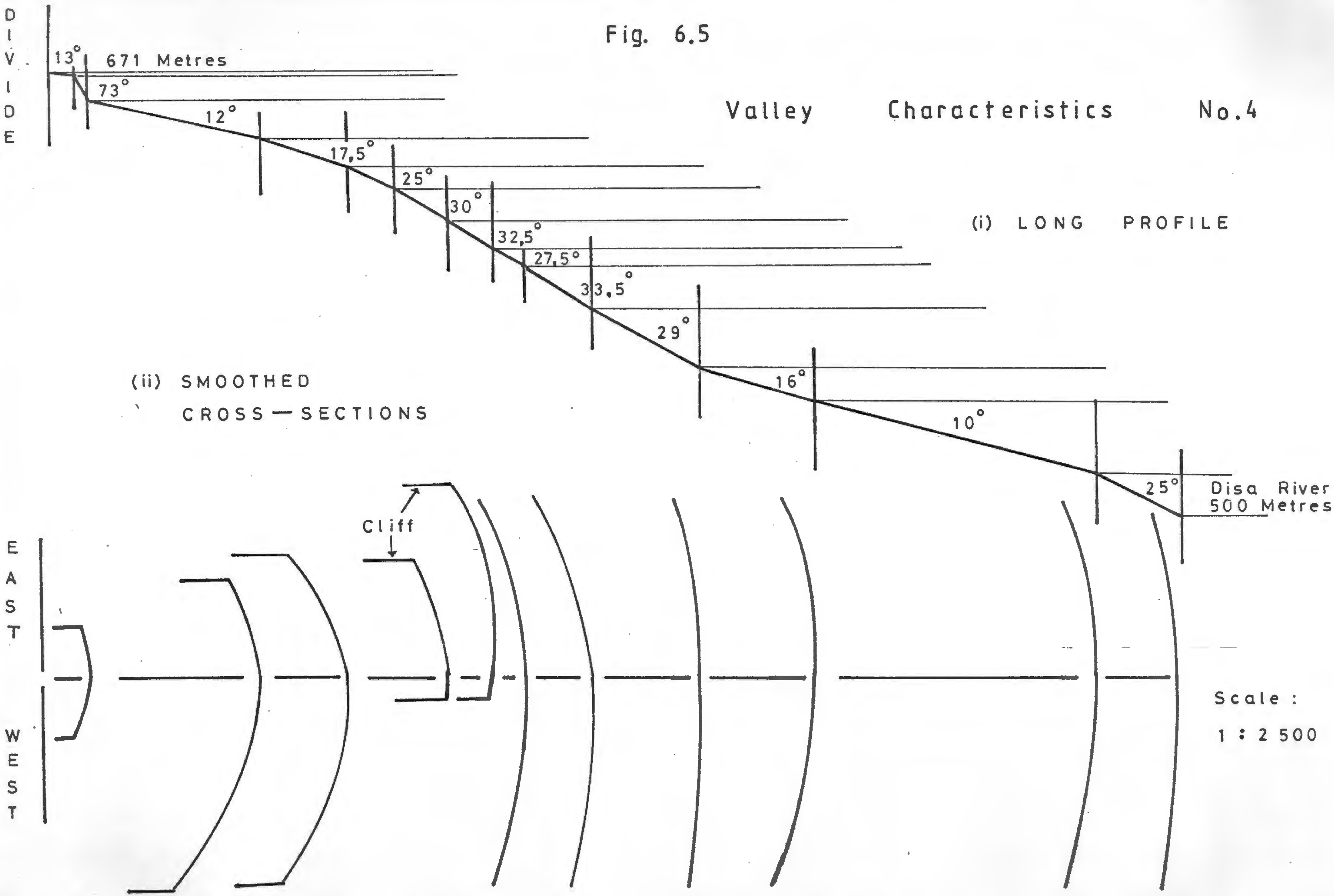
(c) The rugged nature of the terrain with the bare T. M. S. exposed over the greater part of the surface, except where valley formation has resulted in the growth of vegetation or afforestation has clothed the bare landscape.

(d) It is largely a plateau surface.

(e) Another characteristic feature is that the crest line has been notched in various places where valley formation has resulted in the lowering of the divide.

(f) The huge chasm formed by the Disa Gorge dominates the physical landscape. (Plate 18). It extends from the

Fig. 6.5 Valley Characteristics No.4



wall of the Woodhead Reservoir and runs in a south-westerly direction at first and then, after breaking free of the restricting confines of the mountain mass between Orange Kloof and the Twelve Apostles and executing a large meander curve at the base of Groot Kop (852m), flows in a southerly direction and continues its winding course to Hout Bay. (Plate 19).

(g) Moving southwards along the summit of the Twelve Apostles, the surface descends by means of a series of large terraces till the northern face of Groot Kop (852m) is reached south of the capture area.

(h) The bastion to the north comprising the Western, Central and Eastern Tables towers over the plateau landscape to the south. (Fig. 6.4).

(i) The characteristics of Valley No. 4 and Slangolie Ravine are illustrated by the long profile of each. (Fig. 6.5 and 6.6 respectively). It will be noted that Slangolie Ravine has the advantage of eroding headwards from the coast itself, whereas Valley No. 4 joins the Disa River at approximately 500m above sea-level. Moreover, since renewed vertical erosion is very often initiated and propagated back from the coast, it would appear that the advantage in terms of "aggressive possibilities" lies with Slangolie Ravine rather than Valley No. 4.

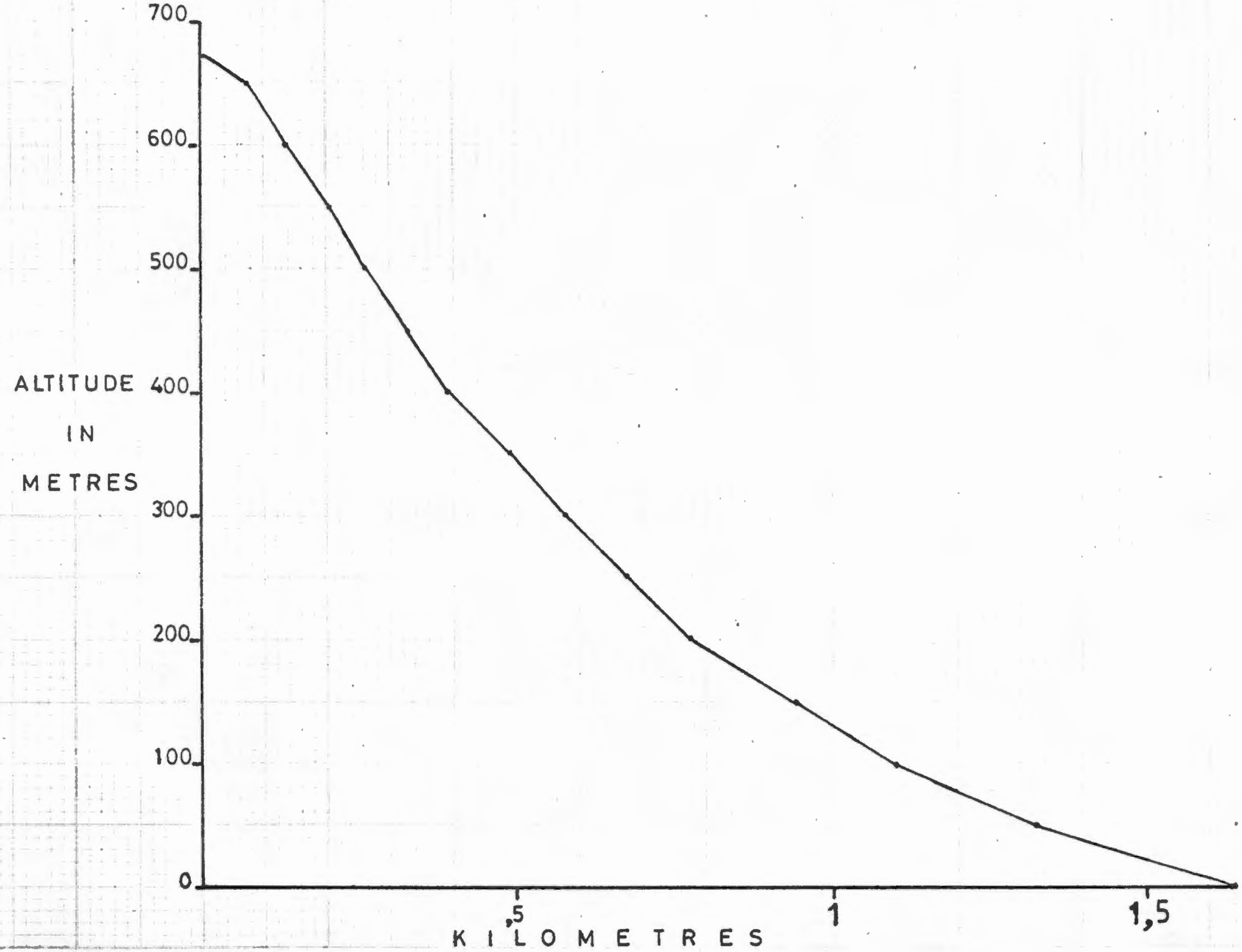
(iii) Climatic Factors

The climate of the study area as a whole was dealt with in detail in Chapter 4.

Since the Slangolie Ravine and Valley No. 4 occur in a straight line running more or less from west to east on the Twelve Apostles, it is reasonable to infer that both will experience similar climatic conditions. Table 6.1 provides an index of the average precipitation which has been received

Fig. 6.6

Slangolie Ravine : Long Profile



in the immediate vicinity of the capture area.

Of the different rain gauges whose data is reflected in the table, the best index is provided by the gauge located at the Woodhead Tunnel in the immediate vicinity of the capture area.

Table 6.1

***** STATIONS REFLECTING AVERAGE RAINFALL

STATION	LAT.	LONG.	HEIGHT	PERIOD	RAINFALL
	S.	E.	M.	YRS.	mm
Table Mtn. Cableway	33° 57'	18° 24'	1 067	13	1 386,6
Waaivlei	33° 58'	18° 25'	975	43	1 638,0
Waaikoppie	33° 58'	18° 25'	945	69	1 614,7
Maclear's Beacon	33° 58'	18° 26'	1 092	43	1 972,0
St. Michael's	33° 58'	18° 25'	930	66	1 780,5
Table Mtn. Disa Head	33° 59'	18° 24'	747	70	1 065,3
Table Mtn. Kasteelspoort	33° 59'	18° 24'	762	66	1 498,3
Table Mtn. Woodhead Dam	33° 59'	18° 24'	747	43	1 623,0
Table Mtn. Ranger's House	33° 59'	18° 24'	761	30	1 779,5
Table Mtn. Woodhead Tnnl.	33° 59'	18° 23'	686	45	1 256,5

***** Source : Climate of South Africa : Rainfall Statistics : W. B. 20, p. 21. (Schumann, T.E.W., 1950) Director.

It would be reasonable to assume that both valleys would receive approximately the same average precipitation since the height of the divide is not of such a nature as to create a marked rain-shadow effect on the leeward side. It would also be acceptable to assume that the Slangolie Ravine with its west-facing slopes might receive slightly more rain than Valley No. 4 since it is located on the windward side from which the rain-bearing north-westerly winds approach the Cape Peninsula.

Rimer (1958,p. 16) points out that almost two-thirds of the precipitation on the Table Mountain mass is due to mist and fog which is not recorded by normal rain gauges. Even though this figure appears to be slightly exaggerated, it does indicate that the official values for precipitation on Table Mountain are under-stated.

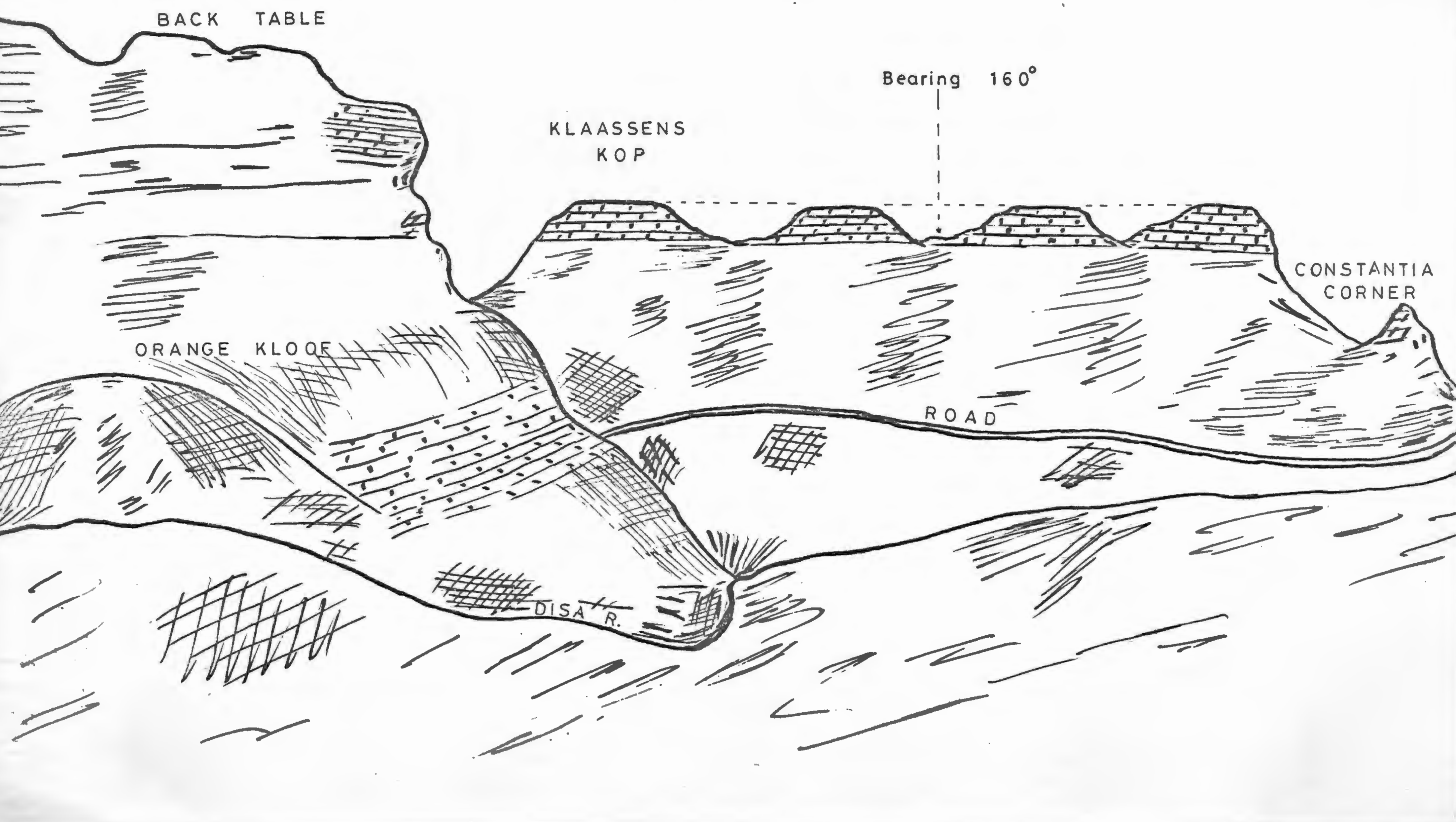
Once again, judging from the limited data available, it would appear that the pirating stream enjoys no particular advantage over its victim in terms of receiving much more rain. If anything, it could justifiably be inferred that the victim could possibly receive slightly more rainfall since it is located on the windward side with reference to the rain-bearing winds. Extra, or heavier precipitation received in the watershed of Valley No. 4 as opposed to the Slangolie Ravine therefore does not appear to provide the reason for this capture having occurred.

(iv) Intermittent and Sporadic Uplift

Whilst engaged in fieldwork the writer observed from various positions what appears to be a clearly defined stripped surface around the 700-metre level. This is clearly discernible in the vicinity of Klaassens Kop. (Fig. 6.7). This surface also forms part of the terrain comprising the Twelve Apostles to the north of Groot Kop. This means in effect that at some time in the geologic past (Early Tertiary) an ancient coastline would have extended between

Fig. 6.7

Old Accordant Surface as seen from Valley No.4



Groot Kop in the west to just north of Constantia Corner in the east.

At that time the land would have sloped very gently southward from the junction of the Western, Central and Eastern Tables in the north, over the rest of the plateau surface toward the south, past the Back Table to its junction with the ancient coastline which, at that time stretched between Groot Kop (852m) and Klaassens Kop (746m).

Thus, by Middle Tertiary times the streams draining the plateau surface must have reached a state of advanced maturity in their development. The gradient at that time would have been very slight with the streams meandering across the gently-sloping terrain. The tortuous courses followed by the streams would tend to support the contention that the streams were mature, possibly even approaching senility.

If the topographic or 'slope' gradient is calculated from the 760m contour where the Disa River flows between St. Michael (920m) to the north-west and south of the Waaikoppie (934m) and Junction Peak (921m) to the south-east to its intersection with the "old shoreline" running between Groot Kop (852m) and Klaassens Kop (746m), a decrease of 60m in altitude takes place over a direct distance of 3,45km. This provides a mean slope gradient of 1 metre per 57,5 metres. This figure is evidently low enough to enable a stream to commence the development of meanders in the resistant T. M. S.

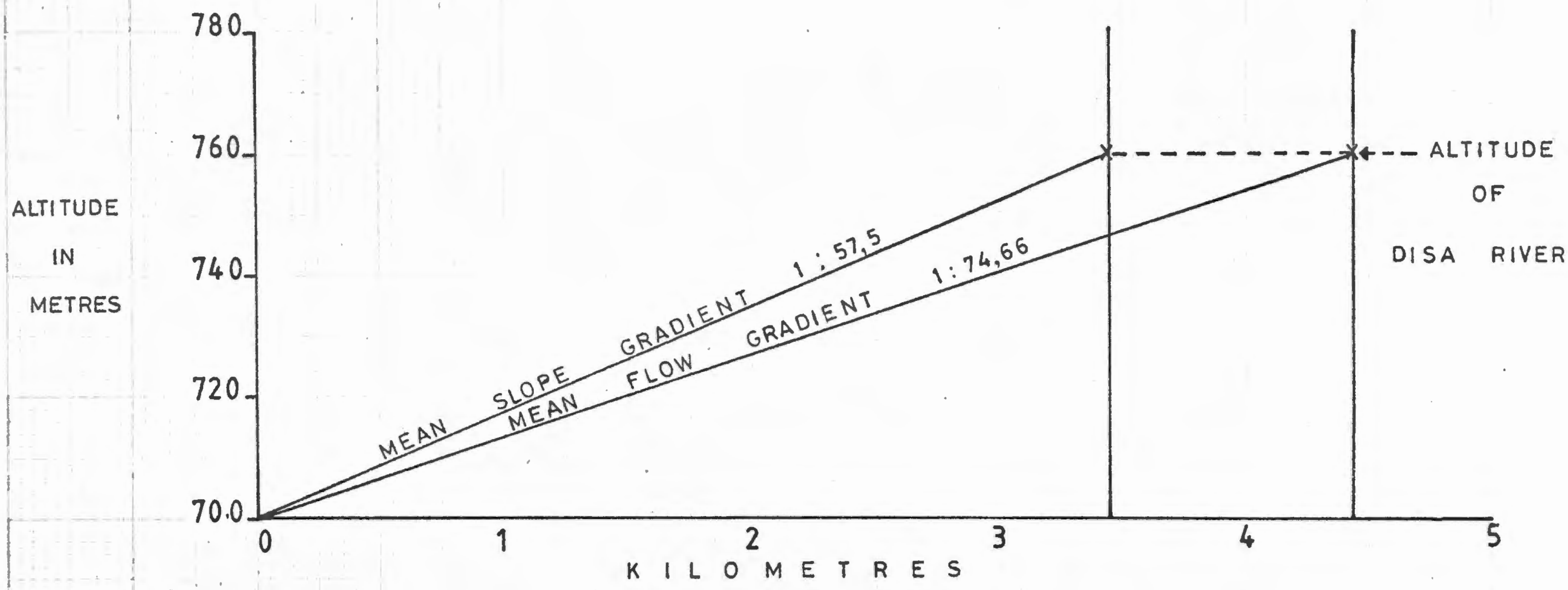
A different picture becomes apparent when the 'flow' gradient of the river is examined --- that is, the decrease in altitude of stream level in relation to the distance covered by the moving water. This gives a total distance of 4,48km and a flow gradient of 1 metre per 74,66 metres. (Fig. 6.8).

Under these conditions the velocity would have been so low that vertical abrasion would, in all probability have ceased, with the river close to being graded. The Disa

Fig. 6,8

GRADIENT PRIOR TO UPLIFT

Conditions in the Disa Valley



Vertical Scale = Horizontal Scale X 25

river would have flowed sluggishly and followed a meandering course across the terrain on its way to the sea.

Subsequent sporadic and intermittent uplift brought about significant changes in the topography of the Table Mountain mass as well as the study area as a whole. It resulted in the creation of new base levels at different times between the uplifted surface and the sea. Primary rejuvenation due to uplift thus resulted. Consequently the rivers began extending their courses through headward erosion and also deepened their channels through vertical abrasion. One example will serve to illustrate the amount of vertical erosion which has resulted.

At the start of the Disa Gorge the writer's attempts to measure the height of the canyon from the wall of the Woodhead Reservoir were frustrated by the excessive convexity of the dam wall approximately one-third the distance from the top. At that point the steel tape with weight attached registered 13 metres. The height of the gorge was thus estimated at 40 metres. Approximately 0,95km downstream within the Prohibited Zone the difference in height between the river bank and the heighest point on the edge of the canyon had increased to 136 metres. This constitutes a drop of approximately 96 metres over a distance of less than 1 kilometre --- bearing in mind that the river was incising its course into solid bedrock of the T. M. S.

Whilst moving southwards from the Woodhead Reservoir within the gorge the writer observed that the stream would flow along a fairly level stretch for a distance and would then descend via a cataract or waterfall to a lower level. (Plate 20). This tends to parallel the manner in which descent occurs along the plateau surface when moving from north to south via a series of large steps or terraces.

Approximately 1,2km downstream, just before the first intake (i.e. a tunnel drilled throught the mountain to supply water to the Camps Bay area), a magnificient waterfall of 7 metres occurs with a plunge pool below. (Plate 21).

The writer observed what could be classified as four incision levels on either side of the rocky face of the Disa Gorge. These incision levels consist of a vertical section of the rock face followed by a section where the slope is less steep, then another vertical incision and so on. Since the canyon is widest at the top and narrows as it reaches the river, these incision levels could be correlated with the periods of uplift resulting in vertical abrasion followed by a period of zero movement when lateral erosion would occur, thus producing the next sloping surface, and so on. (Plate 22). On the other hand these incision levels could also be structurally controlled.

The sporadic and intermittent uplift of the terrain not only affected the Disa River, but all the streams of the Cape Peninsula as well. It is a well known fact that, if for any reason a trunk stream (such as the Disa River) is accelerated or retarded in its work, the effects are felt to the extreme limits of its drainage basin. It is for this reason that such marked contrasts in erosive power become manifest near the actual boundary of two drainage basins such as Stream No. 4 and the Slangolie Ravine.

It is thus clear that Stream No. 4 and Slangolie Ravine would undoubtedly have been affected by the uplift and that new base levels would have been created for each. As has been explained, the Disa River deepened its channel appreciably. This would have elicited a response from Stream No. 4 in the form of renewed headward erosion and vertical abrasion. The same holds true for the Slangolie Ravine which would have had to adjust its course to new sea-levels in turn.

(v) Effects of the Pleistocene

During the Pleistocene ice-ages (approximately 1,8 m.y. B.P.) a negative shift in sea-level of about - 130m occurred. This new base level resulted in primary rejuvenation occurring not only for the Disa River, but for the pirate and victim streams as well. Vertical, as well as headward erosion would have resulted with the streams lengthening and deepening their channels as part of the "complex response of the basin." (Parker 1977,p. 158).

During the Pleistocene ice-ages erosion would, no doubt, have continued. The process might perhaps have continued at a different rate but would, in all probability have contributed to the process of river capture taking place.

(vi) The Over-Riding Factor

In attempting to identify the reasons for Stream No. 4 becoming a pirate stream and the Slangolie Ravine its victim, each of the following factors has been examined, namely :

(a) geological factors such as the structure and form of the Cape Peninsula and the capture area;

(b) the physical landscape and factors of relief,

(c) climatic factors;

(d) sporadic and intermittent uplift, and

(e) the effects of the Pleistocene ice-ages.

Each factor, after due consideration has had to be discarded since the advantage (if any) appeared to be more with the victim rather than with the actual pirating stream. This does not mean to imply that these factors were not involved. It must be stressed that each factor, to a greater or lesser extent would have contributed its share to making the capture possible and assisting in its progress.

At this stage the relevant factor must be introduced which, in the writer's opinion gave Stream No. 4 the ...."very great erosional advantage over its neighbour." (Small, 1972,p. 238). This factor manifests itself in the form of a fault-line indicated on the Geological Survey Map (1933, No. 247) on the eastern half of the Twelve Apostles in the position of Valley No. 4 only, and not on the Slangolie Ravine's half of the mountain. (See Fig. 6.9). Not only is the fault-line on Valley No. 4's half of the Twelve Apostles alone, but an additional advantage in the form of a slight eastward dip of the strata on the side of Valley No. 4 only is observable. (Plate 23).

E. RESULTS OF THE CAPTURE

(a) Valley No. 4 and Slangolie Ravine

(i) Stream No. 4 was enabled to extend its course by means of headward erosion since it had the additional advantage of eroding along a fault-line. As a result it is the longest of the four streams flowing into the Disa River from the west between the Woodhead Reservoir and Slangolie Ravine. The divide has thus migrated in the direction of the victim stream.

(ii) The Slangolie Ravine forms a narrow corridor with a constant width within the confines of the Twelve Apostles. (Plate 24). Stream No. 4 on the other hand has been able to widen its channel to give it a circular basin-

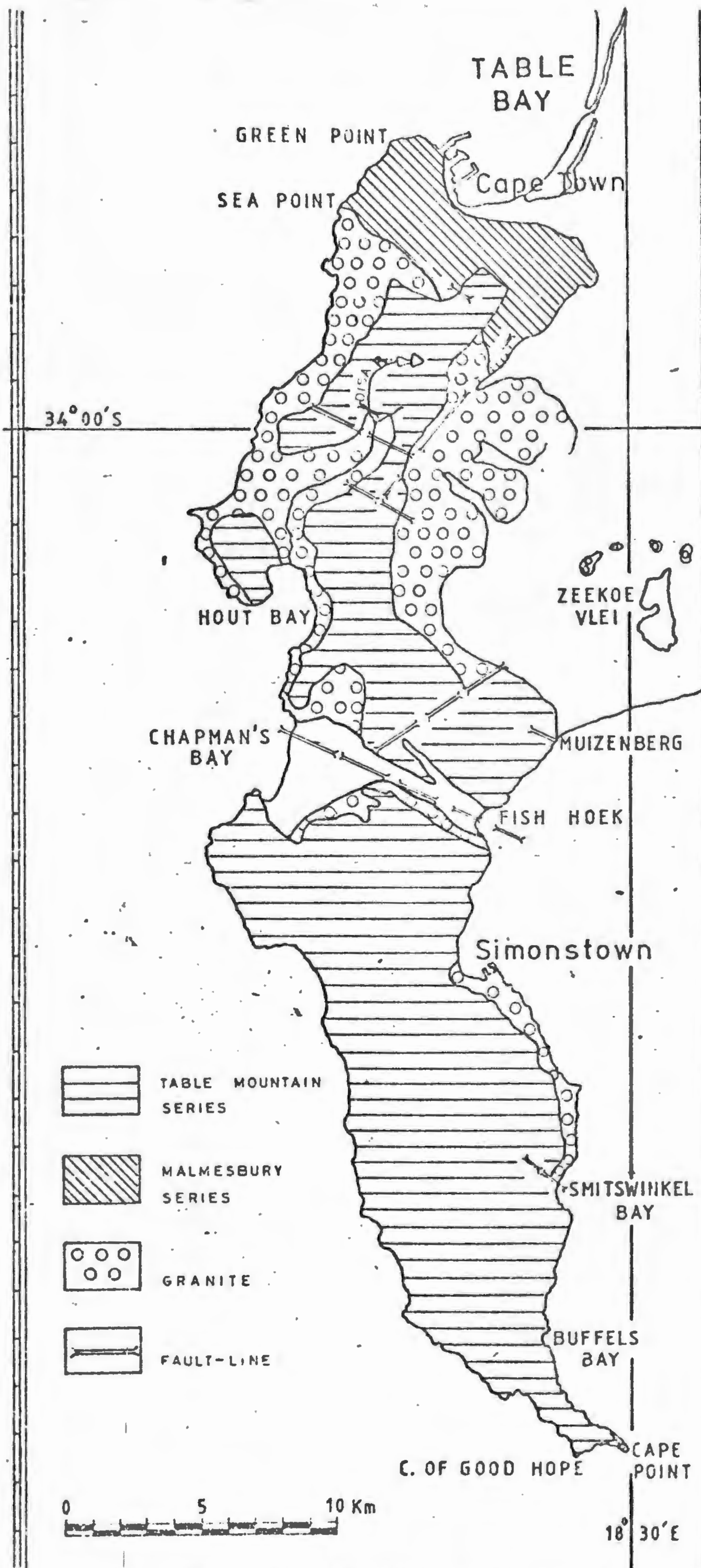


Fig. 6.9 Fault-lines: Position and Alignment

like form. This has had the effect of increasing its catchment area, thus resulting in an increased volume of water being received. As a result the river's erosive powers have been increased.

(iii) The divide has also been lowered in a very striking fashion by 63,3m resulting in a clearly discernible col or wind-gap. No other stream in the immediate vicinity has been able to lower its divide in like manner. This could only have resulted if the stream were eroding along a line of weakness such as a fault. (See Plate 25).

(iv) River No. 4 - because of the factors outlined above - has been enabled to deepen its channel when uplift occurred, so that its junction with the Disa River is an accordant one. (Plate 26). The junctions of Streams 1 and 2 are discordant with hanging valleys. (Plate 27).

(v) In keeping with the sporadic and intermittent uplift, at least three clearly defined rounded basin-like valleys (longitudinally and laterally) have been formed along the course of Valley No. 4. (Plate 28). The writer tentatively suggests that these basins were formed during periods of zero movement following upon uplift when the river was enabled to widen its channel. A well-marked break-of-slope is discernible between each basin and the next, which tends to support the above suggestion. In places the gradient between one basin and the next is fairly steep, as much as $33{,}5^{o}$ downslope. (Plate 29).

(vi) Valley No. 4 has continued to retain its erosional advantage over Slangolie Ravine. Whereas the slope of the Slangolie Ravine commences at the top of the divide (Plate 24), the pirating stream has incised a vertical wall of 12m immediately adjacent to the divide. (Plate 23). It is thus working to a lower level when compared with its victim, and is consequently able to tap water percolating through the bed of the Slangolie Ravine by way of underground abstraction. It is thus able to increase its own discharge and powers of erosion whilst weakening its victim. The writer was able to observe this process of "sapping" in operation.

Whilst clambering on the steep divide on the side of the pirating stream and noting the measurements, the writer accidentally dislodged a small boulder which tumbled downslope. This exposed a hole in the ground extending for about 45cm below the surface. The writer observed water flowing underground in the direction of Valley No. 4. During the period of approximately five weeks during which the writer visited the capture area from time to time, it was noted that the underground stream continued its unbroken flow.

(vii) Valley No. 4 has been able to bring about surface abstraction as well. Since it has eroded along a fault-line, it has been able to enlarge its valley laterally. First order streams flowing along the transverse set of joints have thus enlarged the basin considerably. This is particularly discernible along the lower course of the river. (Plate 28).

(viii) As a result of its rapid erosion along the fault-line Stream No. 4 has dislodged large numbers of boulders which lie scattered at awkward angles along the course of the valley. (Plates 23 & 25). Other valleys in the vicinity do not manifest this phenomenon to the same extent.

(ix) The eastern end of the fault-line referred to above lies athwart the channel of the Disa River itself. This has resulted in a structural feature. The position of the fault-line (which constitutes a line of weakness) is indicated by a sharp right-angled turn of the Disa River in a north-westerly direction toward Valley No. 4

After the confluence of the two streams the Disa River changes course and flows in a south-westerly direction once again.

The writer is of the opinion that Mabbutt (1952,p. 17) has misinterpreted some of the physical features which manifest themselves on Table Mountain. He refers, for example, to ...."the youthful Disa Gorge which has captured the upland streams and led them away to the south-west." These upland streams are in fact subsequent streams of the Disa River and are not "captures" at all. On Plate 3 (facing p. 18) Mabbutt (1952) also refers to ...."a broad shallow valley recently captured by the Disa Gorge." The valley to which reference is made is Valley No. 4 which is a subsequent stream of the Disa River.

Rimer (1958) was probably influenced by Mabbutt (1952,p. 17). Using a photograph which was taken from approximately the same angle and position as that of Mabbutt (1952, Plate 3 -- facing p. 18), Rimer (1958, Plate 16) refers to the junction of Valley No. 4 with that of the Disa River as ..."an elbow of river-capture." What he refers to is in reality a structural feature. Where the channel of the Disa River crosses the eastern end of the fault-line referred to previously, the river executes a sharp right-angled turn to the north-west. The stream draining Valley No. 4 follows the same fault-line, but flows in a south-easterly direction and joins the Disa River where it executes the abrupt right-angled turn. This right-angled turn and confluence is what Rimer mistakenly interprets as "an elbow of river-capture."

(b) Effects of the Capture upon the Disa River

Just prior to its junction with Stream No. 4 the water in the Disa River and its banks on either side are practically on the same level. (Plate 30).

The increased volume of water discharged into the Disa River by the pirating stream has resulted in secondary rejuvenation of the Disa River downstream from this junction. Just below the confluence of the trunk and subsequent streams the writer counted five deeply incised meanders with interlocking spurs. (Plate 31).

Just beyond its junction with Stream No. 4, the Disa River has been enabled to incise its channel very sharply into the underlying basal shales. (Plate 32). The change in colour to that of the red micaceous basal shales is clearly evident.

A knick-point has been produced in the vicinity of the 450m contour. At the commencement of "Hell's Gates" and beyond a series of waterfalls, plunge pools and cataracts occur over a distance of approximately 300m where the river descends abruptly through about 40m of basal shales. (Plate 33). Around the 400m contour another knick-point has been produced where the river flows over the junction of the basal shales with the more resistant underlying granite.

F. TWO EXAMPLES OF INCIPIENT CAPTURE

The writer has observed two examples of incipient river capture on the eastern slopes of Table Mountain. The first occurs on the divide between Nursery Ravine and one of the headwater streams flowing into the Hely Hutchinson Reservoir. The stream has been able to incise a deep channel into the T. M. S. of approximately 45m which is well below the level of the adjacent headwater stream. (Plate 34). This channel has a fairly easy gradient on top of the mountain before the sharp break-of-slope at the edge of the escarpment marking the descent into Nursery Ravine proper.

Skeleton Gorge, however, appears to be closer to capture than Nursery Ravine. At present a small sandy bank about 5m wide forms the divide between the Hely Hutchinson Reservoir itself and the headwaters of Skeleton Gorge. The Department of Forestry has seen fit to plant a row of pine trees on this divide.

A gentle slope covered with Fynbos marks the start of the drainage of Skeleton Gorge on Table Mountain. After fifty-five metres a sharp break-of-slope occurs leading to Breakfast Rock where the edge of the escarpment commences. The gorge has the advantage of working at a lower level than the Hely Hutchinson Reservoir, and through the migration of the divide separating the two drainage areas will eventually capture part of the drainage of the reservoir. Underground abstraction from the Hely Hutchinson Reservoir may be taking place at present. Despite the absence of surface drainage on the initial slope leading to the edge of the escarpment, a fairly strong flow of water emerges from below the surface at the upper end of Skeleton Gorge. This water could very well be seeping through the joint-and bedding-planes from below the reservoir.

The writer has found samples of high grade "alluvial manganese" washed out by the stream in the upper reaches of Skeleton Gorge. The nature of the samples has been confirmed by Dr. Fuller, Department of Geology of the University of Cape Town. The geomorphological implications of the discovery are obscure, but the find once again serves to emphasize the role played by running water in changing the physical landscape of the Cape Peninsula --- and exposing some of its riches.

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CHAPTER 7

CONCLUSION

In this study of the geomorphological development of the Cape Peninsula it has been shown that nothing remains constant in geological time.

As part of the Cape Basin the study area had its genesis in pre-Cape times following upon the deposition of the silt, sand and mud of the Malmesbury Series. Since its formation the areal matrix has passed through periods of intermittent and sporadic uplift during which time various denudational levels were carved out by the sea. Today these erosional surfaces form part of the physical landscape.

Not only has the physical landscape changed through time, but the climate and vegetation have altered as well. This has resulted in distinct morphogenic imprints being left upon the surface of the study area.

The rivers, too have not come through unscathed within the welter of change which has occurred. Competition for drainage has resulted in at least two known examples of river capture occurring within the Peninsula, with two cases of incipient capture in progress.

Running water has also created the gorge-and-buttress landscape along the slopes of the escarpment --- so typical of the Cape Peninsula landscape today. These buttresses are in their turn being eroded and the writer has observed that Nursery Buttress, for example, has five streams incising the main outline of the buttress at present.

The sea is also ceaselessly at work moulding the littoral zone. Stacks running parallel to the eastern shore-line of False Bay indicate where the old coastline used to be, whilst on the other hand the shore is being prograded elsewhere within the areal matrix.

The three types of rock which collectively comprise the bulk of the study area differ in their response to weathering and erosion. This has resulted in distinct scenic types of surface. Here the T. M. S. has shown itself to be highly resistant to weathering and has produced a marked variety of landforms. It has been shown that within the Cape Peninsula the T. M. S. is responsible for the most pronounced topographical features constituting a practically continuous belt of high ground striking in a general north-west south-east direction. Apart from this the T. M. S. also exercises control over:

(a) the form and alignment of the mountains;

(b) the drainage patterns are also structurally controlled, whilst the T. M. S. has also been responsible for one example of superimposed drainage occurring within the study area;

(c) the location of many of the steepest slopes;

(d) the alignment of the shore-line is also structurally controlled where the T. M. S. occurs at sea-level;

(e) the orientation of fault-lines within the T. M. S. is also structurally determined;

(f) since it is almost chemically inert the T. M. S. controls the rate of weathering to a large extent.

Despite its tough, resistant nature, however, the T. M. S. carries within its own Achilles heel in the form of the bedding- and joint-planes which form part of its structure. These joint-planes constitute seepage planes for water, frost action and the solvent action of seepage waters. In the same way that the False Bay anticline was removed by the forces of weathering and erosion, it is predictable that water percolating along the joint- and bedding-planes of the T. M. S. will bring about the slow disintegration and eventual destruction of the T. M. S. which will have to yield to the timeless attrition of such weathering. This would expose the Malmesbury Series and its intrusives to sub-aerial weathering for the third or fourth time during its geological history --- and perhaps initiate the development of new landforms in the area currently occupied by the Cape Peninsula.

PLATES

10-34

10

Bearing: 150^{o} (Facing S. E).

P L A T E No. 10

An outcrop of T. M. S. between two joint planes is clearly displayed in this photograph taken on Table Mountain. Very pronounced parallel nature of joint planes orientated approximately N. N. W. to E. S. E. These planes on the whole are well exposed over the Table Mountain area due to the sparse vegetation over the greater part of the plateau surface.

11

Bearing: 60° (Looking N. E.)

P L A T E No. 11

Transverse set of joint planes occur approximately at right angles to the joint planes referred to in Plate No. 10. Planes deeply weathered in places. Terrain very rugged. Part of buttress projecting southwards towers over the terrain. Horizontal layering of the T. M. S. shows good delineation by way of contrast.

12

Bearing: 330^{o} (Facing N. W.)

P L A T E No. 12

Mature characteristics exhibited by Valley No. 1. Level, open terrain. Gradient very slight. In the distance the divide has been lowered by streams draining the Valley of the Red Gods together with other streams flowing through Kasteels Poort. Disa Gorge discernible in the foreground plus the guard rails on the wall of the Woodhead Reservoir.

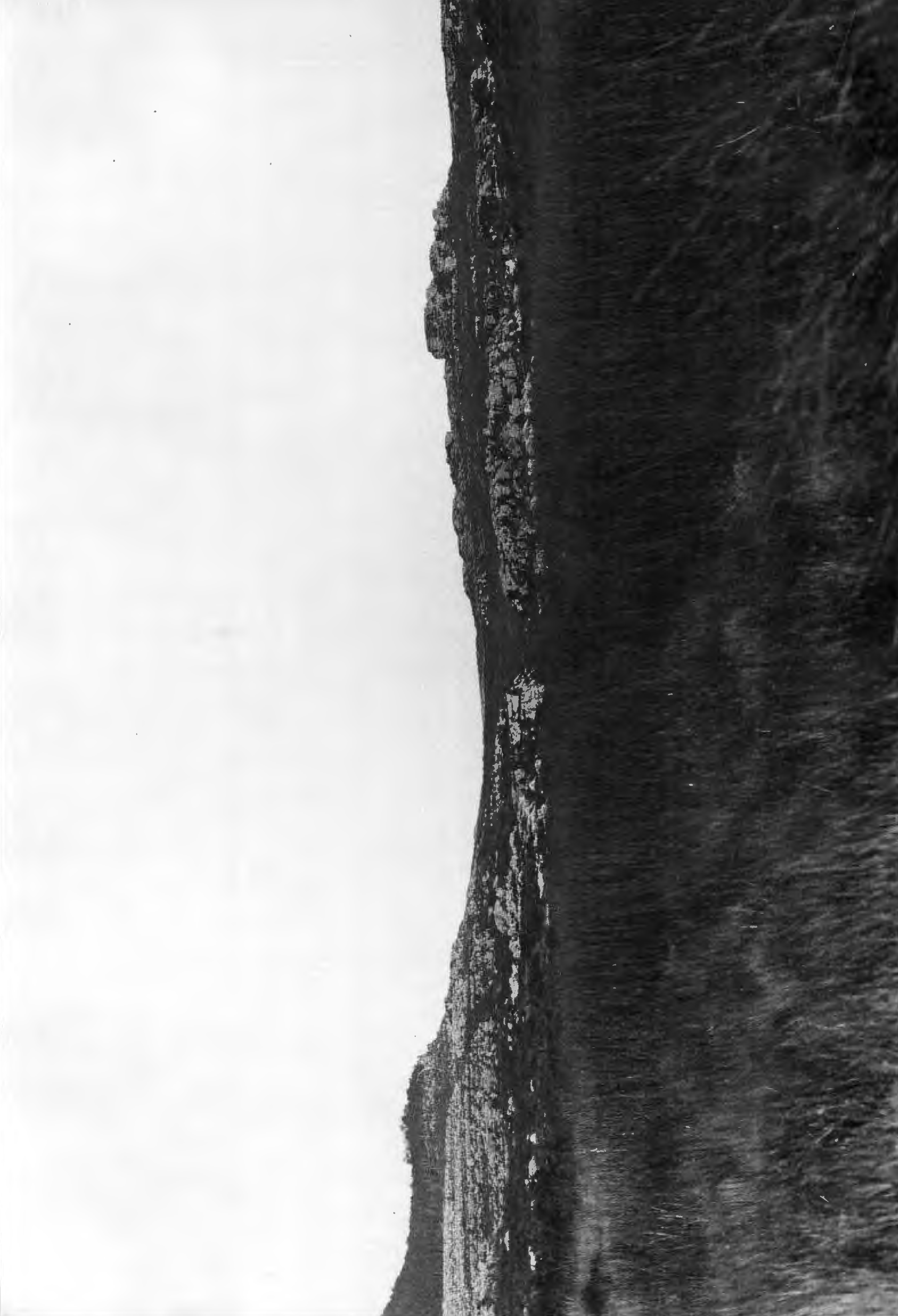
13

Bearing: 146^{o} (Facing S. E.)

P L A T E No. 13

Looking south-east in the opposite direction to Plate No. 12. Level, open nature of Valley No. 1 is accentuated once again. Gradient very slight. Reserve Peak (847m) in centre of the photograph. Lowered divide in the form of a col produced by the drainage into the Hely Hutchinson Reservoir flowing north-westward, and by the stream draining Nursery Ravine flowing in the opposite direction.

14



Bearing: 155^{o} (Looking S. E.)

P L A T E No. 14

Mature characteristics of Valley No. 2 clearly discernible. Note: valley development as a result of erosion usually accompanied by the growth of vegetation as shown in the photograph. Disa Gorge with stream flowing from left to right. On the opposite side of the gorge a valley is seen joining the Disa River. It flows in a north-westerly direction. The divide in the distance is followed by the wall of the Victoria Dam with the other paired stream flowing into it, but this time in a south-easterly direction.

15

Bearing: 113° (Facing E. S. E.)

P L A T E No. 15

Photograph shows mature valleys occupied by the Woodhead and Hely Hutchinson Reservoirs. Very gradual slope of the valley exposed to the south of the Woodhead Reservoir. Valleys must have been formed when the mountain mass was close to sea-level. Contrasts strongly with the buttress from the Central Table towering over it. Col formed by Skeleton Gorge and adjacent peak as a result of erosion by the stream flowing into the Hely Hutchinson Dam and its opposite number draining Skeleton Gorge.

16

Bearing: 76° (Facing E. N. E.)

P L A T E No. 16

Central Table and Junction Peak (921m) show up well in this photograph. Headwaters of the Disa River have their source in the distant heights. Valley formation as a result of erosion by running water is clearly evident.

17

Bearing: 78° (Facing E. N. E.)

P L A T E No. 17

Very gradual slope to the north of the Woodhead Reservoir illustrated once again. Note the marked contrast between the adjacent buttress projecting south-westwards from the Central Table which towers over the adjacent landscape to the south and south-west. Horizontal bedding planes of the T. M. S. discernible together with the vertically aligned joint planes. Very little natural vegetation to be seen apart from the afforested section in the north-east where pine trees have been planted.

18

Bearing: 190° (Looking southward)

P L A T E No. 18

The Disa Gorge shows up as an impressive chasm incised in the resistant T. M. S. as a result of sporadic and intermittent uplift since Tertiary times. Following upon primary rejuvenation the Disa River has, over the years abraded its channel in response to the new base levels. The result has been to produce the Disa Gorge. The "canyon" bisects the Table Mountain mass into Eastern and Western sectors. Groot Kop (852m) broods in the distance.

19

Bearing: 257° (Facing W. S. W.)

P L A T E No. 19

Photograph shows the Disa River "breaking free" from the restricting confines of the Table Mountain mass through the Back Table. Youthful characteristics of this part of the stream apparent as evidenced by the V-shaped nature of the valley. The extent to which the Disa River has incised its course into the solid bedrock of the T. M. S. is well portrayed in this photograph. River describes a large meander curve at the base of Groot Kop (852m) in the distance.

20

Bearing: 45^o (Looking N. N. E.)

P L A T E No. 20

A cataract within the Disa Gorge approximately 400m from the dam wall of the Woodhead Reservoir. Here the stream descends by means of a series of "steps" to a new level. In this instance a drop of about 5m occurred over the full distance of the cataract. Bedding planes of the T. M. S. clearly visible in the centre of the photograph. Note the dense vegetal growth.

21

Bearing: 62^{o} (Facing N. E.)

P L A T E No. 21

A magnificient waterfall within the confines of the Disa Gorge approximately 1,2km downstream from the wall of the Woodhead Reservoir. It occurs just north of the First Intake. It will be noted that the stream has eroded along the transverse plane of the master-joint system. Water drops approximately 7m into the plunge pool below.

22

P L A T E No. 22

Exposed rock face on the western side of the Disa Gorge. Horizontally bedded T. M. S. clearly discernible together with bedding planes. At this juncture the highest ground is at a height of 736m in relation to the level of the Disa River at 600m gives an inkling of the manner in which the river has incised its course into the solid bedrock of the T. M. S. This has been in response to sporadic and intermittent uplift during geologic times. Four vertical incision levels are discernible. They could tentatively be correlated with periods of uplift followed by periods of zero movement.

23

P L A T E No. 23

The lowered divide or col is seen which has resulted from headward growth and the incising of the divide by Valley No. 4. This has been developed along a fault-line which occurs on the half of the Twelve Apostles on which Valley No. 4 is located only i.e. the eastern half. Note the additional advantage of the slight dip of the rock strata on the side of Valley No. 4, whilst on the side of Slangolie Ravine the layers are horizontal.

24

P L A T E No. 24

Looking westward down Slangolie Ravine. Note the narrow corridor-like form of the ravine throughout. Very steep gradient within the mountain confines. Break-of-slope occurs with noticeable flattening of the gradient before the coastline is reached.

25

Bearing: 322^{o} (Looking N. W.)

P L A T E No. 25

Photograph taken from the southern side of the Disa Gorge next to the beacon whilst facing in a north-westerly direction. Valley No. 4 in the centre of the photograph. Note the considerable extent to which the divide has been lowered to produce a well-marked col or wind-gap. Whilst the gradient of the valley is very steep, considerable lateral erosion has also occurred to produce an open valley in sharp contrast to the narrow "corridor" of the Slangolie Ravine on the opposide side of the divide. One of the open "basins" can be discerned at the head of the valley immediately adjacent to the wind-gap.

26

P L A T E No. 26

Accordant junction between Valley No. 4 and the Disa River. Final slope before the junction was measured at 26^{o}. Note very dense vegetal growth along the river banks together with secondary rejuvenation resulting from the increased supply of water provided by Valley No. 4.

27

P L A T E No. 27

Photograph depicts the junction between Valley No. 1 and the Disa River taken from within the Gorge. Note the discordant junction and hanging valley.

28

P L A T E No. 28

A clearly discernible basin along the course of Valley No. 4. This represents one of the three basins which occurs along the length of the valley. Note the open nature of the valley when contrasted with the narrow, corridor-like shape of the Slangolie Ravine. Abstraction is occurring on both sides of the valley as a result of lateral expansion by the basin.

29

P L A T E No. 29

A very steep section along the course of Valley No. 4. The gradient was measured in this instance and recorded at $33,5^{o}$. Note scattered boulders and dense vegetal growth along this section of the valley.

30

P L A T E No. 30

A view upstream along the Disa River just before its junction with Valley No. 4. There is very little difference to be seen between the water level and the height of the adjoining river banks. A slight gradient is noticeable with the stream tumbling over rocks in the stream channel. The river changes direction in a very marked manner at this point and flows in a north-westerly direction in response to the structural control exercised by the fault-line at right angles to its channel.

31

P L A T E No. 31

A view upstream approximately 250 metres below the junction of Valley No. 4 and the Disa River. At least five incised meanders were counted along this section with the river eroding rapidly into the underlying basal shales. This incision of the river bed can be largely attributed to secondary rejuvenation resultant upon the increased water supply made available by Valley No. 4. The open basin shape of Valley No. 4 can be seen on the left of the photograph.

32

P L A T E No. 32

Photograph was taken whilst looking downstream approximately 400 metres below the junction of Valley No. 4 and the Disa River. Note vertical cliffs on the right of the photograph where the river has abraded its channel into the underlying basal shales which are clearly exposed along the dirt road leading towards Hout Bay.

33

P L A T E No. 33

Vertical walls on either side of the Disa River within "Hell's Gates" where the river has incised its course very markedly due to secondary rejuvenation. Apart from the increased supply of water made available by Valley No. 4 following upon the incorporation of part of the drainage basin of the Slangolie Ravine, the marked abrasion of the channel of the Disa River can also be attributed to the fact that at this particular point the river is incising its channel into the softer basal shales which lie at the base of the T. M. S.

34

P L A T E No. 34

Nursery Ravine looking northward. The upper course of the ravine has eroded its channel by approximately 45m into the T. M. S. at this point. The channel is orientated along the master-joint aligned from north-west to south-east. Good exposures of the transverse set of joints can be seen striking in the opposite direction. Headward erosion is also taking place and will eventually result in the beheading of the adjacent stream flowing into the Hely Hutchinson Reservoir.