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THE GEOLOGICAL EVOLUTION CORRELATED TO THE STRATIGRAPHY OF THE KALPITIYA PENINSULA

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Abstract

Core drilling investigations in the Kalpitiya Peninsula reveal near surface, well graded, dense, dune sands of Quaternary origin. The horizon of unconsolidated sand provides an excellent perennial fresh water aquifer. These sands grade into a sandstone basement at a depth between 6 m and 9 m MSL.

The top surface of the sandstone basement, in relation to the existing sea level shows a variation from –3.6 m MSL to –11.2 m MSL. This shows a maximum regression of the MSL up to –11.2 m during the Quaternary period. Within the sandstone bed are patches of mudstone with complete mixing of clay, which shows that marine/estuarine environments overlapped periodically with fluctuations in MSL.

Below the sandstone, a limestone basement at depth from –11.4 m MSL to –14.2 m MSL forms an unconformity of approximately 20 million years in the geologic history. It represents Miocene-Quaternary period of transition. The thickness of the clastic fossiliferous limestone is more than 60 m in the Kalpitiya peninsula. A thin bed of mudstone within the limestone indicates that a complete marine environment of continued deposition did not exist during the Miocene period.

The southern Miocene boundary indicated in geological maps needs to be extended at least up to south of Mundal Lake and even beyond up to the Deduru Oya river mouth. Further core drillings can exactly demarcate this boundary.

Introduction

The Kalpitiya Peninsula in Sri Lanka is situated within longitudes 79° 41′ E-79° 44′ E and latitudes 7° 59′ N-8° 21′ 30″ N (Fig. 1). It is a compound shaped like a beckoning finger (Swan, 1983). Cooray (1968); Cooray and Katupotha (1991) have identified several stages of evolution of this peninsula. The entire Kalpitiya peninsula falls in the 'flat terrain' of the Dry Zone Low Country of Northwest coast of Sri Lanka. It is 6 km wide at the Kandakuda area and has a length of 40 km from Mampuri (south) to the end of the spit (north).

Based on elevation, configuration of micro-relief and composition of the deposits in the Peninsula, it is possible to identify wide beaches, dune formations, sand-ridges and runnels, saline flats with salt marshes, mangrove fringes, salt-water holes as well as sand spits. The peninsula has multi-concave and largely convex outlines (Swan, 1983).

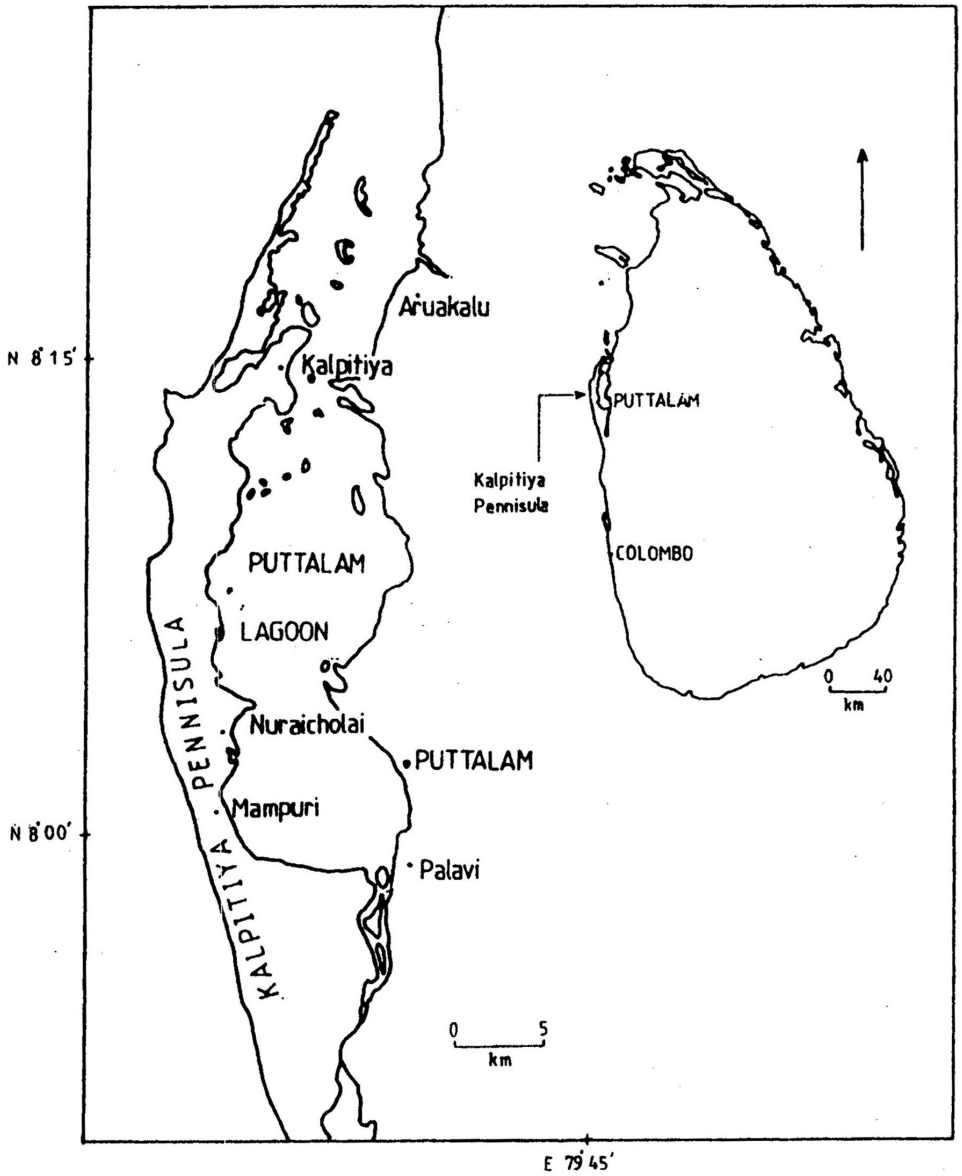


Fig. 1. Map Showing Location of the Kapitiya Peninsula

A core drilling programme by the Foundation and Waterwell Engineering (Pvt) Ltd was undertaken in the area of Narakkali in Kalpitiya peninsula, for the geotechnical feasibility study to establish a Coal Fired Thermal Power Project for the Electricity Board. Using the samples of these boreholes, from surface to the end-point (down), this paper adopts a model of stratigraphic features and geologic history as evidence along with material from previous authors, in order to arrive at the final conclusions.

A total of 8 boreholes were drilled on the coastal sand dunes near Nuraicholai, between Mampuri and Narakkali (Fig. 2). The surface level of the boreholes was between 1.96 m in BH 7 and 3.83 m in BH 4 above from MSL.

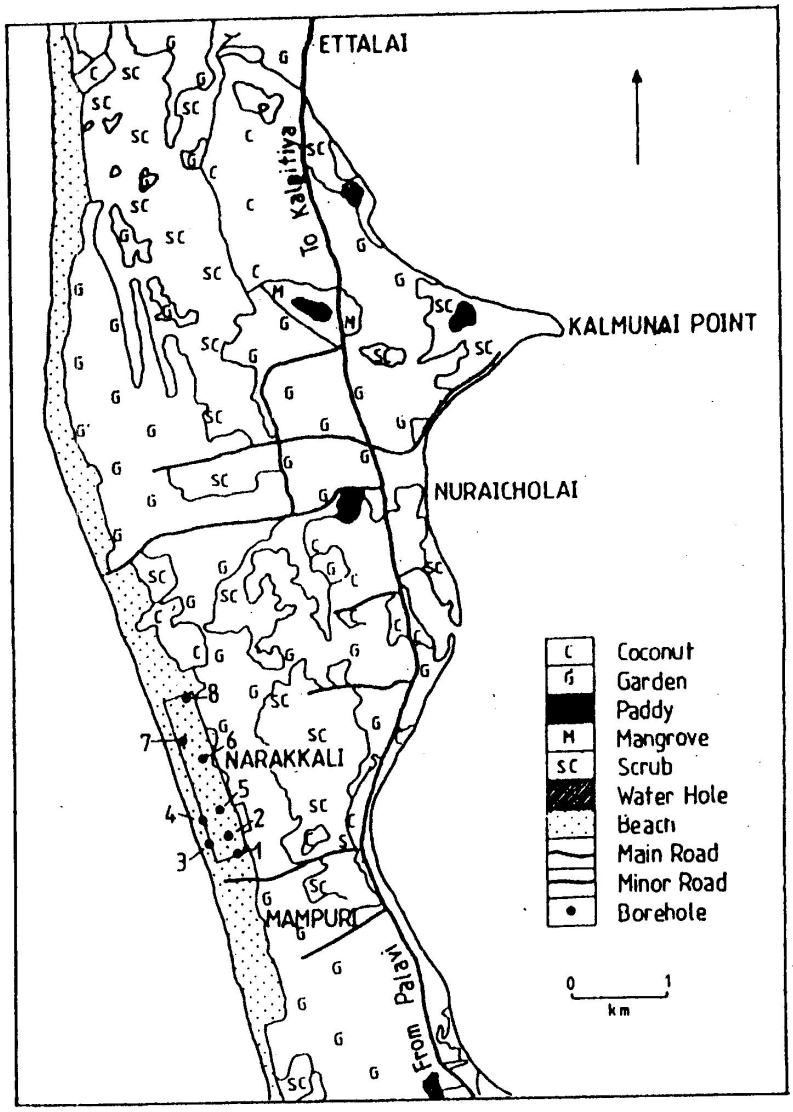


Fig. 2. Location of the Study Site at Narakkali, Kalpitiya Peninsula

In this investigation the overburden sand had wash samples of Standard Penetration Test (SPT). The stratigraphy of the overburden was classified on split spoon samples, and not on washings. The lithology, sandstone and the limestone, is reliable in classification because the cores were recovered in a double tube core barrel during diamond core drilling of NX size.

Geographical Setting

The Quaternary deposits of the Kalpitiya Peninsula overlie the Miocene limestone beds. The Miocene deposits are mainly sedimentary limestone (Cooray, 1984). This bed is placed on the Precambrian basement of crystalline gneisses; the 'Wanni Gneiss Complex' varying between 950 to 1390 million years (Kroner and Jaeckel, 1994). An unconformity exists

within the Quaternary deposits, in the transitional zone between the Quaternary deposits and the Miocene limestone beds.

The mean annual rainfall in the area varies between 750-1500 mm, while the maximum occurs in the cyclonic-depression season of October and November. Mean monthly rainfall of the period, October to December, varies within 100-250 mm. The least amount of rain falls during the period June to September (ranges 10-15 mm). Such a climate favours rapid evaporation of saline flats and water holes and helps the formation of sand dunes at different heights (about 15-20 m), shapes and types. Most of the active and migratory dunes, commonly southwest-northeast are composed of sandy regosols (Panabokke, 1996). Although barren lands appear along and close to the coast, a considerable part of the peninsula is covered by *Spinifix littorerus* (Maharawana) on sand dunes, where as *Ipomoea pescaprae* (Mudubinthamburu) occur as patches. Thorny scrublands are common in leeward sides of the dunes. Hyper-saline plants and mangrove fringes can be seen along the lagoon shore (Puttalam Lagoon) and tidal pools.

Investigation and Sampling

Rotary Drilling was carried out during the months of October and November in 1997 for continuous sampling and wash-boring. In the Quaternary overburden, at specific intervals, the SPT was carried out to estimate the load bearing strength of strata. The visual identification of sediment was carried out on samples from the split spoon sampler, during the SPT and recorded as borehole logs.

In addition, in order to collect samples from hard strata diamond bits and double tube core barrels (54 mm diameter) were used. In friable strata, sludge samples were recovered. In some corings, which reached the 'sandstone basement' cores was recovered, while in more friable sandstone disintegrated sands were collected. On reaching the 'limestone basement' continuous coring recovered fresh limestone in some horizons, while friable, fractured and weathered limestone yielded calcareous sludge.

The recovered basement cores were studied for mineralogy and for engineering appreciation of the sub-surface. The rock type, structures, Core Recovery (CR) and Rock Quality Designation (RQD) were evaluated to establish bedrock competency. On withdrawal of borehole casings, the groundwater table was continuously monitored. In order to study the ground water variation with the 'tidal cycle', selected boreholes bordering the coast were monitored for the cycle period. Four representative limestone core samples were used to prepare thin sections for microscopic study at the Geological Survey and Mines Bureau of Sri Lanka.

Results and Discussion

Figures 3 and 4 show that plan of drillings along A - A′ line (BH 3, 4 and 7 in Fig. 2) and B - B′ line (BH 1, 2, 5, 6, and 7 in Fig. 2) of the study area. The lithologs and inter-boreholes comparisons of the strata are also indicated in these figures. From a geotechnical engineering perspective, four distinct strata can be identified at this site as follows: dune sand, dense sand, sandstone and limestone. These sedimentary layers have been deposited on the Precambrian crystalline metamorphic gneiss basement.

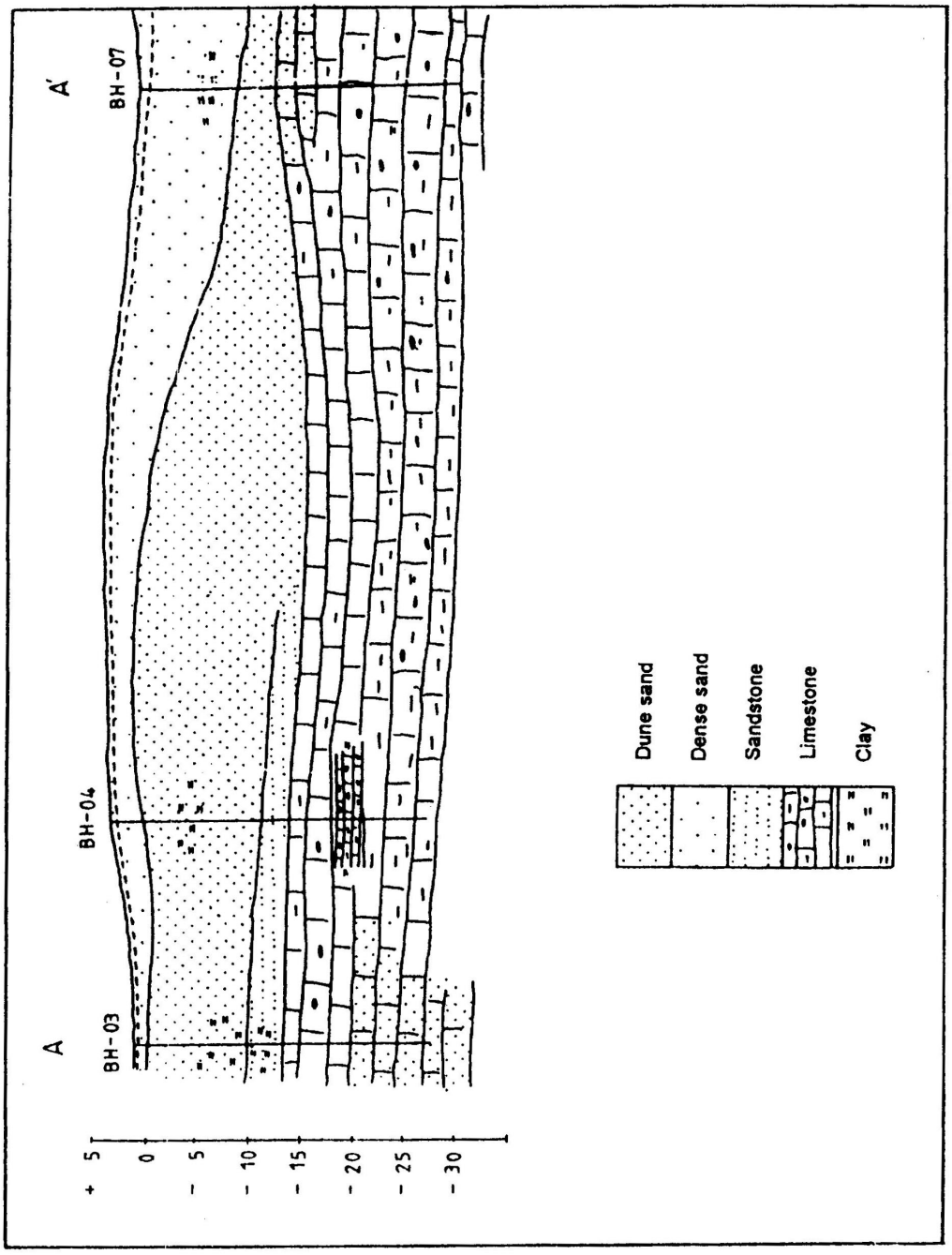


Fig. 3. Stratigraphic Sequence of the Profile from A to A'

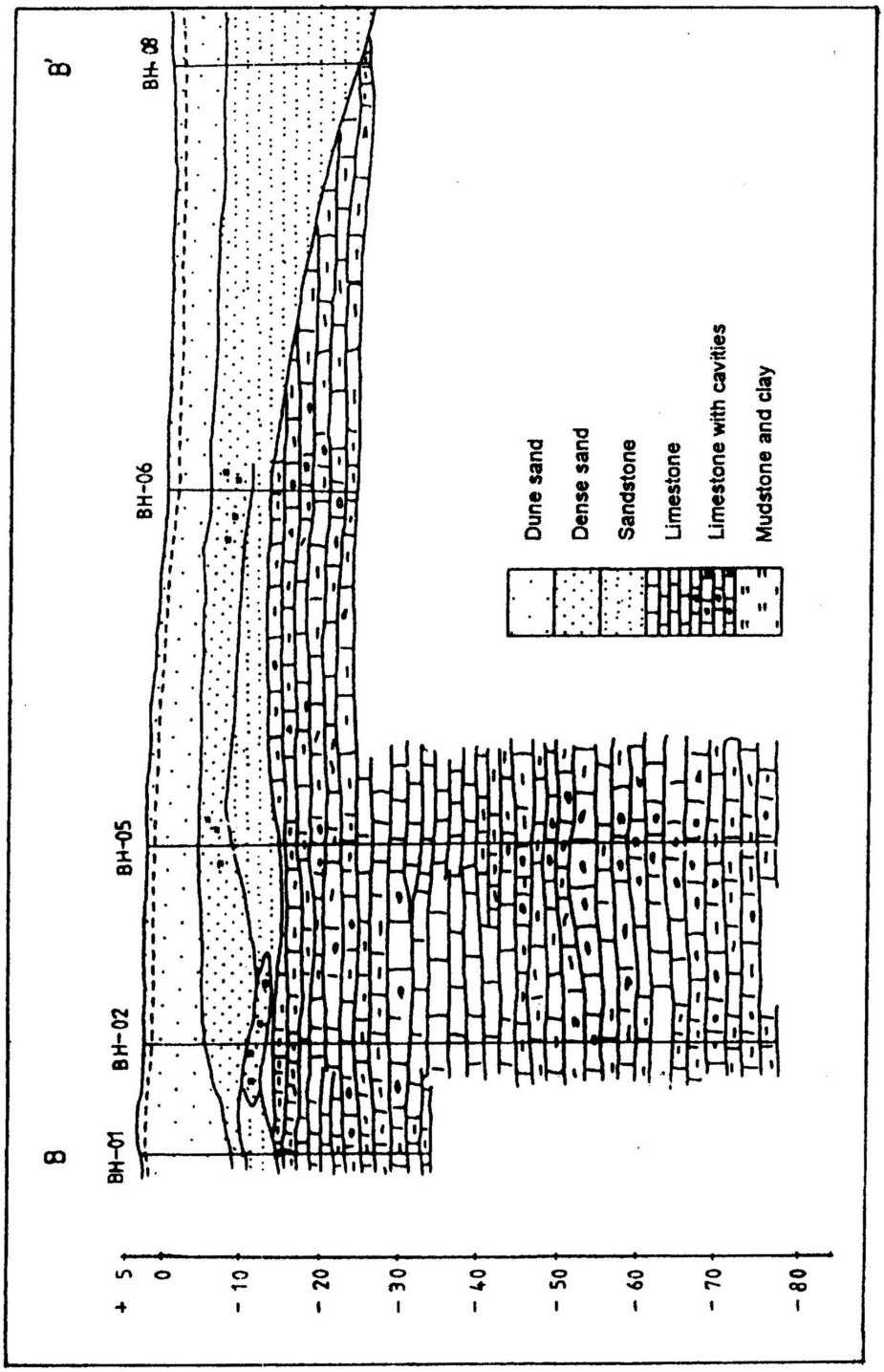


Fig. 4. Stratigraphic Sequence of the Profile from B to B'

Dune Sands

The surface dune sands of the Kalpitiya Peninsula are well-graded, angular to sub-rounded quartz sands with traces of ilmenite. Figure 5 shows that more than 70 percent of medium sands come from sand sample at 4.0-4.45 m depth of BH 5. Fine sand and gravel content are both less than 5 percent. These results are almost similar in other boreholes.

A sand dune system lying at the head of a wide low-tide beach, sands have been picked up by the wind and blown through the air onto the dune. In fact the movement of the sand in air is a highly complex process, but this complexity is required for the formation and morphology of the sand dunes (Pehick, 1984). In the Kalpitiya Peninsula the wind blown origin of this sand has already been proved by accepted classifications by earlier researchers (Swan, 1979, 1983; Cooray, 1984). Aerial photographic studies have also proved that the monsoon wind patterns follow the northwest-southeast direction of dune formation of the area (Survey Department of Sri Lanka, 1956).

Dense Sands

At a shallow depth of 2 m just below the groundwater table, the sands are mostly densely compacted due to excellent gradation. The dense character is revealed by the 'N' value of SPT (Fig. 6). As shown in Figure 6, 'N' values are recorded greater than 100 along a horizon making high load bearing stratum (up to 300 kN/m^2), which is classified as 'very dense' sands. However along the profile as shown in Figs. 3 and 4, pockets of less dense unconsolidated sands occur by virtue of poorer gradation. The thickness of these sands is variable across the site, terminating in sandstone at a depth between 6 m and 9 m below MSL.

Sandstone Basement

The sandstone stratum is variable across the site in elevation and composition as shown in the cross-sections A-A′ and B-B′ (Figs. 3 and 4). This sandstone basement is encountered in BH 1-7 at a depth between 10 m and 18 m, but it extends in BH 8 up to 30 m depth. The geotechnical variation of this dense basement across the study site is as follows:

- Dense sandstone with core recovery 50-80 percent.
- Friable sandstone disintegrating to sands.
- Hard sandstone disintegrating to sands.
- Moderately dense sandstone with core recovery having patches of lagoonal stiff and plastic clays.
- Moderately dense sandstone with patches of mudstone.

The above variation indicates that the sandstone layer was deposited between mid-Holocene and Late Pleistocene times due to the fluctuation of MSL (Swan, 1983; Katupotha, 1994). The cement of sandstone is $CaCO_3$ as in most littoral sandstones. However calcium carbonate ($CaCO_3$) was not observed in cores (reaction to HCl). This is understood as

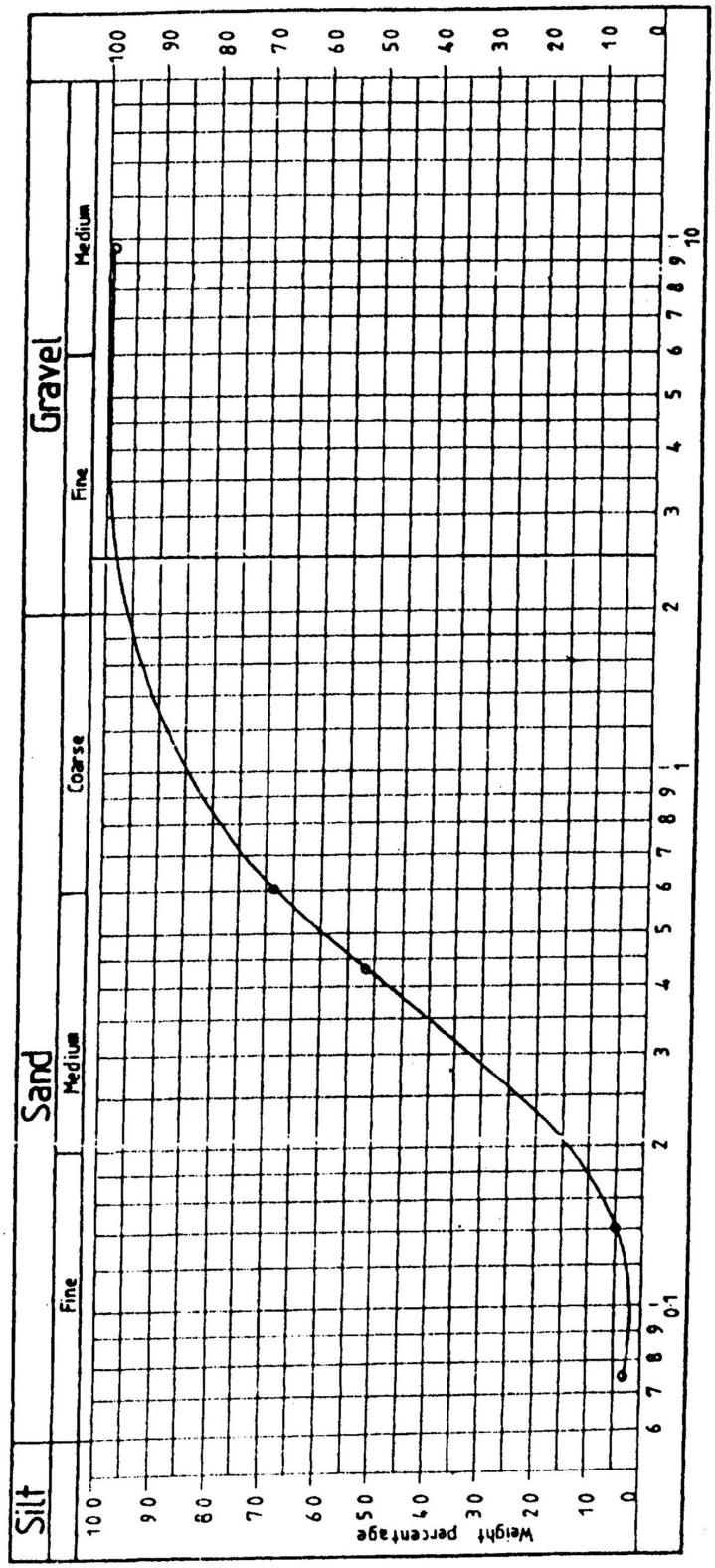


Fig. 5. Grain Size Analysis Curve for the Surface Dune Sand at the Site

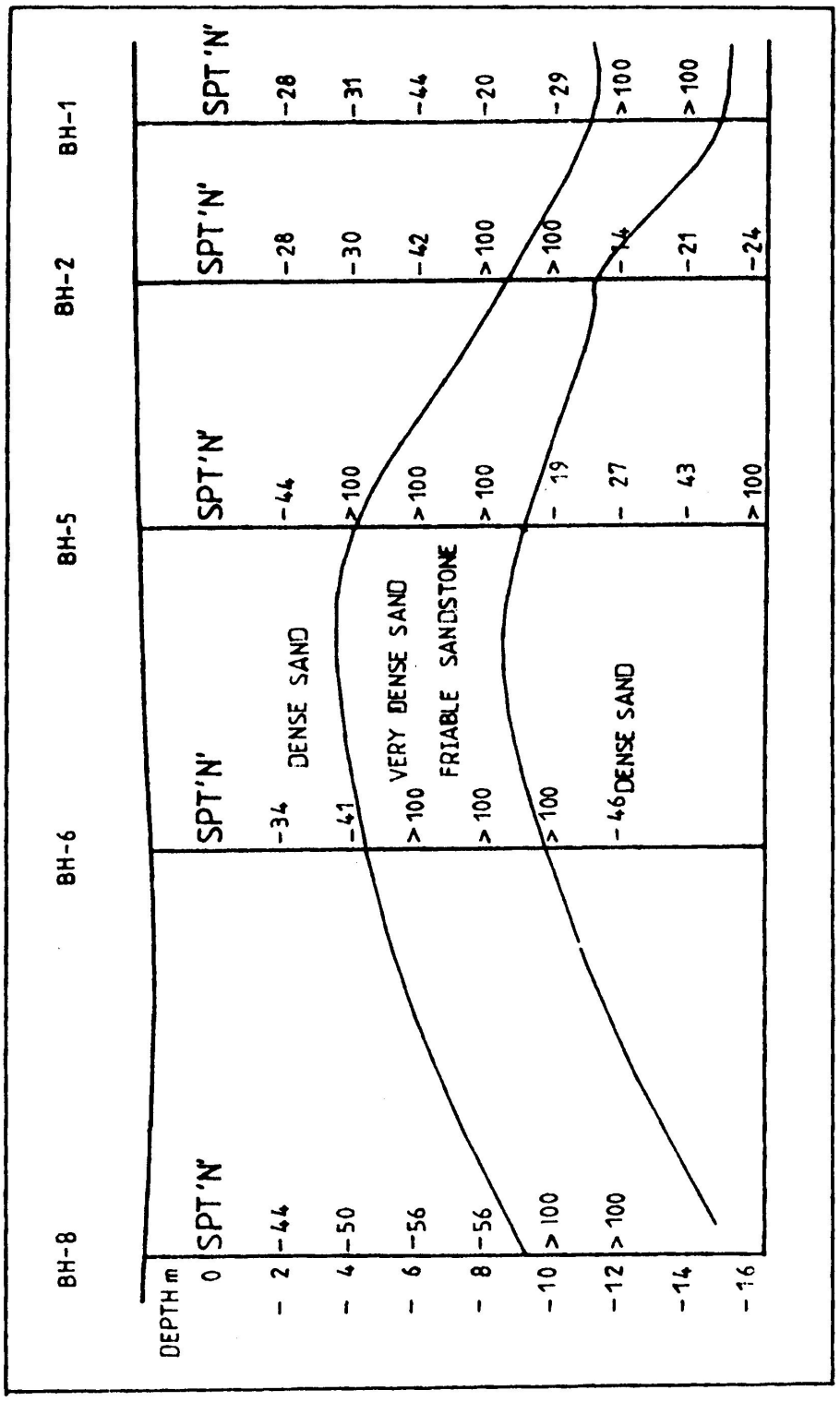


Fig. 6. Variations of SPT with Depths in Overburdened Deposits in Cross-section B to B′

depletion of 'Calc Minerals' with a flow of on-shore fresh acidic waters of low pH producing soluble bicarbonates.

In Sri Lanka two processes of lithification of dense sand are identified. One is siliceous sandstone and the other is $CaCO_3$ cementation. In this particular dense sand horizon in the absence of $CaCO_3$ the lithification is identified as siliceous.

The sandstones are not pure associations of silica sands, especially at a depth as shown in cross-section A-A'. The terminal horizons of cores in general have an association of 'lagoonal muds' and 'stiff clays'. A component of organic matter is also noted in these layers. This is identified by other authors as the Mannar sandstone with facies variations (Basnayake, 1986; Cooray, 1984). A pertinent conclusion here is that the sandstone depositional environment had been periodically disturbed under lagoonal or estuarine environments. These fluctuations could have been possible through sea-level variations during the Late Pleistocene Epoch. Identified sandstone levels of BH 1–7 can be correlated with several levels of sandstone reefs marked along the submerged peneplain of Sri Lanka (Somerville, 1907; Deraniyagala, 1958; Swan, 1983; Katupotha, 1994).

Sandstone with Lagoonal Mud

In 5 boreholes (out of 8), the sandstone is not pure, especially at depth of about 5-10 m below MSL. The mud fractions appear to be typical lagoonal clays, and in BH 2 a pure consolidated mudstone is seen at 10 m below MSL (cross-section B-B' in Fig. 4). This observation also indicates that the former sea level has fluctuated between shorelines and lagoonal environments. Drilling records of the northwestern coastal belt reveal that the sandstone becomes more silty towards the base and that it thickens and dips to the coast where it attains a thickness of over forty meters (Basnayake, 1986). The sandstone has a gradation contact with the overlying Miocene limestone referred to as the Venathavillu limestone within the basin.

In addition, calm water conditions prevailed in the marine/estuarine environments for the deposition of clays provided by the Quaternary fluvial systems, where the sandstone shows a complete mixture of sand and mud. The overlapping of marine and estuarine material can be inferred as Pleistocene deposits related to interglacial and glacial phases (Deraniyagala, 1958; Deraniyagala, 1992).

Miocene Limestone Belt

Drilling of the limestone basement at the project site shows areas of fresh clastic limestone with horizons of friable weathered limestone. Recovery of borehole cores indicates the following variations:

- Clastic fossiliferous limestone with core recovery.
- Sandy (siliceous) friable limestone with fissures.
- Limestone with patches of calcareous clay.
- Highly fractured limestone with cavities, resulting in heavy water losses during drilling.
- Thick horizons of weathered limestone with yellowish calcareous sludge recovery.

The above variability is not consistent with depth across the site, as observed from the logs of 8 boreholes. However, extremely high drilling water losses were observed at varying depths in karstic limestone, which indicate large cavities.

Within the profile in BH 2, a 1.56-m thick mudstone was core drilled at a depth of 61.69 m. This mudstone is highly compressed lagoonal mud with silty sand. The deep boreholes also established a minimum thickness of 63 m for the Miocene limestone bed in the Kalpitiya Peninsula.

The formations and epochs in the Cenozoic Era in Sri Lanka are given in Table 1. This Table indicates that the Quaternary deposits above the Miocene can be incorporated from Pleistocene to Holocene.

Petrographic Analysis of Limestone

Visual examinations of clastic limestone cores show fossils of shell, lamellibranchs, brachiopods and gastropods. These fossils are very similar to the fossil assemblages noted by Adams (1929), Wayland (1919), Krishnan (1982) and Cooray (1984) as Jaffna and Kudremalai Series in the north of Puttalam. Krishnan (1982) after a critical examination by several researchers has come to conclusion that the faunas of the Jaffna beds are not Upper Miocene. It is closely allied to that of the Upper Gaj bed (Lower Miocene). Preferably, the fauna of the study area can be included into Lower Miocene.

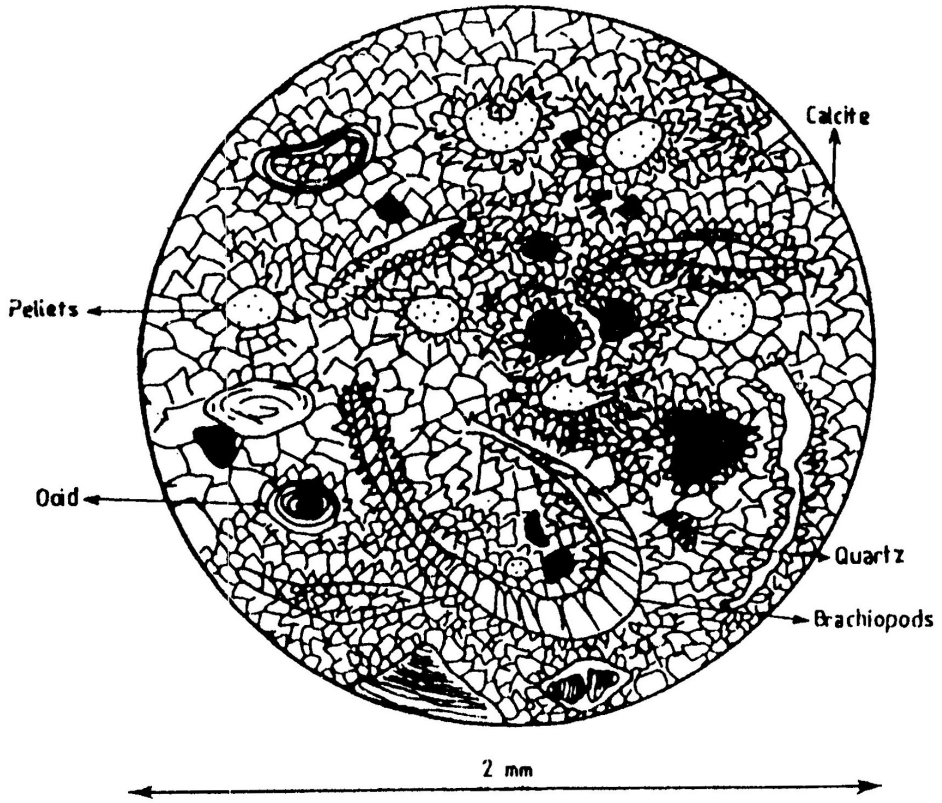
Four representative limestone samples were used to prepare thin sections for microscopic study. Three of the samples were classified as biosparite (sample 1, Fig. 7; sample 3, Fig. 9 and sample 4, Fig. 10), whereas the sample 2, Fig. 8 was bio-pelsparite.

TABLE 1: FORMATIONS AND EVENTS IN THE CENOZOIC ERA IN SRI LANKA

Era	*System*	*Epoch*	*Event/Formation*
PHANEROZOIC	TERTIARY	Holocene to present 0.01 m.y.	Post-glacial sea level rise, drowning the continental shelf. *Younger Group*—beach and dune deposits, lagoonal and estuarine clays, beachrock/sandstone, alluvium, buried and emerged coral reefs, beaches, lagoons formed
		Pleistocene 1.6 m.y.	Marked sea level fluctuations, submergence, canyons cut or developed. *Older Group*—Red beds, gravels, raised beaches and dune deposits, laterites, nodular ironstone
		Pliocene 2.0 - 5.0 m.y.	Uplift and erosion
		Miocene 5.0 - 22.0 m.y.	Limestone facies on northwest and north; arenaceous facies on southeast. Tectonic control of sedimentation with step faulting common. Submergence, separation from India

Source: Katupotha, 1994

BH - 01 DEPTH 27·0 - 28·0 m



Bioclast - 10 - 15 %
Pellets - 3 - 5 %.
Sparite - 60 - 75 %

Name - Biosparite

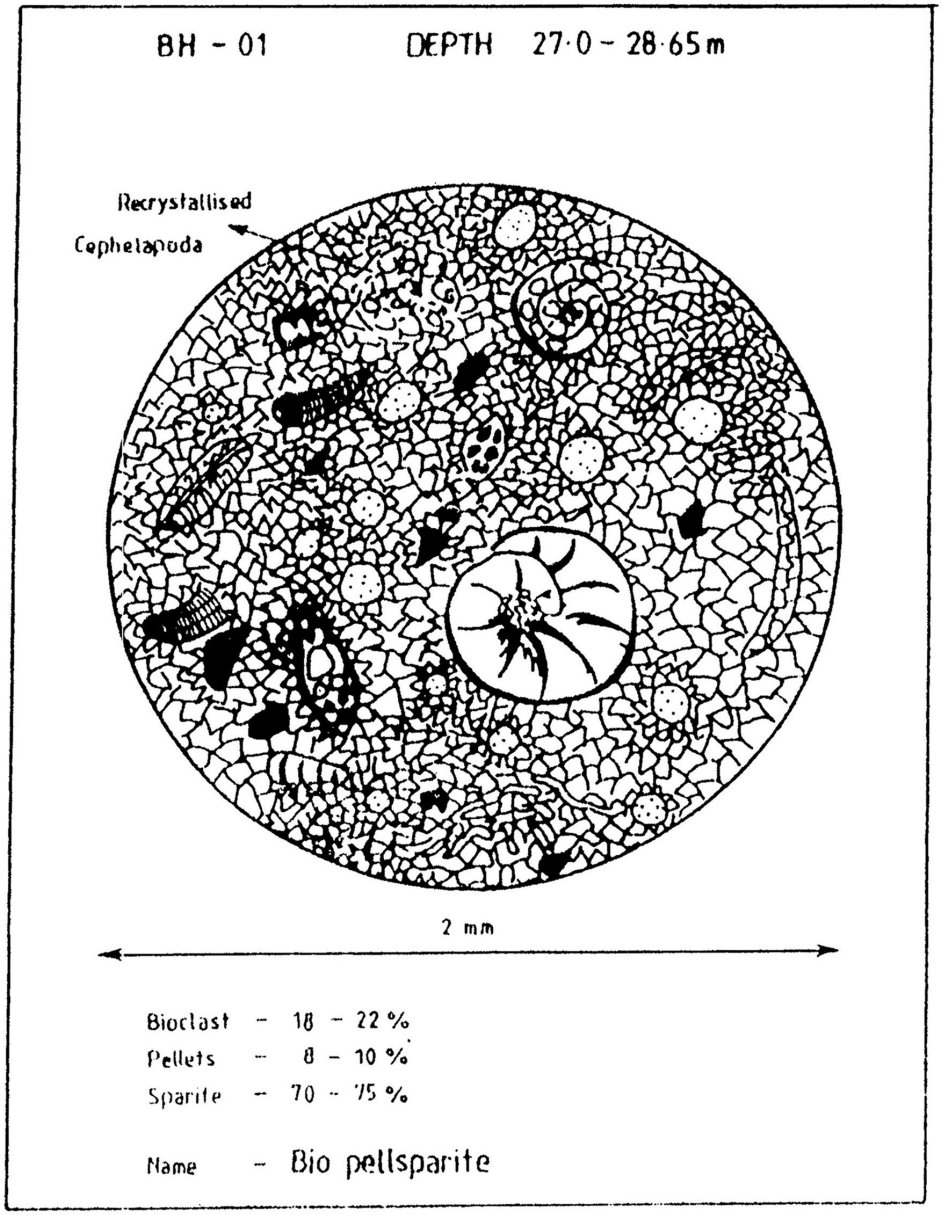


Fig. 8. Thin Section of Sample 2 at Depth 27.00 - 28.65 m in BH-1

Although the quartz content at a depth 20 m below MSL in BH 2 (sample 4) varies between 8 and 10 percent, the content of bioclast and sparite are not different at BH 1. This indicates that the northern Aruwakkalu limestone bed is continuous to the Kalpitiya area.

Miocene Limestone Belt

In this sector, an unconformity exists between the Miocene bed and the overlying Quaternary deposits, leaving an approximately 20 million-year hiatus in geological history of Sri Lanka. The cores of the boreholes reveal that the sandstone layer has been placed directly on the

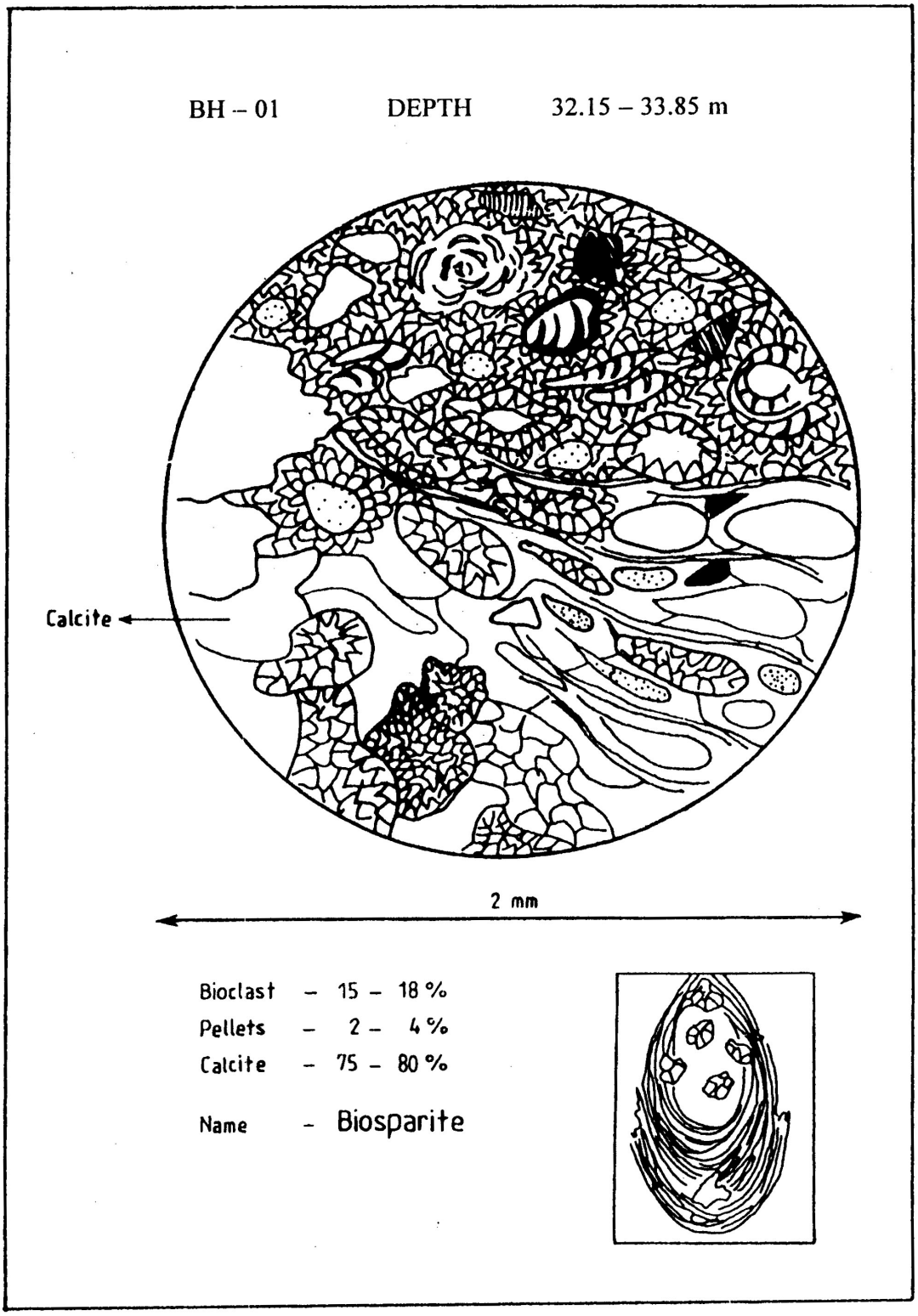


Fig. 9. Thin Section of Sample 3 at Depth 32.15-33.85 m in BH-1

Miocene limestone basement. In the absence of proper dating, it is relevant to observe that this sandstone can be either of Pliocene age or of the Quaternary. However the lowermost basement of 'Wanni Gneiss' was not encountered at 75 m below MSL.

In the geotechnical borings undertaken by the Foundation and Waterwell Engineering (Pvt) Ltd for the Road Development Authority in 1996, the 'Miocene limestone' bed was proved further south. The fossiliferous 'Miocene' limestone was encountered at depths of around 21 m in the area of the Muthupanthiya lagoon, which is south of Mundal Lake. The Miocene limestone basement is a proven lithological entity, which engulfs the entire Jaffna peninsula and terminates southwards along the coast near Puttalam. This is noted in updated geological maps. Accordingly, a revision for a southern extension of this belt is necessary, which is deep seated below the Quaternary. It is possible that this extension can be up to the mouth of the Deduru Oya river.

Conclusions

The borehole investigations and studies on samples have revealed the following:

- The near surface horizon is a well graded quartz sand, which is of aeolian origin, where the dominant fraction is medium grained.
- The aeolian sand grades into dense sand at depth due to packing of different grain sizes, along with possible siliceous concentration as observed from cores.
- Within the dense sand, consolidated friable sandstone beds exist, which have 'N' values > 100.
- The dense sands/sandstones is directly followed by the Miocene limestone, which is karstic and fossiliferous.
- The Miocene limestone bed is continuous to a thickness of more than 60 m. The unconformity in depth between this Miocene limestone and the basement Precambrian gneiss is unknown.
- Within the Miocene bed there are patches of mudstone and hard clay. They indicate lagoonal/estuarine conditions interrupting the limestone deposition cycles.
- When considering the thickness of the limestone bed at site, it is clearly indicated that this bed extends further south.

The above data and information collected in this investigation clearly suggests the following conclusions:

In the near surface windblown sands, at depth siliceous consolidation is observed in this Quaternary formation. Below this Quaternary formation a sequence of subsequent deposits are not found down to the Miocene limestone basement. Accordingly an unconformity exists at the Miocene limestone basement.

The Miocene basement at depth in this investigation known to outcrop further north along the coastal belt, as in Puttalam, Manar and Jaffna, which again show shallow Quaternary deposits surrounding such outcrops (Wayland, 1919; Adams, 1929; Deraniyagala, 1958; Cooray, 1984; Deraniyagala, 1992). Conversely towards to southern coastal belt the Miocene limestone formation was proved at a depth of about 21 m MSL at Muthupantiya Lagoon.

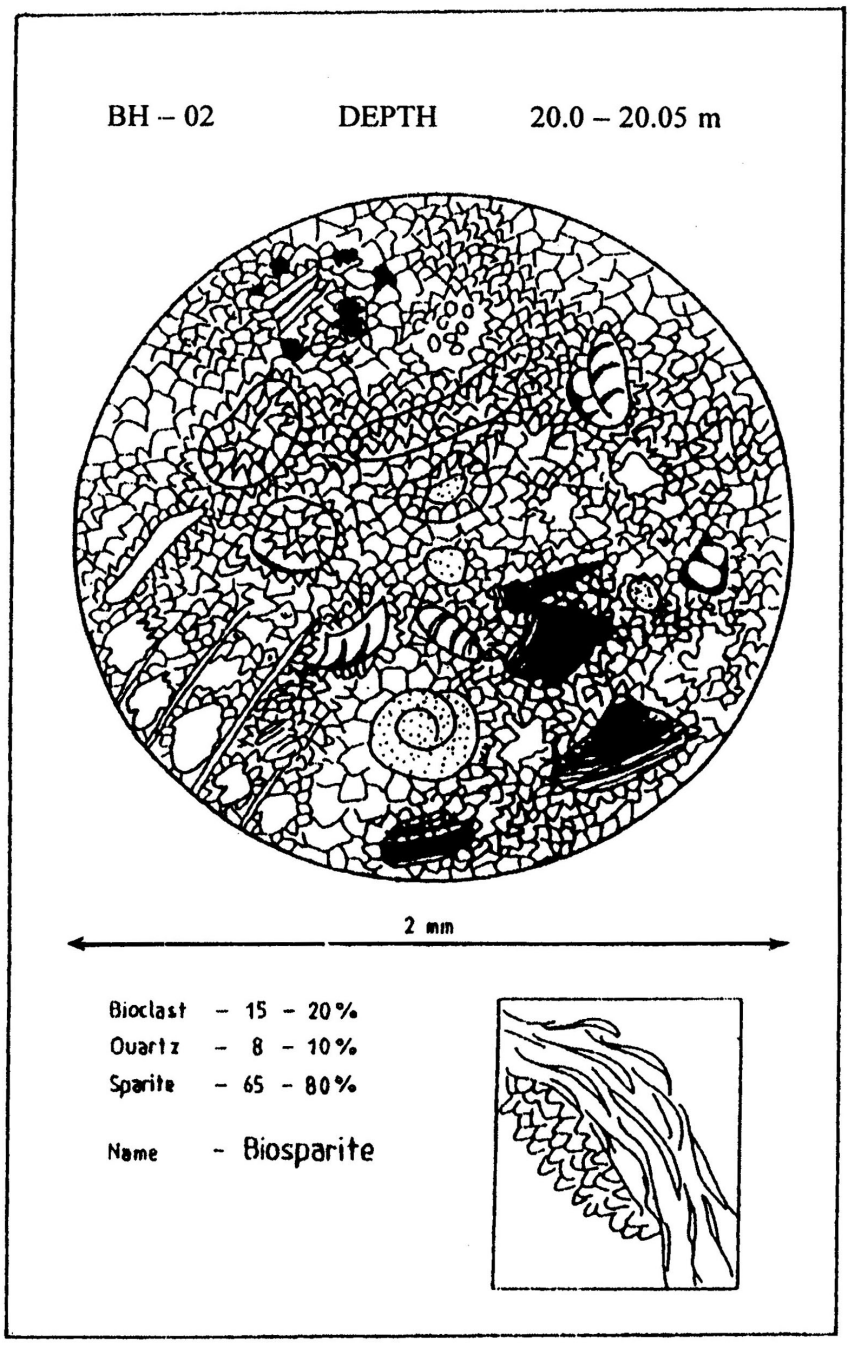


Fig. 10. Thin Section of Sample 4 at Depth 20.00 - 20.05 m in BH-2

This gives a clear indication that along the western coastal belt the Miocene basement profile dips from north to south.

The limestone itself being drilled to a thickness of 60 m has shown patches of mudstone and hard clay within the cores. Therefore, it is inferred that during the Miocene period sea level fluctuations would have occurred intermittently to promote terrestrial depositions.

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