THE NEOGENE AND QUATERNARY OF AKROTIRI, CYPRUS, DETERMINED BY MEANS OF A RAPID GROUND RECONNAISSANCE ASSISTED BY STEREO-LINE-OVERLAP PHOTOGRAPHS

by

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Summary

In the cliffs of Akrotiri, Cyprus, the Miocene Dhali Group is overlain by the Pliocene Nicosia Formation and Athalassa Conglomerate, whilst Quaternary calcrete and sand form a capping to the cliffs, each unit being separated from the next below by an unconformity. The structure is simple, with the strata nearly horizontal, but the unconformities indicate that periodic earth movements have continued to the present.

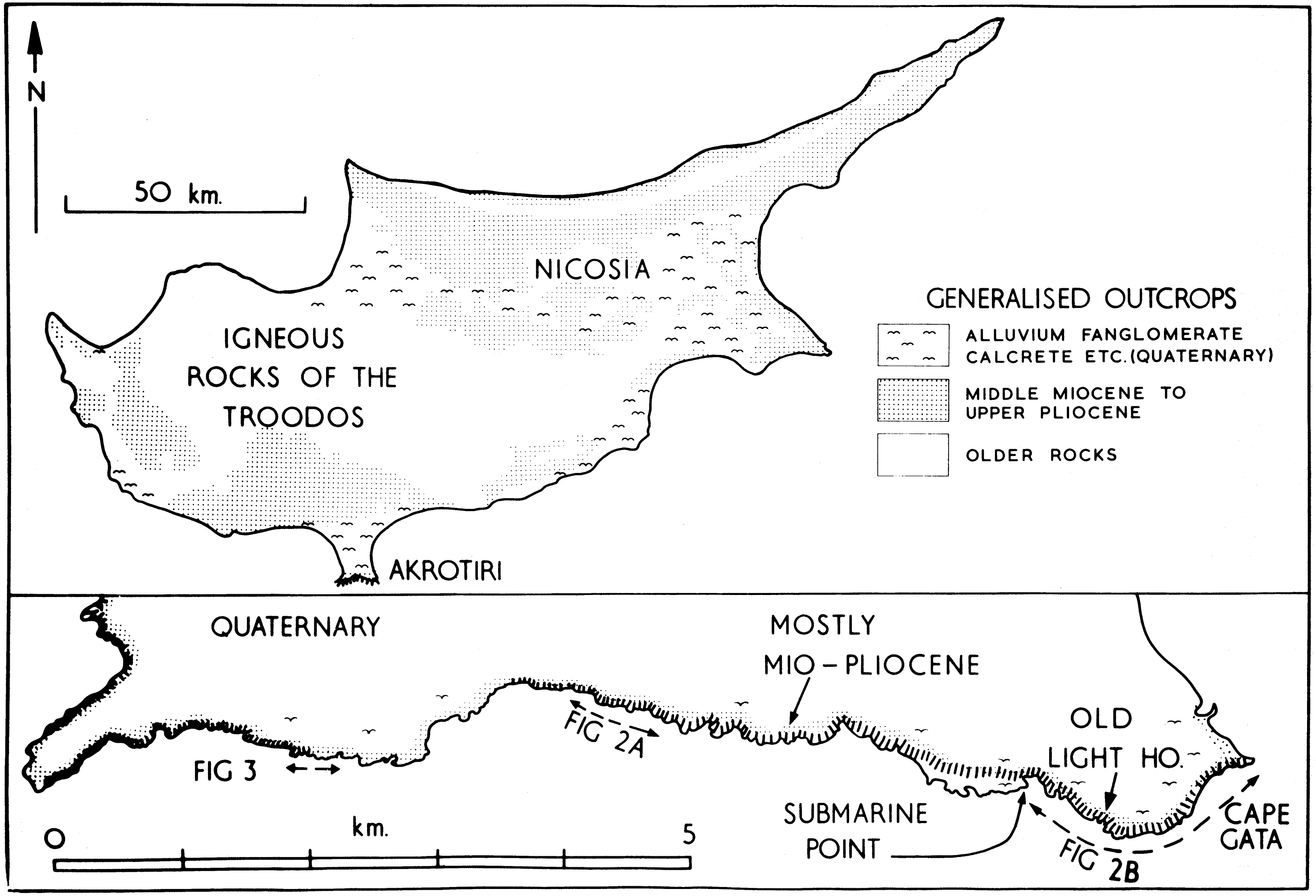
The principal object of this paper is to illustrate the geology of cliff sections by means of a photographic reconnaissance with ground control. The method has wide application to coastal and mountainous sections and greatly speeds up the geological survey.

Introduction

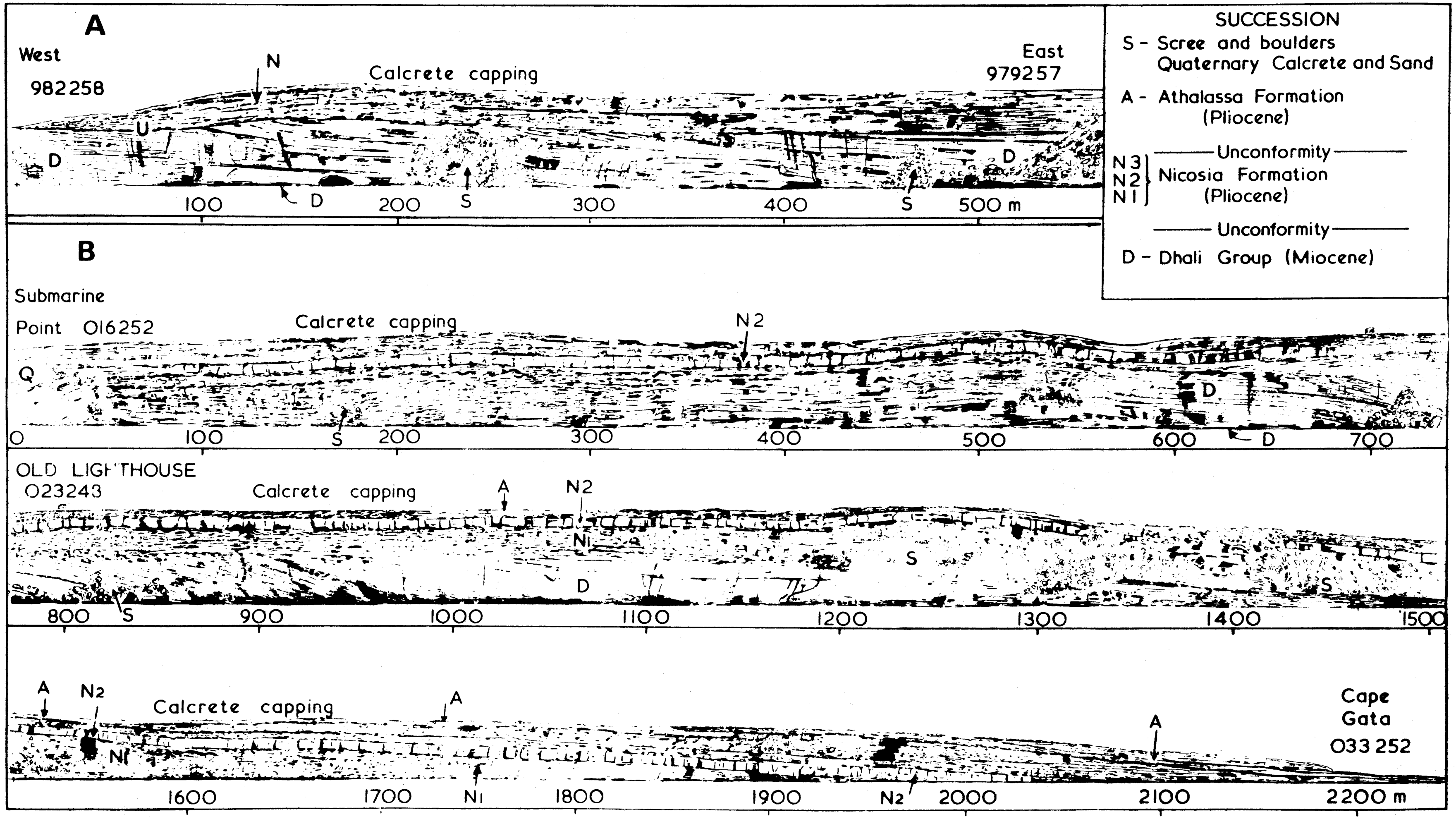
The Akrotiri Peninsula, connected by a low stretch of alluvium to mainland Cyprus, ends in an east-west line of cliffs some 9 km long and 50 to 60 m high. Examination of the cliffs was primarily to determine engineering properties of the rocks, and to decide whether any of the material would be suitable for construction and repair of the mole of a small harbour nearby. A number of items of fundamental geological interest were involved, including the sequence exposed in the cliffs and the methods employed to record it in the strictly limited time available, and these form the basis of the paper.

Field work was limited to one week and, with time at such a premium, it was necessary to record the cliff sections photographically, reserving more detailed measurements and collections for specific localities selected after an initial reconnaissance. The framework of the investigation was provided by a stereo-line overlap of 80 photographs covering the 7 km west of Cape Gata (text-fig. 1). These were taken from a motor launch at a range of about 400 m, an operation which took only 20 minutes and resulted in a tremendous saving of time in comparison with that required for conventional survey. Using a stereoscope, it was then possible to examine at leisure, and in any required photographic detail, all parts of the section. Comparative measurements were made and lateral variations in the strata observed. This is an effective but simple method which to some may seem to be so obvious that description is unnecessary. However, apart from the detailed and accurate surveys resulting from use of such instruments as the photo-theodolite, which are not relevant to reconnaissance surveys, and the references in Moseley, (1972), it is by no means apparent that others have used this method. The stereo photographs were taken every few seconds with an ordinary 35 mm camera using black and white film, the time interval being judged so that there was approximately 60% overlap between successive photographs. Apart from the fact that the camera was horizontal and the section vertical, there was no difference in principle to a normal stereo run from an aircraft. In this case the absolute measurements of stratal thickness etc. were land based and made by normal survey methods (50 m tape), and the photographic section was scaled empirically from them. Had it been the intention to derive the measurements from the photographs it would have been necessary to plan the course and speed of the motor launch, and time the interval between photographs with greater care. Text-fig. 2 is reproduced from the stereo-photographs.

Mercian Geologist, Vol. 6, No. 1, 1976, pp. 49-58, 4 text-figs, Plates 2 & 3.



Text-fig. 1. The location of Akrotiri, Cyprus showing the positions of sections drawn in detail in text-figs. 2, 3 and 4.



Text-fig. 2. Sections of the Akrotiri cliffs. For the location of A and B, see text-fig. 1.

	Quaternary		Alluvium, blown sand, calcrete, scree, shell sands (marine) and conglomerates (shoreline deposits)
NEOGENE	Pliocene	Athalassa Formation	Small unconformity Shell sands and conglomerates
NEOGENE	Pliocene	Nicosia Formation	Small unconformity Shell marls, shell sands, limestones and occasional conglomerates
NEOGENE	Miocene	Dhali Group	Small unconformity Chalk, chalk marl, shell marl, shell sands, limestone, boulder beds
	Oligocene to Upper Cretaceous	Lapithos Group	Unconformity Marls and chalk with limestone and chert bands.
	? Jurassic to Trassic	Trypa Group	Unconformity Radiolarites and bentonitic clays
	? pre-Triassic	Troodos ophiolite complex	Unconformity Pillow lavas, sheeted intrusives, gabbros, serpentinite etc.

Table 1. Geological succession of the Akrotiri-Troodos region.

Those parts of the cliff selected for detailed investigation were then examined in the normal way as indicated above, and specimens were collected, although the time factor inevitably resulted in fossil collections being incomplete.

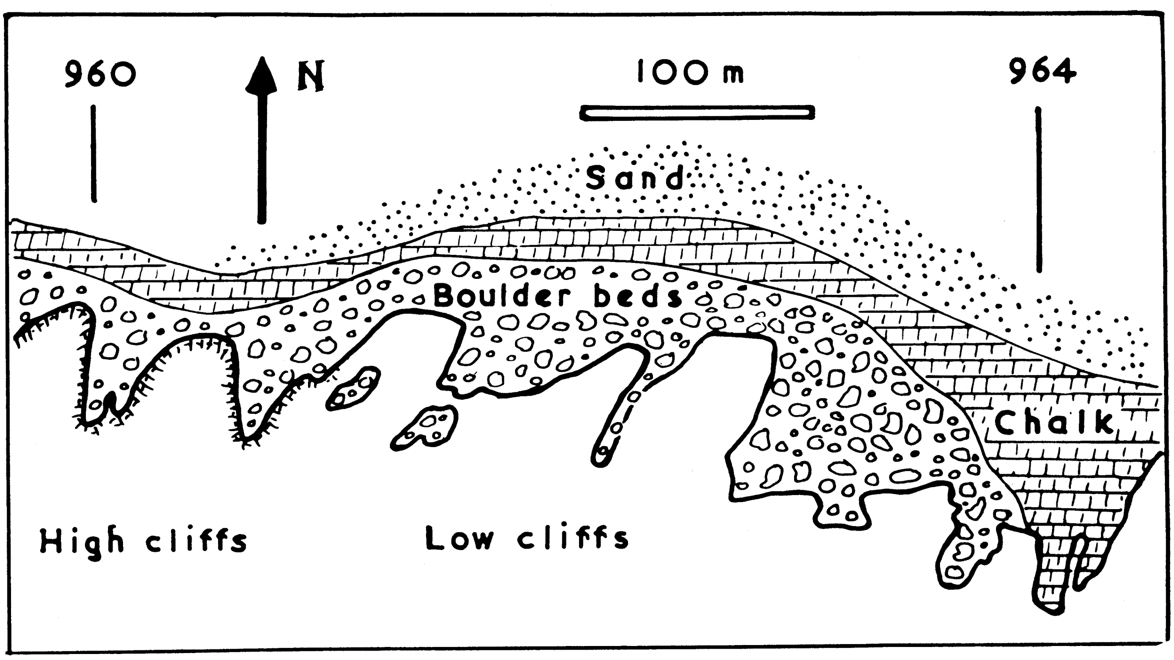
In outline the geology of Cyprus south of the Troodos Mountains igneous complexes is simple, with the strata nearly horizontal or dipping gently to the south. The overal succession in this region is shown in table 1, and that of the Akrotiri cliffs in text-figs. 2 and 4. Closer acquaintance, however, reveals the complexities well seen in the Akrotiri cliffs. Here the oldest rocks exposed in the west are strongly folded shales and other rocks of the Trypa Group (Morel, 1960), overlain with strong unconformity by Nicosia Beds; the outcrops of the Trypa Group were not examined during the survey and will not be considered further. Most of the cliff line consists of a lower part formed by the Miocene Dhali Group, these rocks being overlain unconformably by the Pliocene Nicosia and Athalassa Formations (Morel 1960), with another noticeable unconformity between the two. Quaternary sands and calcretes are the youngest beds and form a capping of the cliffs.

Stratigraphy

Neogene

(a) Dhali Group

This group was first defined by Henson, Browne and McGinty (1949), and the lowest Neogene sediments of Akrotiri were referred to the same group by Morel (1960). To the north of Akrotiri, the sequence has been estimated to be more than 1000 m thick and is dominated by chalk and chalk marl. In the Akrotiri cliffs, there is a greater range in lithology, perhaps as suggested by Morel (1960) because the area is close to an important tectonic line. In the west (text-fig.3, Plate 3, fig.A), there are impressive exposures of boulder beds, well seen in cliffs up to 30 m high and also in the adjacent lower-lying bays. The boulders, ranging from blocks exceeding 3 m in diameter to small pebbles, are set in a chalk matrix, and are mostly composed of hard crystalline limestone. This is unlike any other rock in the local sequence. According to Morel (1960), this limestone has a similar Vindobonian age to other Dhali rocks, and he suggests that it accumulated at the foot of a submarine fault scarp during Dhali sedimentation. In the cliffs west of those shown in text-fig.3, the boulder beds are succeeded unconformably by Nicosia Beds, whereas within the area of text-fig.3, they are overlain by a few metres of chalk and chalk marl and then by Quaternary



Text-fig.3. Boulder beds and chalk of the Dhali Group, overlain by Quaternary sand.

sands. About 1 km further east, the boulder beds pass laterally into chalk and shelly chalk marl, which is deformed into shallow E-W folds with limb dips of about 5°. Still further east, on the western margin of text-fig. 2,A, the Dhali beds become pale brown as the iron content increases and there is a gradual change into shelly marls and shell sands. From here to the eastern margin of text-fig.2 ,A, the Dhali beds are buff coloured, well-bedded shelly marls and sands, interbedded with thin, strongly-cemented bands of shell limestone (Plate 2, fig. B), and locally complicated by irregular shell masses, by washouts and by false bedded units. The shell masses are typically up to 1 m thick and several metres long, and the false-bedded units are from 5 to 10 m thick. There is a rich fauna, especially in the shell limestones, including oysters, pectens, echinoids and foraminifera of many species.

(b) Nicosia Formation

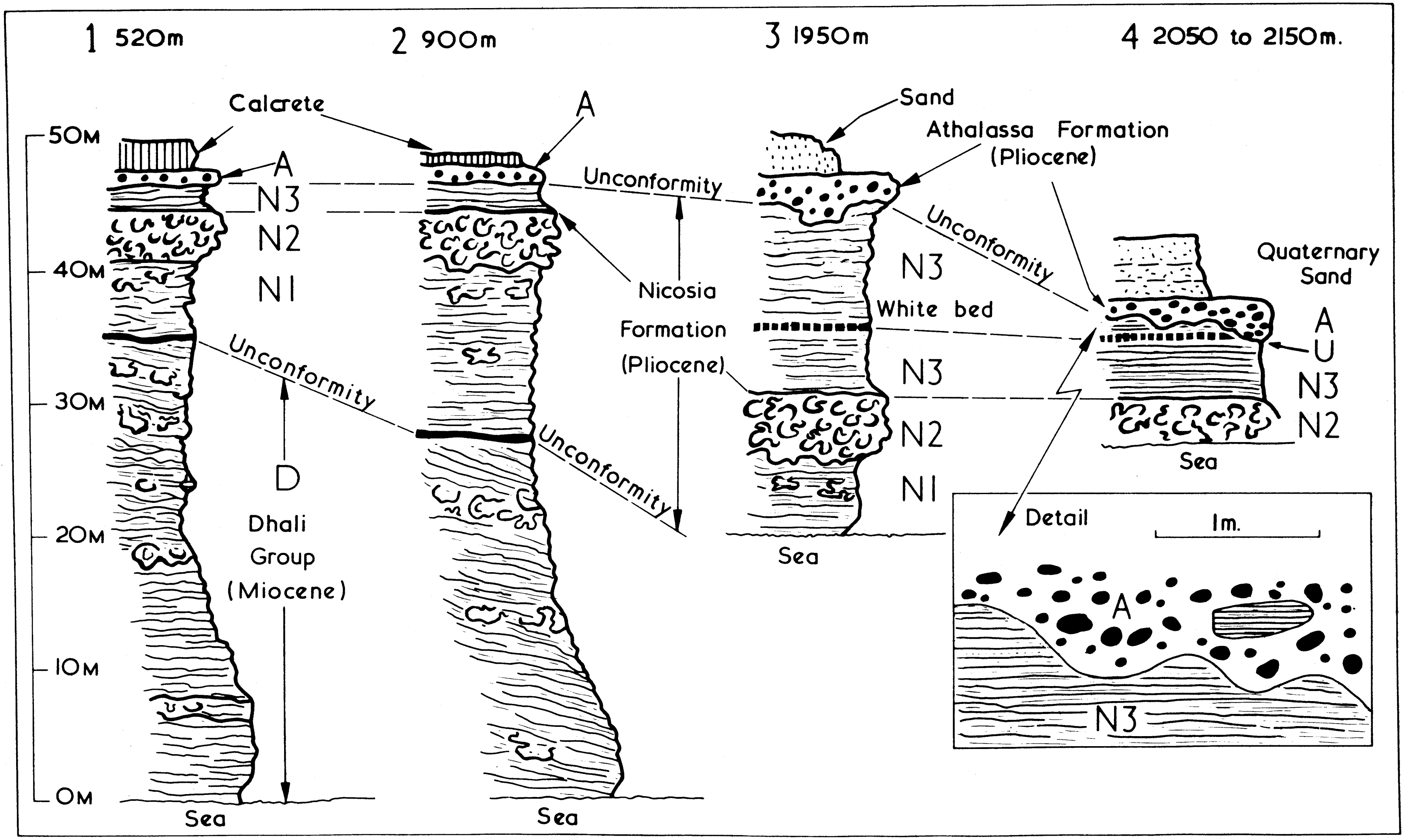
The unconformity below the Nicosia Formation is easily recognised in the cliff sections, particularly where there are local divergencies of strike, near the old lighthouse (text-fig. 2,B), and further west (981 258, text-fig. 2,A, and plate 2,Fig. B). It provides good evidence of the earth movements which affected the area in late Tertiary times. The local sequence of the Nicosia Formation is best seen in the eastern part of the peninsula between the old lighthouse and Cape Gata (text-figs. 2 and 4). At the base (N1), there are loosely cemented and well bedded shell marks and sands, not unlike those in the underlying Dhali beds. They contain irregular, strongly-cemented shell masses, which frequently coalesce into continuous bands, interbedded with the loosely cemented material (Plate 2.fig. A). The fauna, as with the underlying Dhali Beds, is extremely varied and would repay a detailed study; oysters, pectens and other bivalves, gastropods, echinoids and foraminifera, whole and broken, are pressed together in great abundance. Occasional intraformational conglomeratic bands are also present, with phenoclasts of a variety of limestones and igneous rocks, the latter almost certainly derived from the Troodos Mountains ophiolite complexes.

The lower (N1) division of the Nicosia Beds is of variable thickness (text-figs. 2 and 4), but averages about 10 m. Above it there is a prominent band of well-cemented sandy shell limestone about 4 m thick (N2), which can be followed from Cape Gata as far as Submarine Point (text-fig. 3, B) Plate 2, Fig. A, Plate 3, fig. B). The base of the limestone is highly irregular, as shell masses and variable cementation have locally resulted in thickening (Plate 2, fig. A). Two strong sets of vertical joints are well developed in this bed, with mean trends of N255° E and N180° E respectively. It is noticeable that most of the joints end abruptly at the top and bottom of the limestone, no doubt a reflection of its relative competence, although there are a few master joints which extend through overlying and underlying strata.

Thin sections of this band (N2) show that the great bulk of the rock is made up of complete shells and eroded shell fragments, almost all within a grain size range of from 0·1 to 1 mm, with the upper part generally slightly coarser-grained. The majority of the shells are foraminifera of a variety of species, but there are also bryozoans, gastropods and bivalves in abundance. In addition there is a scatter of quartz and chert. The cement is extremely fine-grained calcite.

Above the shell limestone (N3), lithologies are similar to those in the lower part of the Nicosia Formation, with buff shell sands and marl loosely-to-moderately cemented and interspersed by shell masses. Strong slump folds overturned to the north-east were observed 200 m west of Cape Gata, and 'worm' burrowed surfaces are common. About 5 m above the shell limestone, there is a noticeable 30 cm white band of shelly, calcareous, partly cemented and partly concretionary sand, which can be traced for some distance along the cliffs until it is truncated by the Athalassa unconformity (text-fig. 4).

To the west of Submarine Point and as far as text-fig. 2,A, the Nicosia Beds maintain a similar lithology, with the exception of the massive limestone unit N2, which passes laterally into shell sands with thin shelly bands indistinguishable from the rest of the formation. West of text-fig. 2,A, (980258) a 6 m lens of lenticular, strongly-cemented calcareous sand sharply truncates the bedding of the underlying strata and appears to be a channel-fill deposit. It is



Text-fig. 4. Sections of the Akrotiri cliffs between Cape Gata and Submarine Point (text-fig. 2, B)
D - Dhali Group, N. - Nicosia Formation, A - Athalassa Formation.
Near horizontal lines - loose sand and marls.
irregular ornament - well cemented shell limestone.
black spots - conglomerate and conglomeratic limestone.

composed of rounded grains, mostly between 1 and 3 mm diameter, of basalt (several varieties), hornblende dacite, micro-granodiorite, gabbro, chert, vein quartz and crystalline limestone, as well as shell fragments, and is cemented by crystalline calcite.

(c) The Athalassa Formation

This formation is also of Pliocene age (Morel, 1960), and overlies the Nicosia Formation with a slight but distinct unconformity, which clearly transgresses more than 10 m of Nicosia Beds between Cape Gata and the old lighthouse (text-fig. 4). In this area, outcrops of the Athalassa Formation are restricted to the basal conglomerate, a strongly cemented bed ranging from 1 to 3 m in thickness. This conglomerate is of variable composition, with phenoclasts mostly of hard limestone but also including abundant pebbles of chert, basalt, dolerite, gabbro, dacite, quartz porphyry and granite, again presumably derived from the Troodos Mountains; there are also fragments of moderately consolidated sand (text-fig. 4), which must have been redeposited after short transport. The matrix is composed of shell fragments and shell limestone, with occasional grains of quartz, hornblende, pyroxene and other minerals, and there are also frequent interbedded shell layers, mostly of *Glycimeris* sp. which show up well on exposed bedding surfaces. This unit, as a whole, is interpreted as a former beach deposit. The Athalassa Conglomerate forms the hard rock cap along the crest line of much of the Akrotiri cliffs, and in this position is often overlain by Quaternary calcrete, from which cementing solutions, penetrating downwards, have increased the hardness of the rock (see below). These solutions, precipitated in the pore space as extremely fine-grained calcite, have in places resulted in replacement and destruction of shell material.

(d) Quaternary

Sediments which can be attributed to the Quaternary Period include dune and wind blown sand, marine calcareous sands with shell beds, and calcrete. The detailed sequence is by no means certain, although local sequences along the top of the cliff can be readily established.

Calcrete or havara, which is the local name, is best seen along the cliff top between Cape Gata and Submarine Point, where it generally rests on Athalassa Conglomerate. The most complete successions, comparable to those in other Mediterranean areas and elsewhere (Browne, 1956; Moseley, 1965), consist of a hard cap rock underlain by a soft friable zone. The cap rock, which varies from about 30 cm to 1 m in thickness, is mostly calcite mudstone, in the form of travertine, with either horizontal banding where precipitation has been controlled by bedding, or vertical banding where precipitation has been along joints. There are also pistolitic layers and zones of brecciation. The friable zone, about the same thickness as the cap rock, is soft chalky marl with irregular concretionary areas, and below this the older rock formations (mostly the Athalassa Conglomerate) are calcreted to depths of 1 or 2 m. These latter effects are particularly noticeable where banded calcrete penetrates along bedding and joint planes and results in substantial alteration to a calcite mudstone, although the exotic pebbles of the conglomerate remain unaffected and traces of the original shells are always preserved.

The calcreting processes would appear to have operated over a considerable time, and are probably still operative today. The fact that earlier calcrete has been jointed and there is subsequent calcrete penetrating these joints is additional evidence of this.

Wind blown and marine sands are most likely to have been contemporaneous with much of the calcrete, although evidence for their detailed relationships has not been established. Near Cape Gata red and grey sands rest on calcrete and, near Submarine Point, marine conglomerate shell beds are followed by about 30 metres of false bedded dune sand, the whole sequence dipping southwards into the sea, and resting unconformably on the earlier Pliocene and Miocene formations.

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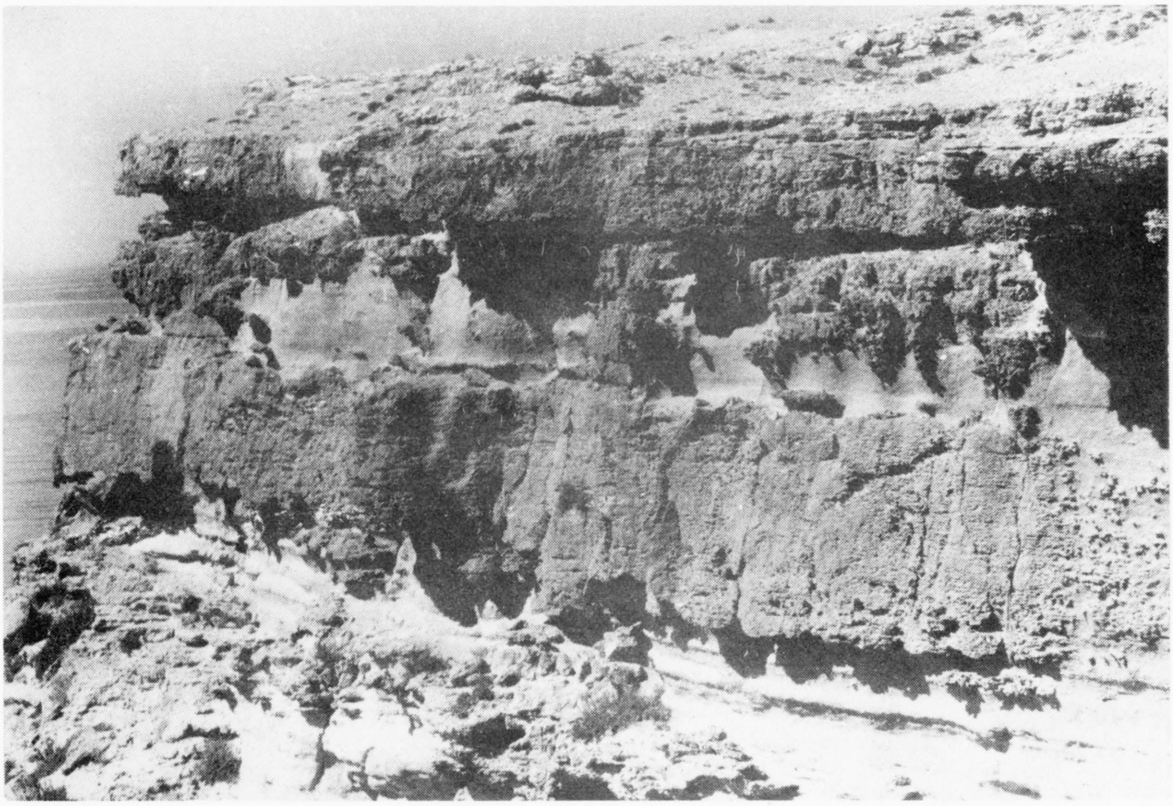
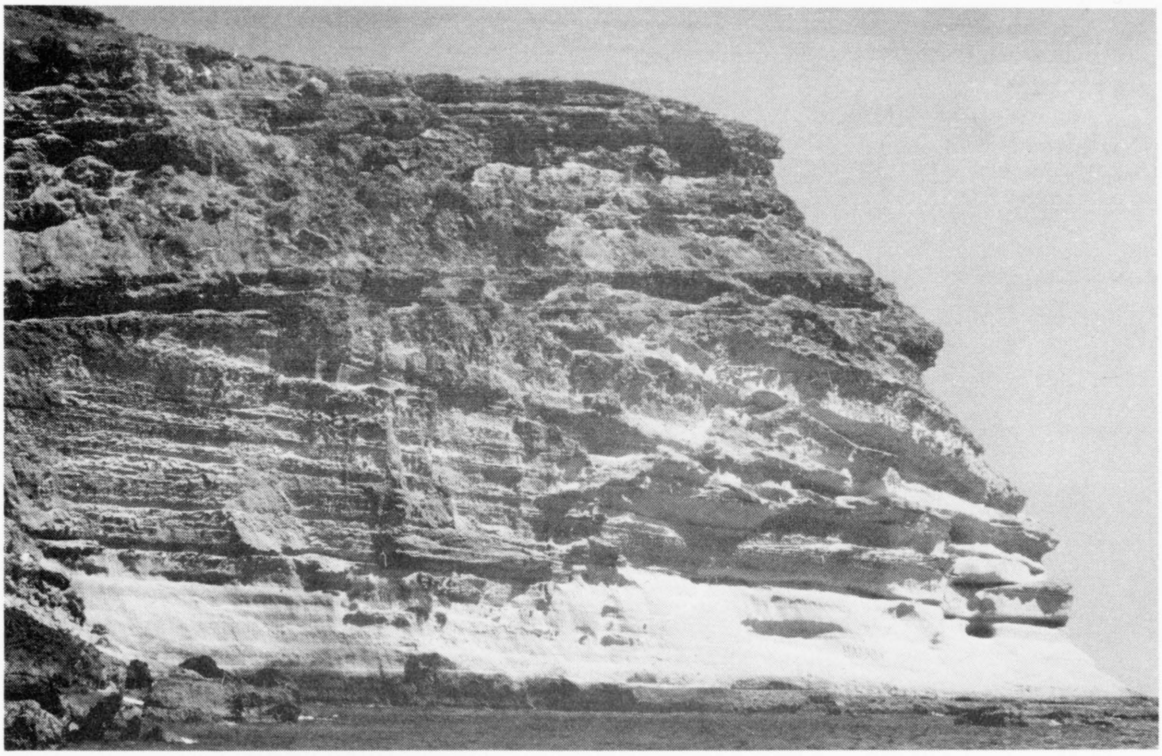
Explanation of Plates

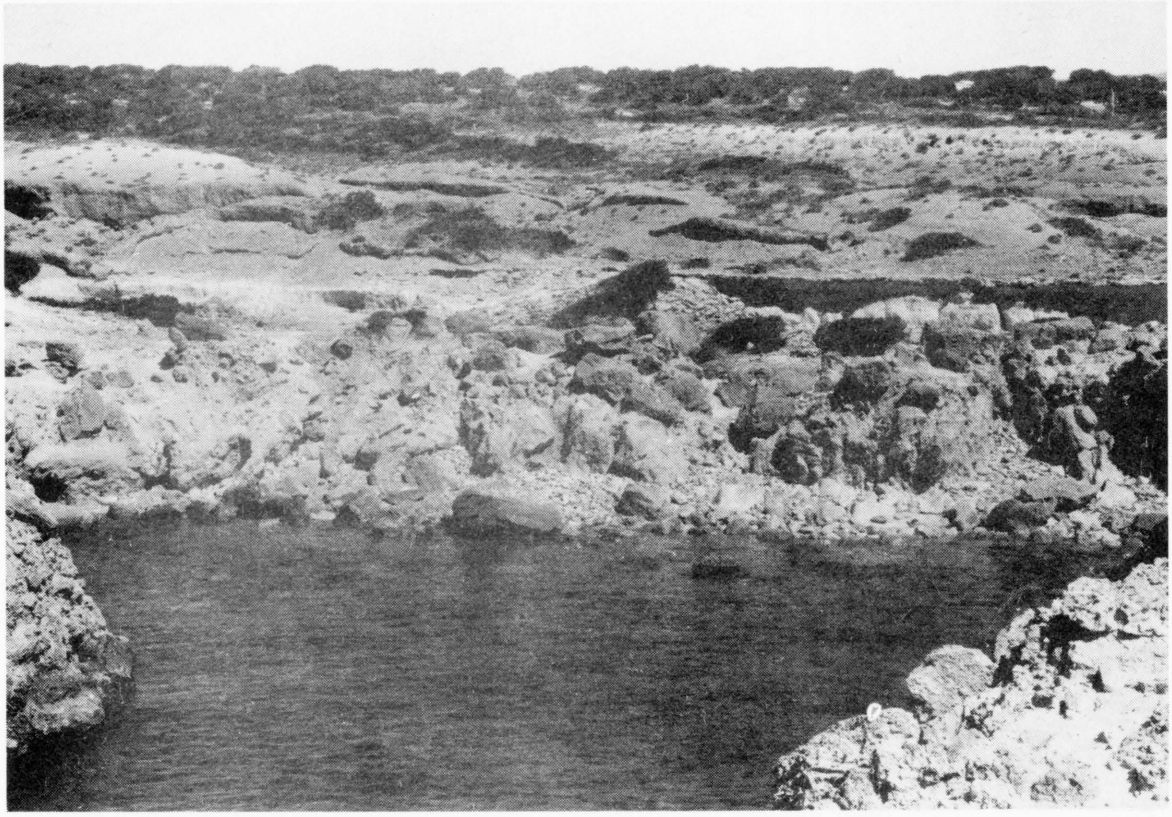
Plate 2	Fig. A.	Succession at 1100 m, location on text-fig. 2, B showing: Q - Quaternary calcrete. A - Athalassa Conglomeratic shell limestone. N3 - loosely cemented shell sand and slit with irregular shell masses. N2 - well cemented shell limestone; about 3 m thick at this point. N1 - Similar to N3.
	Fig. B.	Succession at 150 m, location on text-fig. 2, A. Shell marls, sands and cemented shell beds of the Dhali Group are overlain unconformably by Nicosia Beds of similar lithology.
Plate 3	Fig. A.	Boulder beds and chalk of the Dhali Group overlain by Quaternary sand. (See text-fig. 3.)
	Fig. B.	Part of the stereo-line overlap of the Akrotiri cliffs with Nicosia Beds resting unconformably on Dhali Beds and the massive sandy limestone (N2) near the top of the cliff. The position is at 900 m on text-fig. 2, B.



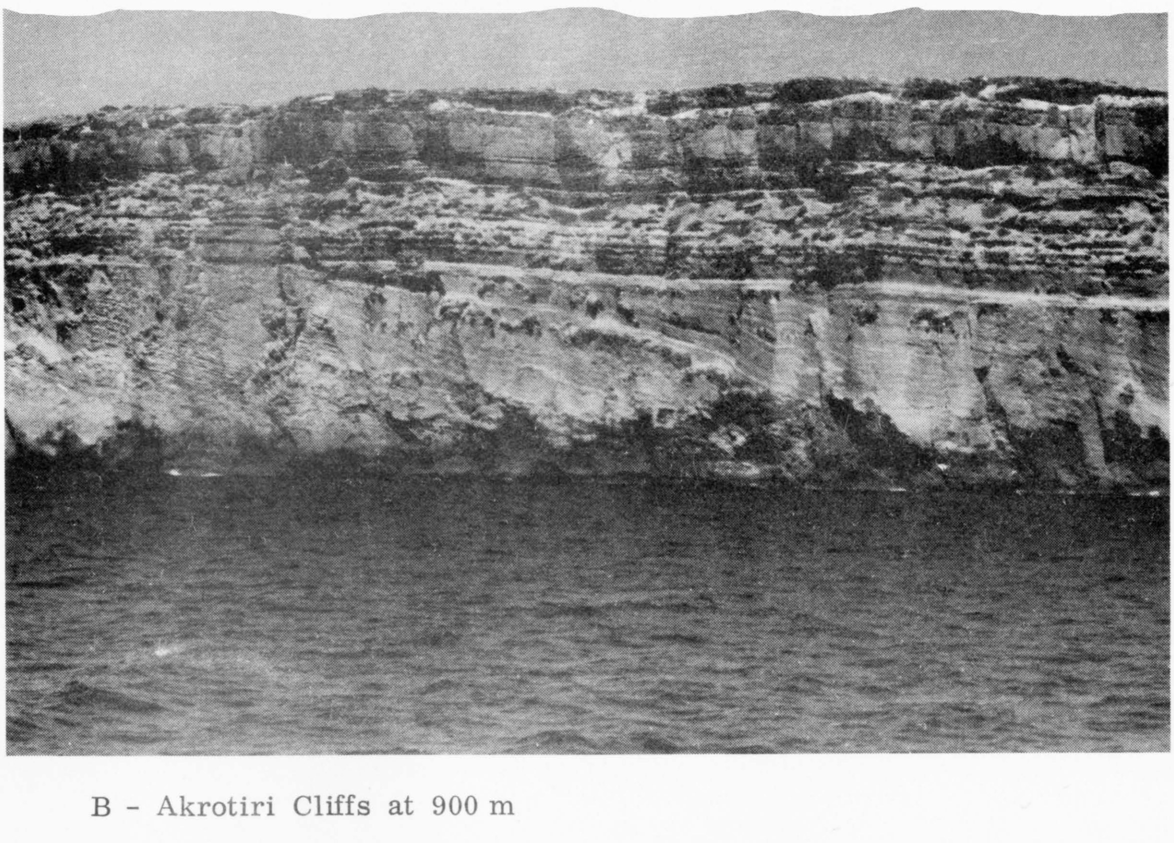
A - Succession at 1100 m, Akrotiri Cliffs.



B - Succession at 150 m, Akrotiri Cliffs



A - Low Cliffs, text-fig. 3.



B - Akrotiri Cliffs at 900 m