Quaternary diatomaceous sediments and the geological evolution of lakes, Turkana, Baringo and Bogoria Kenya Rift Valley.

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QUATERNARY DIATOMACEOUS SEDIMENTS AND THE GEOLOGICAL EVOLUTION OF LAKES TURKANA, BARINGO AND BOGORIA, KENYA RIFT VALLEY

by

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Thesis presented for the degree of Ph.D. in the University of London


DIATOMITE - A SILT COMPOSED OF THE SILICA
SHELLS OF COUNTLESS MICROSCOPIC
PLANTS THAT LIVE IN WATER. THE DIATOMS
ARE VERY SMALL BUT UNDER FAVOURABLE
CONDITIONS THEY MAY MULTIPLY EXTREMELY
RAPIDLY. THE SHELLS OF DEAD DIATOMS
SINK TO THE BOTTOM AND ACCUMULATE
THERE. PURE DIATOMITES SUCH AS THE ONE
SEEN HERE FORM ONLY UNDER STILL
DEEP WATER.
ALL THE SILTS SEEN ALONG THIS PATH
WERE LAID DOWN UNDER STANDING LAKE
WATERS. BANDS OF GREY VOLCANIC ASH
REPRESENTING EXPLOSIVE ERUPTIONS CAN
ALSO BE SEEN.

ABSTRACT

Quaternary diatomaceous sediments and the geological evolution of Lakes Turkana, Baringo and Bogoria, Kenya Rift Valley.

R.B. Owen

Quaternary lacustrine sediments are described from three contrasting areas within the Kenya Rift Valley. Descriptions are given of the mid-Pleistocene Olorgesailie Formation at Olorgesailie (southern Kenya Rift Valley), a series of lacustrine sediments deposited between the mid-Miocene and present in the Baringo District (central Kenya Rift Valley) and finally of Quaternary (largely Holocene) deposits at East Turkana (northern Kenya Rift Valley). A wide range of environments are represented by these deposits including offshore and littoral lacustrine, deltaic and alluvial situations. Emphasis is placed on the examination of lacustrine and lake marginal sediments.

Diatom assemblages found in these deposits are described for the first time. These have been studied using optical and scanning electron microscopy. The relationships between diatom assemblages and sedimentary facies are examined and evolutionary trends in certain diatoms are discussed. The contemporary ecology of diatoms at East Turkana is discussed and a review is given of diatom ecology and lake classification in East Africa. Diatoms are used to indicate transgression-regression cycles during the Holocene, and palaeoecological conditions through the Quaternary. Mapping in conjunction with some altimetric data is used to indicate the location, extent and height of several Holocene lacustrine still-stands.

Geochemical and sedimentological data is presented for the Holocene deposits at East Turkana and in the Baringo District. Several erosional and depositional processes operating at East Turkana are briefly discussed. A classification of Holocene environments at East Turkana is presented.

The palaeogeography of the northern Kenya Rift Valley and the development of diatom floras during the Holocene is discussed. Data presented here and in the literature is considered and reviewed from a palaeoclimatic viewpoint. The development of Lakes Turkana, Baringo and Bogoria through the Quaternary are also considered.

Conclusions are drawn as to the value of diatoms in palaeoecology and stratigraphy.

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PART I

GENERAL INTRODUCTION

CHAPTER 1

INTRODUCTION TO THE THEMES, METHODS AND STUDY AREAS

1(i) The scope and objectives of this thesis

This thesis concerns Holocene and Quaternary sedimentary basins in the Kenya Rift. Three contrasting basins are described, all of which contain diatomaceous sediments. The three basin are as follows (fig. 1.1).

1. The East Turkana basin.
   This basin lies in a complex faulted basin outside the main Rift, and between Kenyan and Ethiopian Domes. The structure is known as the Turkana depression. The deposits formed on the margins of a large fluctuating lake.

2. The Baringo basin.
   This lies within the main Kenya Rift. The deposits were formed in lakes separated both in time and space, during the Miocene to Pleistocene. Quaternary sediments occur in much the same area as modern Lakes Baringo and Bogoria. The deposits have been strongly influenced by tectonism and volcanism.

3. Olorgesailie.
   Middle Pleistocene graben sediments have formed at Olorgesailie (southern Kenya Rift). These deposits contrast with those of 1 and 2 above.

The Holocene sediments, which form the bulk of this thesis, have previously received little attention. In contrast, the older deposits have been intensively studied.

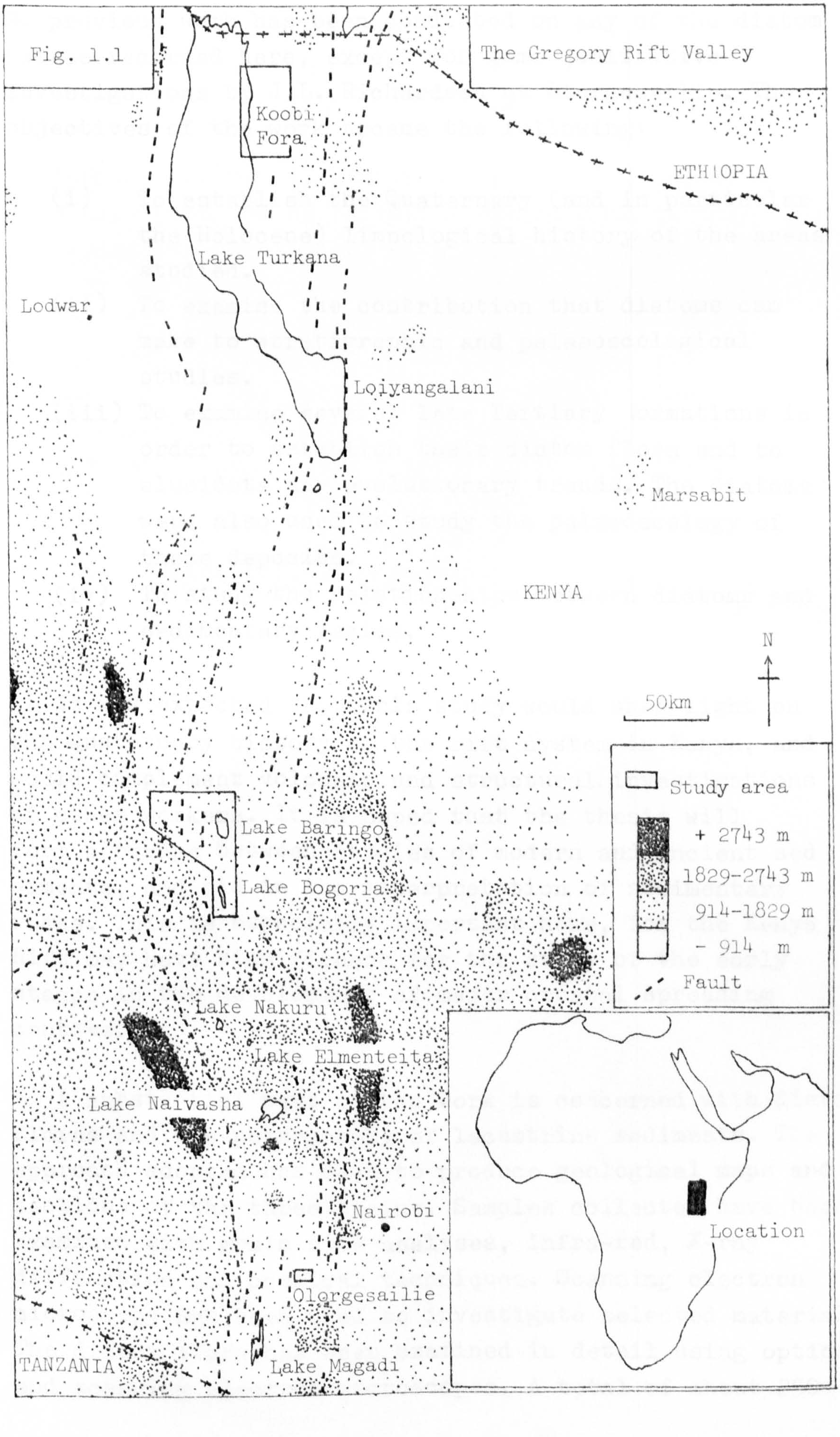


Fig. 1.1 The Gregory Rift Valley

No previous work has been conducted on any of the diatom floras recorded here, except for some qualitative investigations by J.L. Richardson at Olorgesailie. The objectives of the work became the following:

(i) To establish the Quaternary (and in particular the Holocene) limnological history of the areas studied.

(ii) To examine the contribution that diatoms can make to stratigraphic and palaeoecological studies.

(iii) To examine several late Tertiary formations in order to establish their diatom flora and to elucidate any evolutionary trends. The diatoms were also used to study the palaeoecology of these deposits.

(iv) To study the relationships between diatoms and sedimentary facies.

It was expected that this study would shed light on the Quaternary history of the rift system in Kenya, and would complement volcanic and structural investigations of other workers. It is hoped that the thesis will form a bridge between studies of modern and ancient sed -iments, and aid in the interpretation of sedimentary rocks. This is especially important here, for the Kenya Rift may have significance for the study of the early stages in the development of major crustal spreading centres.

A substantial part of the work is concerned with diatom floras and the petrography of lacustrine sediments. The approach adopted has been to produce geological maps and sections of the three basins. Samples collected have been examined with grain size analyses, infra-red, X-ray diffraction and chemical techniques. Scanning electron microscopy has been used to investigate selected material. The diatom flora has been examined in detail using optical and scanning electron microscopes. A total of about 250 species have been identified (see appendices). The role of diatoms in forming sediment has been studied, along with more formal aspects of the floral assemblages.

Mapping was based on stereoscopic aerial photos and base maps produced by earlier workers. Much of the surveying was carried out at a scale of 1:24,000. The geology was established by the detailed examination of selected traverses. Fieldwork occupied about 25 weeks, most of which was spent under canvas with the cooperation of the National Museum of Kenya. Some 14 weeks were taken up at East Turkana, 8 weeks at Lakes Baringo and Bogoria, and 3 weeks at Olorgesailie. The structure of this thesis is based on the description of these three individual basins and a resume of each is given in the following sections.

1(ii) The geography of the East Turkana basin

Lake Turkana (240 km long, 50 km wide) is a large body of alkaline water within a basin of inland drainage in northern Kenya (fig. 1.1). Formerly the lake was much larger and at several times it has formed one part of the Nile drainage system. The lake was discovered in 1888 by Count Teleki, and named Lake Rudolf after the Crown Prince of Austria. This was changed in 1975 by a decree of the Kenyan Government to Lake Turkana, after the tribe who occupy its western and southern shores. The eastern side, between Loiyangalani and Allia Bay, is thinly populated by the Rendille, while the El Molo tribe, who specialise in fishing, occupy the south-eastern shoreline. Prior to 1968, the Gabra tribe made use of grazing between Allia Bay and Koobi Fora. The area north of Koobi Fora used to be inhabited by the Dassenetch (locally known as the Shangilla). Human occupation was effectively removed from East Turkana (strictly speaking the area to the north east of the lake) by the creation of a National Park in 1972. The Dassenetch are now concentrated in the extreme north of East Turkana, at Ileret. They herd sheep, goats and cattle. Wildlife is abundant and includes lion,cheetah,topi, gerunuk, gazelles and snakes such as sand vipers.

Rainfall is low over the whole area, decreasing with altitude. This, combined with very high temperatures throughout the year (shade temperatures of 43°C are common) has reduced the region to a semi-desert. Climatic data within the area are scarce, but information from other parts of the lake are shown in table 1.1. Maximum rainfall on high ground is about 500 mm/annum, but this decreases rapidly with falling altitude. Most of the rain is concentrated into two seasons. One from March to June, peaking in April and the other from October to December with a slight maximum in October. For most of the year an easterly wind prevails. This is particularly strong near the lake shore. The wind commences after sunset and

Table 1.1 Lake Turkana climatic data.

Climatic observations in the Omo Basin, 1968. (after Butzer, 1971)

	Temperatures (°C)					Rain	Humidity %			Wind speed Km./hr.		
	max.	min.	7	14	21	mm.	7	14	21	7	14	21
June 11-22	-	-	25	34	27	-	65	39	57	5	11	2
June 23-30	-	-	25	35	28	-	60	36	46	7	8	3
July	39	22	24	36	29	9	62	33	47	7	10	2
Aug.	40	23	26	37	29	0	57	29	48	9	8	6

The data is rounded off to the nearest degree.
The number 7 refers to 7 a.m., 14 to 2 p.m. and 21 to 9 p.m..

Climatic observations from the western shore of Lake Turkana. (after Walsch and Dodson, 1969)

Station	Total Rainfall (mm.)				Yearly average and number of years recorded
	1959	1960	1961	1962	
Lodwar	305	124	497	200	165 (37)
Ferguson's Gulf	320	107	505	203	221 (9)
Lokitaung	345	251	899	314	398 (26)
Todenyang	NR	12	NR	482	193 (9)
Lokichogio	470	401	955	363	523 (8)

NR - Not recorded
Original data in inches was rounded off during conversion

continues until the following noon, after which a dead calm prevails for several hours.

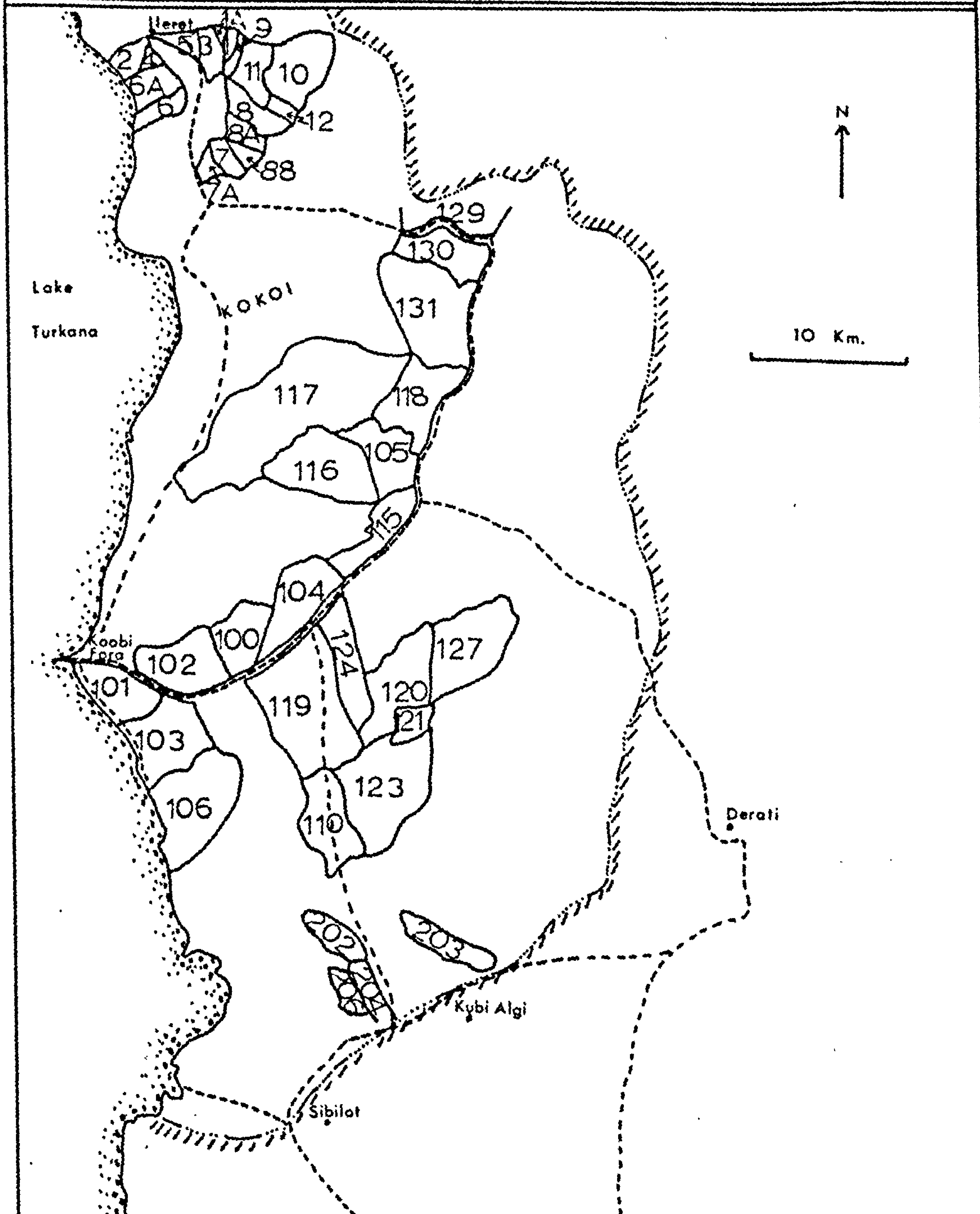
Acacia thorn scrub (particularly common on the Holocene sediments) is ubiquitous, with larger trees occurring along river courses. Doum palms are common along the ephemeral sand rivers and at oases (eg. Derati). Spike rush and sedges are found in shallow water along the lake margin.

Access to the area is via two main routes. It is possible to reach Isiolo on a tarmac-surfaced road from Nairobi. From here a dirt track road extends 120 km north to Marsabit, and for another 100 km to North Horr. From here conditions become more difficult until Allia Bay is reached after a further 70 km. Several possible routes may then be used to cross East Turkana (fig. 1.2). A second approach runs from Maralal to Loiyangalani at the south-east end of the lake. Northwards this road connects with that from North Horr. Several dirt tracks cross East Turkana, but these are widely spaced and traverse difficult terrain. It is not uncommon for a Landrover to become trapped in one of the many ephemeral sand-rivers. A number of the roads are boulder strewn or impassable in rain. It is often necessary to make 'new roads' in order to get to field localities. Much of the work was conducted from a permanent base camp at Koobi Fora. Several temporary camps were set up in order to save petrol (a scarce commodity). This also allowed one to work during the cooler hours rather than spending this time in driving.

The large geographic extent of the region necessitated the designation of a system of locality references by the 'Koobi Fora Research Project' team. The areas that they recognised are shown in figure 1.2, and have been adopted in this study.

Lake Turkana is shown at a scale of 1:1,000,000 on

Fig. 1.2
Area Numbers in use in the East Turkana Sedimentary Basin



KEY

Approximate Boundary of the Basin

Road

Area number

the SK.41 Kenya (north) sheet. East Turkana lies on sheets NA-37-1 and NB-37-13 of series Y503 (edition 2-SK) at a scale of 1:250,000. For more detailed work a 1:100, 000 scale is available on sheets 5 and 13 of series Y6333. These maps contain only rough form lines. Aerial photographs were obtained from Hunting Surveys Ltd. with the permission of R.E.F. Leakey. These date from 1970 and are at a scale of 1:24,000.

A physiographic map of East Turkana is presented in figure 1.3. Several landscape elements can be recognised.

(i) The surrounding mountains.

The high ground which surrounds East Turkana rarely exceeds 1000 m, but includes several distinct peaks (plate 1.1): Shin, Derati, Kubi Algi, Sibilot and Jarigole. These highlands are composed mainly of Miocene basalts.

(ii) The Kokoi uplands.

These are formed of a north east to south west trending upthrown fault block, consisting of Pliocene basalts and lacustrine sediments. They lie in the centre of the East Turkana basin.

(iii) The Bakate Gap.

This is an erosional feature to the north east of the basin and was cut by rivers flowing from Lake Chew Bahir. During the Pliocene and Pleistocene much sediment was introduced to East Turkana via this route (Findlater, 1976).

(iv) The ridges and cuestas.

The Koobi Fora Ridge is a north east to south west trending feature forming a topographic high with steep northerly-facing slopes. Eastwards it merges with higher ground and the Karari Ridge. In the extreme north is a north to south trending upland region known as the Chari Ridge. The

Fig. 1.3 Prominent physiographical features at East Turkana

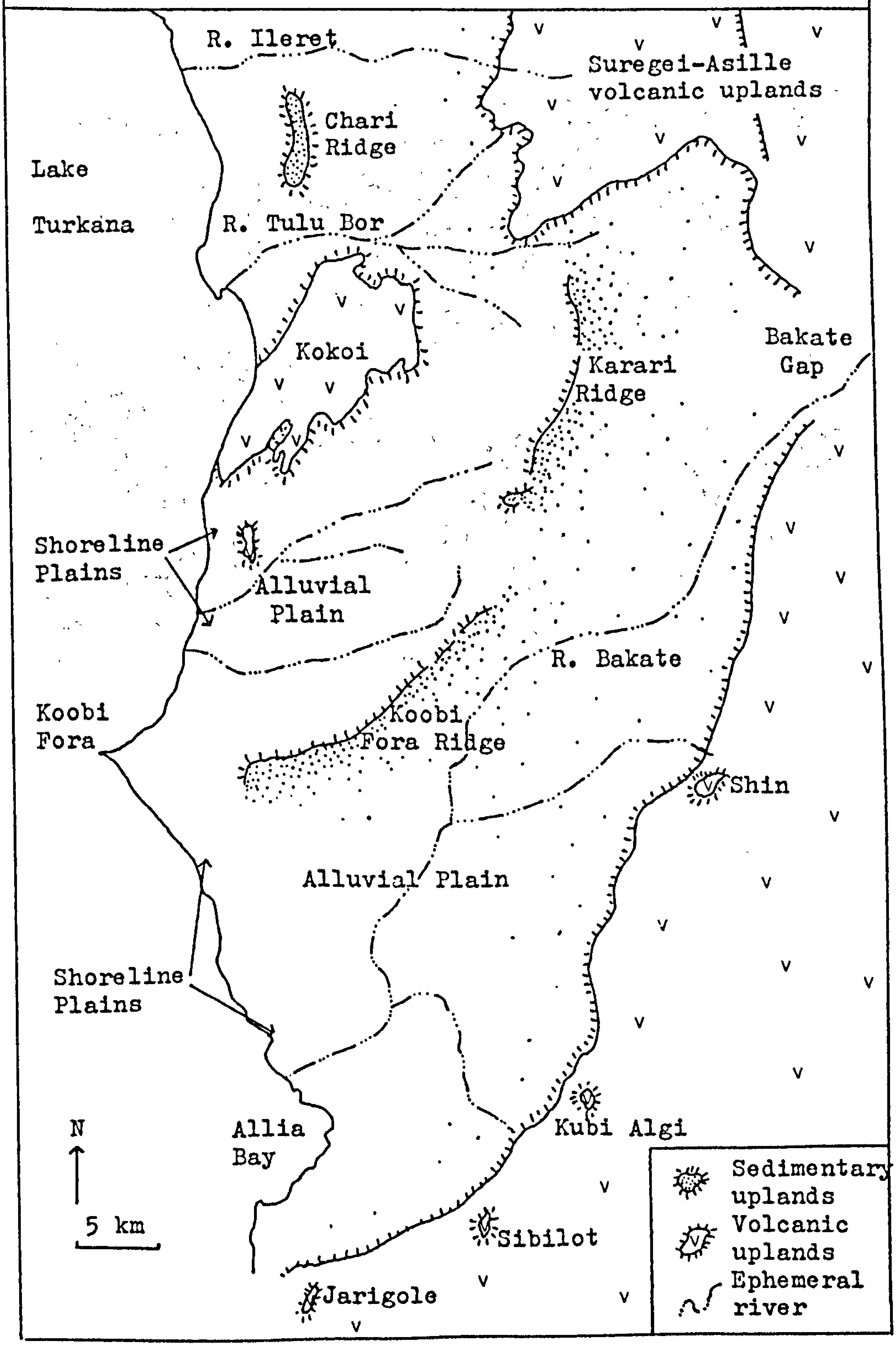


Plate 1.1

East Turkana. Semi-desert Acacia scrub can be seen sitting on Pleistocene sediments (lighter patches are Holocene sands). The distant mountains (the highest in the photograph is called Shin) are composed of Miocene and Pliocene volcanics.

Suregai Cuesta forms part of the eastern margin of the basin and consists of interbedded basalts, palaeosols and sediments (Bowen & Vondra, 1973).

(v) The alluvial plains.

These are aligned along major rivers such as the Bakate, Tulu Borr and Ileret. The only perennial river entering the northern part of Lake Turkana is the Omo, which lies at its northern extremity and outside East Turkana. The rivers at East Turkana are ephemeral in character.

(vi) The shoreline plains.

These form a narrow zone adjacent to the lake and consist of recently deposited beach sediments.

1(iii) Background to the late Quaternary geology of Lake Turkana

1(iii)a History of research

Prior to 1968 the major source of palaeontological and geological data for East Turkana was a report of Teleki and Von Hohnel's expedition in 1888, during which the lake was dicovered (Von Hohnel, 1894). Von Hohnel collected invertebrate fossils and rock specimens and noted the presence of beach ridges and lavas near the lake. V.E. Fuchs made two trips to the lake, and dèscribed the sediments in three papers (1934, 1935, 1939). The National Museum of Kenya organised expeditions to East Turkana in 1968 and 1969. An intensive research effort resulting from these and follow-up studies lead to the publication of a series of papers. Those dealing with the geology of the area include: Behrensmeyer (1970, 1973, 1975), Bowen (1974), Bowen and Vondra (1973), Cerling (1979), Findlater (1978), Johnson (1974) and Vondra, Johnson, Bowen and Behrensmeyer (1971). These studies were mainly concerned with the Pliocene and Pleistocene deposits and for the most part ignored the Holocene.

There are numerous reports dealing with other parts of the lake. Prominent amongst these are: Arambourg (1934, 1935, 1939), Butzer and Thurber (1969), Dixey (1944, 1948), Dodson (1963) and Walsh and Dodson (1969). Yuretich (1979) describes the modern sediments and depositional processes operating in Lake Turkana.

1(iii)b The late Quaternary sediments around the lake

The geological structure of the Lake Turkana basin is related to the Gregory Rift and the Ethiopian and Kenyan domes. These domes are of disputed origin, but may represent large upwarps of continental crust extending over hundreds of kilometres. The Kenya dome, to the south of Lake Turkana, is crossed by the faults of the Gregory Rift. The Ethiopian Rift extends this structure across the Ethiopian dome. The Gregory Rift broadens and becomes less well defined northwards, and in doing so opens into the Turkana basin. To the north, the Turkana basin passes into the more clearly defined Ethiopian Rift. East of the Turkana depression, a recently active rift and swell structure passes through the southern end of Lake Turkana and extends to Lake Chew Bahir.

Late Quaternary sediments surround Lake Turkana and are well exposed. A map showing the distribution of these deposits is available at the back of this thesis. The sediments are briefly described in the following paragraphs.

To the north of Lake Turkana lies a north to south linear depression known as the Omo basin. Sediments of Pliocene to Holocene age crop out here (table 1.2). Deltaic and littoral Holocene deposits are represented by Members IVa and IVb of the Kibish Formation and by the Lobuni Beds (Butzer, Brown & Thurber, 1969). These sediments were formed during periods of high lake level. Episodes of lower lake level have been inferred from periods of non-deposition. Such periods are reported between 37,000 and 9,500 yr. B.P., 7900 and 5750 yr. B.P., and from 5,450 yr. B.P. until Lobuni Bed sedimentation. The Lobuni Beds are alluvial, deltaic and littoral deposits laid down during the last two millenia (Butzer and Thurber, 1969).

Quaternary sediments to the west of the lake have received less attention. A series of 'levels' above the modern lake were recognised by Walsh and Dodson (1969). These were interpreted as representing former lake levels, and have been identified at various elevations between 380 and 480 m O.D.. A distinct level at <u>ca</u>. 445 m seems to be of Holocene age. The sediments which make up this level are characterised by considerable lateral facies

Table 1.2

The late Cenozoic stratigraphy of the lower Omo basin

Epoch	Unit	Formation
Holocene	Lobuni Beds	
	M. IVb	Kibish Formation
	M. IVa	Kibish Formation
Middle to Upper Pleistocene	Nakwa extrusions	Kibish Formation
	M. III	Kibish Formation
	M. II	Kibish Formation
	M. I	Kibish Formation
Pliocene & Pleistocene	Faulting in type area	
	Shunguru & Usno Formations	
	M. III	Nkalabong Formation
	M. II	Nkalabong Formation
	M. I	Nkalabong Formation
	Faulting	
	M. IV	Mursi Formation
	M. I-III	Mursi Formation
	Downwarping and faulting	
Lower Pliocene & Miocene	Volcanics	

Based on Butzer and Thurber, 1969

variation. A 380 m level is a beach ridge only a few decades old, whilst many of the other surfaces indicate different Pleistocene stages.

Lacustrine sediments are less extensive at the south end of Lake Turkana. Dodson reports a 445 m level at Nakwamosin (table 1.3). Although he considered it to be upper Pleistocene, it may well prove to be Holocene. To the south of the lake lies the Suguta graben, which Fuchs thought to have formerly contained a southerly extension of Lake Turkana. Today it is arid and separated from the lake by the 'Barrier Volcanic Complex'. Truckle (1976) suggested a separate 'Lake Suguta' existed during the early Holocene. Holocene sediments have been described from the south-eastern shores of Lake Turkana, near Loiyangalani, by Phillipson (1978).

East Turkana itself forms a large sedimentary basin to the north-east of the lake. This basin extends some 40 to 50 km from north to south by 30 km from east to west. Its northern limit is marked by the border between Kenya and Ethiopia. Miocene basalts lie to the east and south, while the lake shore forms an effective western boundary. This area has been subject to inundation by Lake Turkana several times since the Pliocene.

The East Turkana basin is split by the Kokoi and Suregai plateaux. Holocene sediments sit with pronounced unconformity on Plio-Pleistocene deposits in the southern, Koobi Fora and Kubi Algi areas (table 1.4). In the northerly Ileret region they rest on the middle Pleistocene Guomde Formation (Findlater, 1978). The Holocene Galana Boi sediments show rapid facies variation reflecting their origin as littoral and offshore lake deposits. They include quartz and feldspar-rich sands and silts, diatomites and coquinas. Algal stromatolites are locally important.

Table 1.3

445 m - level sediments at Nakwamosin, S.E. Lake Turkana

SEDIMENTS	THICKNESS feet	THICKNESS inches
Patchy overburden of ashy soil..................		
5 White diatomite................................	5-11	
4 Grey diatomaceous layer with dark coarser-grained sandy lenses along the upper and lower edges. Fossil fish vertebra and dorsal spines: <u>Lates niloticus</u>, <u>Clarius sp.</u> ...	1½-2½	
3 Shelly limestone, composed of shells cemented in a greyish calcareous matrix........	1½-2½	
Fossils: <u>Melanoides tuberculata</u>, <u>Corbicula africana</u>, <u>Corbicula consobrina</u> (?), <u>Etheria elliptica</u>, <u>Mutela nilotica</u>, <u>Mutela iridina</u> (?), <u>Mutela truncana</u>		
2 Whitish conglomeratic bed composed of lava pebbles cemented in a calcareous matrix........		0-10
Fossils: <u>Melanoides tuberculata</u>, <u>Corbicula africana</u>		
1 Pale grey ashy sediment........................	4	
Fossils: <u>Melanoides tuberculata</u>, <u>Corbicula africana</u>, <u>Etheria elliptica</u>		

after Dodson, 1963

Table 1.4

Late Cenozoic sedimentation in the East Turkana basin

	Ileret area	Koobi Fora area	Kubi Algi area
Holocene	Galana Boi Formation (10m)	Galana Boi Formation (30m)	Thin remnants of Galana Boi
Middle Pleistocene	Guomde Formation (45m)		
Plio-Pleistocene	Koobi Fora Formation (150m)	Koobi Fora Formation (170m)	Lower Koobi Fora Formation (70m+)
Pliocene	Kubi Algi Formation (20m)	Kubi Algi Formation (20m+)	Kubi Algi Formation (80m+)

Based on Bowen & Vondra, 1972

1(iv) The geography of the Baringo district

The Baringo district lies within the Gregory Rift some 160 km to the south of Lake Turkana. It extends 70 km from north to south by 50 km from east to west.

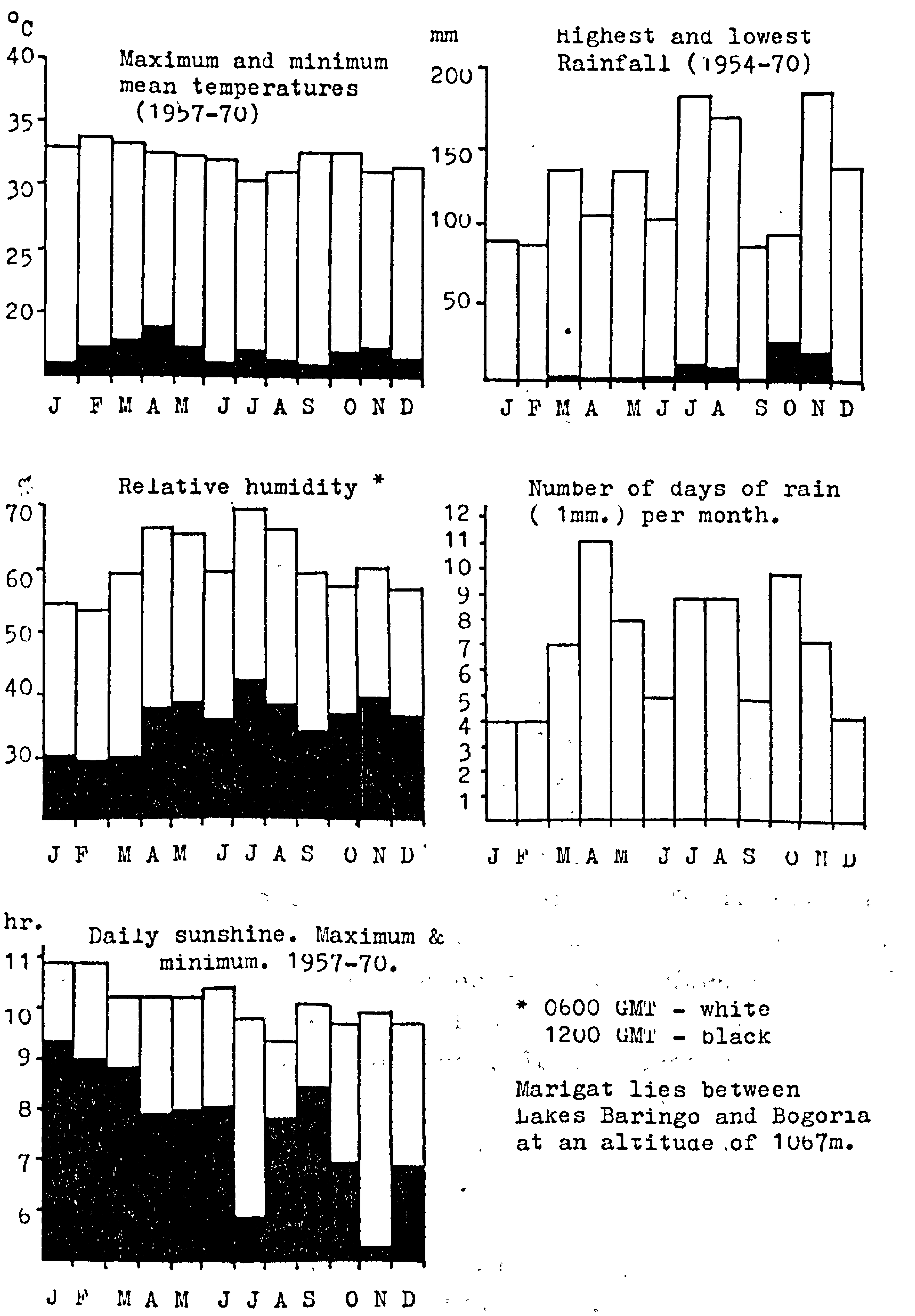
This investigation involved the sampling of mostly type sections, from several different sedimentary units. Much of the work was conducted from temporary camps at the localities, whilst most of the equipment and supplies were kept at a base camp by the shores of Lake Baringo.

The area is populated by several tribes. The Pokot inhabit the northern regions. These semi-nomadic people were involved in tribal fighting with the Turkana during the first field season. The latter live to the north of the study area. Herding of cattle and goats forms the main occupation of the Tugen, who inhabit the Kamasia Hills (part of which are named after them). The Njemps tribe live in the area around Logumukum to the south-east of Lake Baringo, and in the northern parts of the Ngelesha reserve.

Climate varies depending on location. On the shoulders of the Rift and in the Tugen Hills, rainfall is high but declines rapidly with falling height. Around Lake Baringo (ca. 967 m O.D.) it is usually less than 750 mm/annum. Rainfall may vary widely from month to month, and from year to year. The rains normally fall as short-lived, heavy downpours which often give rise to flashfloods. Precipitation is heavier in two seasons, one from March to August (peaking in July), and the other from October to December. Shade temperatures vary with altitude, but average 25 to 33°C throughout most of the year at Lake Baringo. Climatic data are presented for Marigat (south-west of Lake Baringo) in figure 1.4.

Vegetation varies rapidly with height. At the lowest levels Acacia thorn scrub dominates. At higher altitudes

Fig. 1.4 Lake Baringo climatic data, Marigat station



this becomes denser and eventually gives way to luxuriant montane forest. Reeds are common in the littoral zones of Lakes Baringo and Bogoria. Nile cabbage is presently choking the waters of the Molo Delta, at the southern end of Lake Baringo. Extensive papyrus swamps lie between the two lakes. Cash crops are being cultivated near Marigat by the Perkerra Irrigation Scheme.

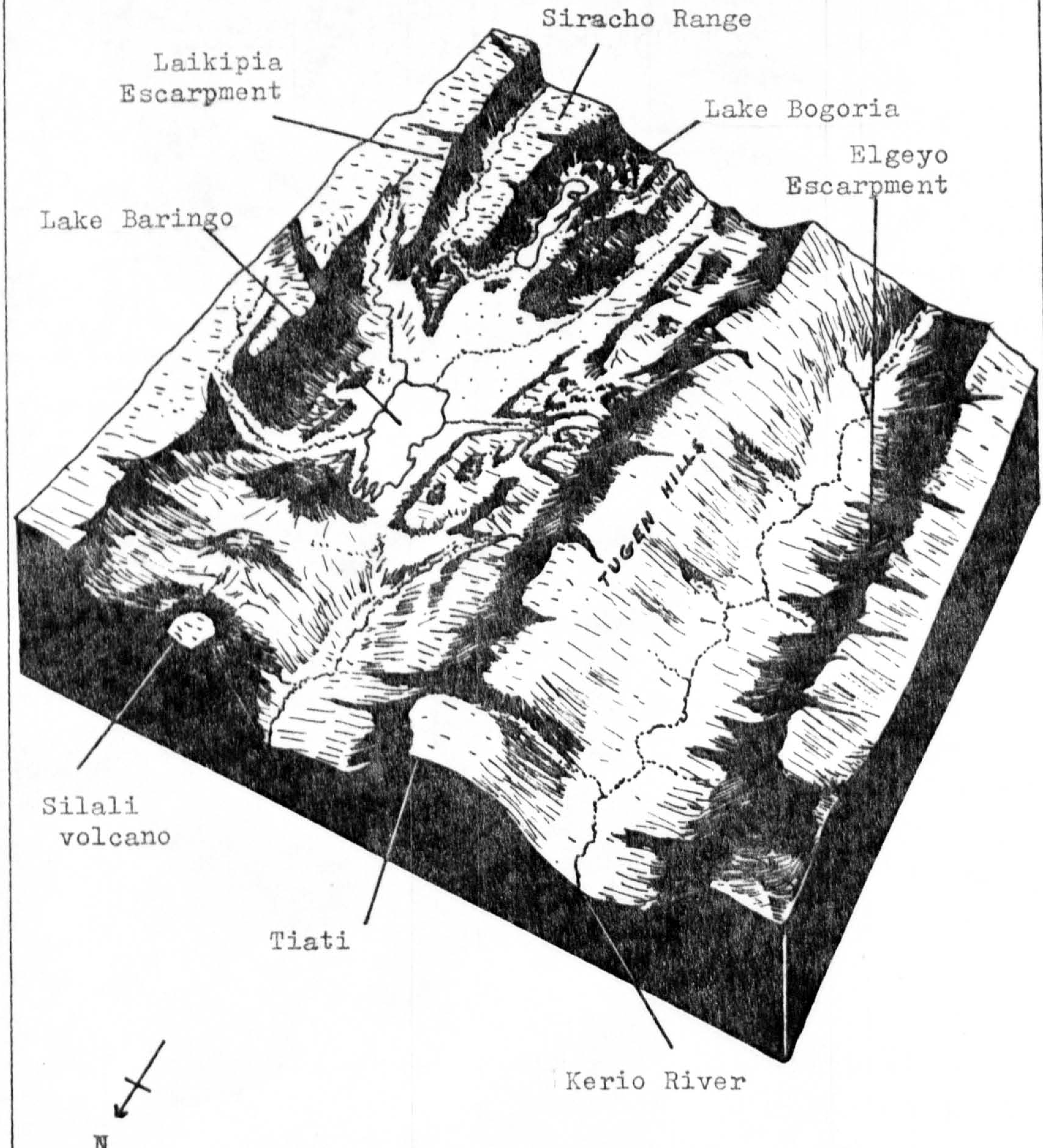
Wildlife was once widespread, but much of the game has now disappeared. A few large mammals still survive in the remoter regions, while crocodile and hippo remain common in Lake Baringo. Dik dik are plentiful and larger antelopes may occasionally be seen. In contrast, birdlife is still abundant and includes shrikes, eagles, silver birds, starlings, maribou stork, hornbills etc..

The area can be approached by the B4 road, which connects Marigat with Nakuru to the south. This fine-earth (murram) road becomes treacherous after rain. It is crossed by several ephemeral rivers north of Marigat which occasionally wash the road away. Eventually it reaches the Suguta Valley, passing Lake Baringo on the way. Lake Bogoria may be reached from the south on a recently constructed road, or from the west via Maji-ya-Moto. It may also be approached from Marigat, in the north, but this route crosses the Molo River at a ford, and the river is frequently too high to make the attempt. A newly constructed road now circles the lake. However, a bridge across the Sandai-Waseges River (at the north end of the lake) is subject to collapse. To the east of Lake Baringo roads are primitive, boulder strewn and often difficult to find. West of the lake roads are scarce, but mostly passable except after rain.

The region contains an amazing topographic diversity, which is illustrated in figure 1.5. The dominant feature is the westerly-dipping tilt block of the Tugen Hills. This range falls from a height of 2600 m to a level of 967 m at Lake Baringo in a series of steep fault scarps.

Fig. 1.5

The physiography of the Baringo district

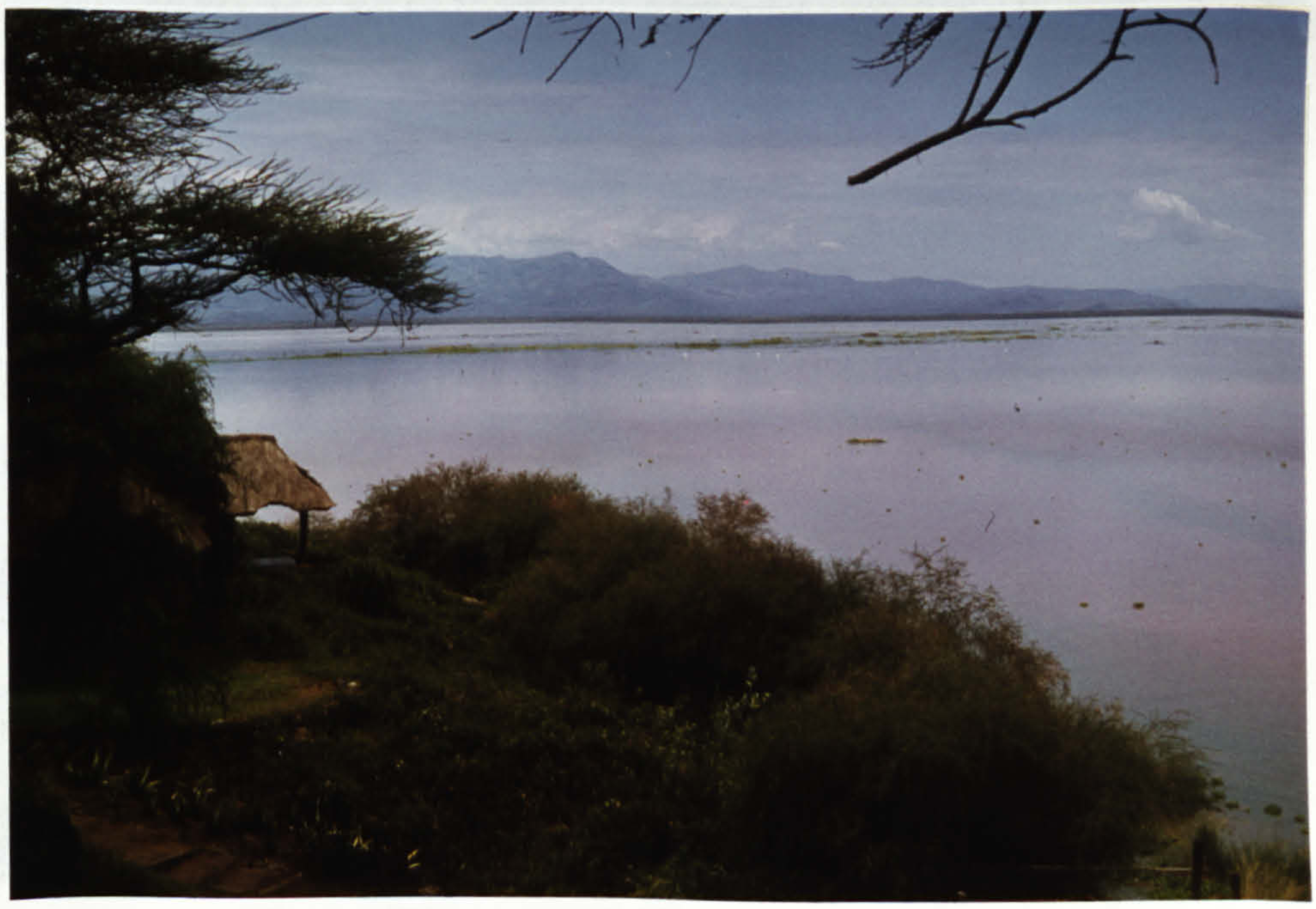


The western dip slope has been deeply incised. The western margin of the Rift Valley is marked by the impressive Elgeyo Escarpment, which rises from the Kerio Valley floor at 1200 m to heights in excess of 3000 m. The Rift margins east of Lake Baringo are gentler, but southwards become more pronounced. Near Lake Bogoria the large fault scarps of the Siracho and Laikipia ranges lift the surface from 1000 m to heights of over 2500 m. West of Lake Bogoria lies a low range of hills composed of westerly dipping tilt blocks.

Freshwater Lake Baringo (plate 1.2) has a surface area of 160 km^2. It is 13 km wide (east to west) by 21 km long (north to south), and has a broadly rectangular shape that is structurally controlled. The Perkerra and Molo Rivers are normally perennial and supply the bulk of water and sediment input to the lake. In contrast, Lake Bogoria (plate 1.3), which lies at ca. 990 m O.D., is strongly saline, alkaline. It lies 20 km to the south of Lake Baringo in a fault controlled asymmetric trough, and extends some 17 km (north to south) by 3.5 km (east to west). It is a shallow lake of less than 9 m depth (Lake Baringo averages less than 6 m). The Sandai-Waseges River, rising near Menengai Caldera 50 km to the south, flows northwards and parallel to the lake before turning and entering it from the north. The lower course of the river is perennial and provides the bulk of the water input to the lake. Both lakes lack a surface outlet although Lake Baringo may have a subsurface drainage to the north.

Lake Baringo is shown at a scale of 1:1,000,000 on the Kenya (north) sheet SK 41. The area is covered at a scale of 1:50,000 by series Y731 on sheets 90/2, 90/4, 91/1, 91/2, 91/3, 91/4 and 105/1. Aerial photographs were obtained for 1950 (R.A.F.) and 1956 (Hunting Aerosurveys Ltd.).

Plate 1.2



Lake Baringo. View looking south-east from Ol Kokwe Island. The high ground forms the eastern wall of the Rift Valley. Vegetation on the lake is 'Nile cabbage', introduced by a recent flood from the Molo River.

Plate 1.3

Lake Bogoria. View looking southwards from its north-eastern shore. High ground is the steep Siracho Escarpment. Flamingoes can be seen feeding in the shallow lake margins. White patches in the foreground are salt, probably trona.

1(v) Background to the geology of the Baringo district

1(v)a History of research

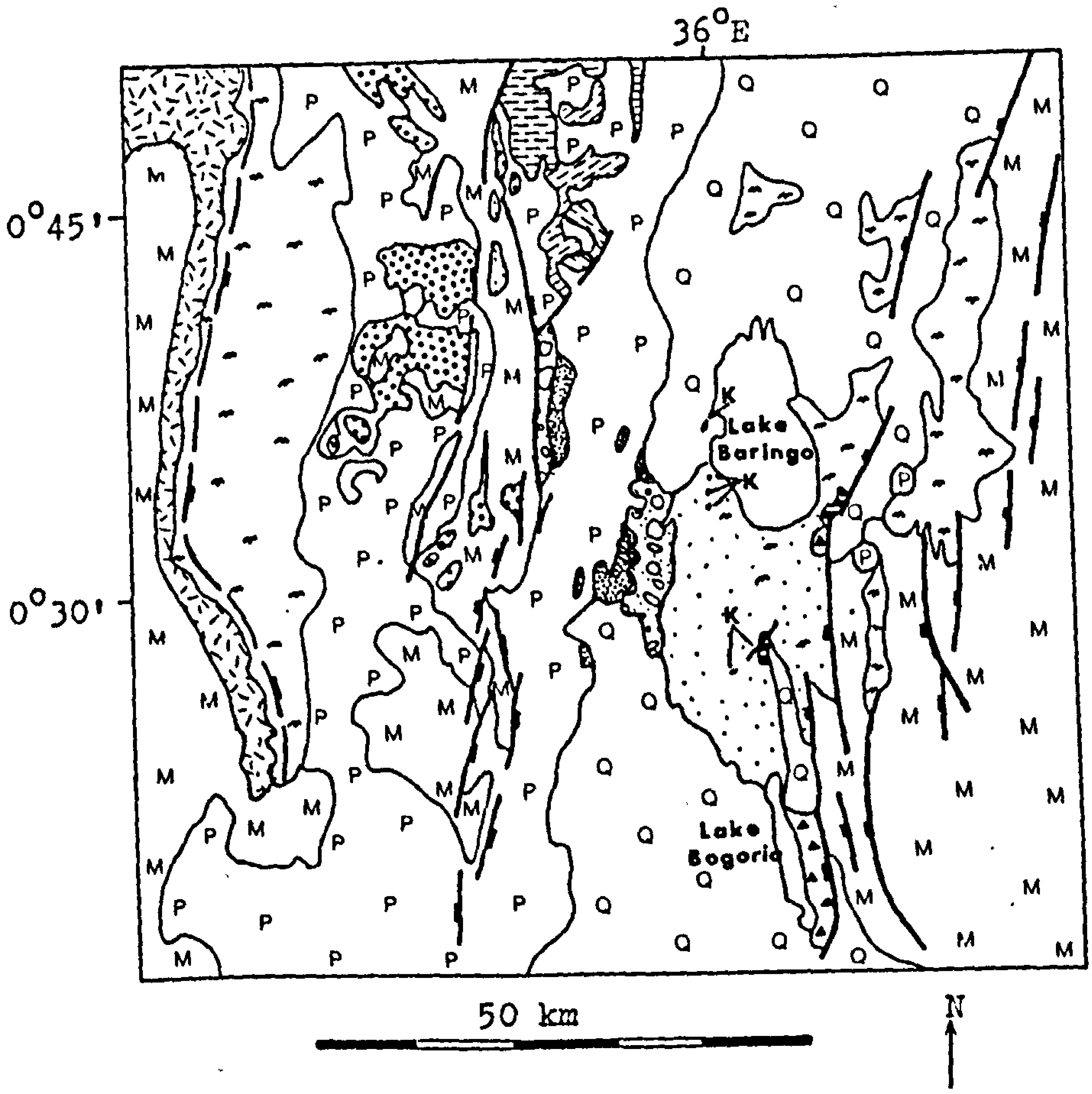
The geology of the area was first examined by Gregory (1921) who recognised sediments at the foot of the Kamasia Hills, which he termed the 'Kamasia lake beds'. These deposits were formally raised to 'pluvial status' by the 1947 Pan African Congress on Pre-History (Leakey, 1952), a concept which was later abandoned. The first mapping was conducted in reconnaissance style by the Kenya Geological Survey in the southern part of the study area, during the early 1960's (McCall et. al., 1967). The East African Geological Research Unit began a project of detailed mapping in 1965 (King, 1970). Pickford (1975, 1978) has examined Miocene to Pliocene sediments over a wide area of the Tugen Hills. Bishop and Chapman (1970) have described early Pliocene deposits, while Martyn (1967, 1969) has studied Plio-Pleistocene strata. Tallon (1978) has investigated Pleistocene fluvial units to the west of Lake Baringo, and Carney (1972) describes Pleistocene deposits to the east of this lake. Holocene lacustrine deposits were recognised above modern Lake Baringo by Nilsson (1932) and Fuchs (1934). These sediments were later reassessed by Bishop (1971) and Bishop, Spooner and Buckland (1969).

1(v)b Geological setting of the Baringo district

The modern Lakes Baringo and Bogoria are the successors to a series of lacustrine sedimentary basins that have existed in the area for the last 15 my (Chapman & Brooke, 1978), as a result of interplay between faulting and volcanism. The evidence for the former lakes lies mainly in the Kamasia Range, a tilt block complex of interbedded alkaline lavas and graben sediments dating back to the Miocene (fig. 1.6). The gross stratigraphy of these sediments and volcanics is shown in figure 1.7. The

Fig. 1.6

Simplified geological map of the Baringo district



Sediments

Holocene
- Alluvium
- Fanglomerate
- Kokwob F.
- Loboi silts

Pleistocene
- Loiminange & Ilosowuani Beds
- Kapthurin F.

Pliocene
- Chemeron F.
- Kaperyon F.
- Lukeino F.
- Mpesida Beds

Miocene
- Ngorora F.
- Muruyur F.

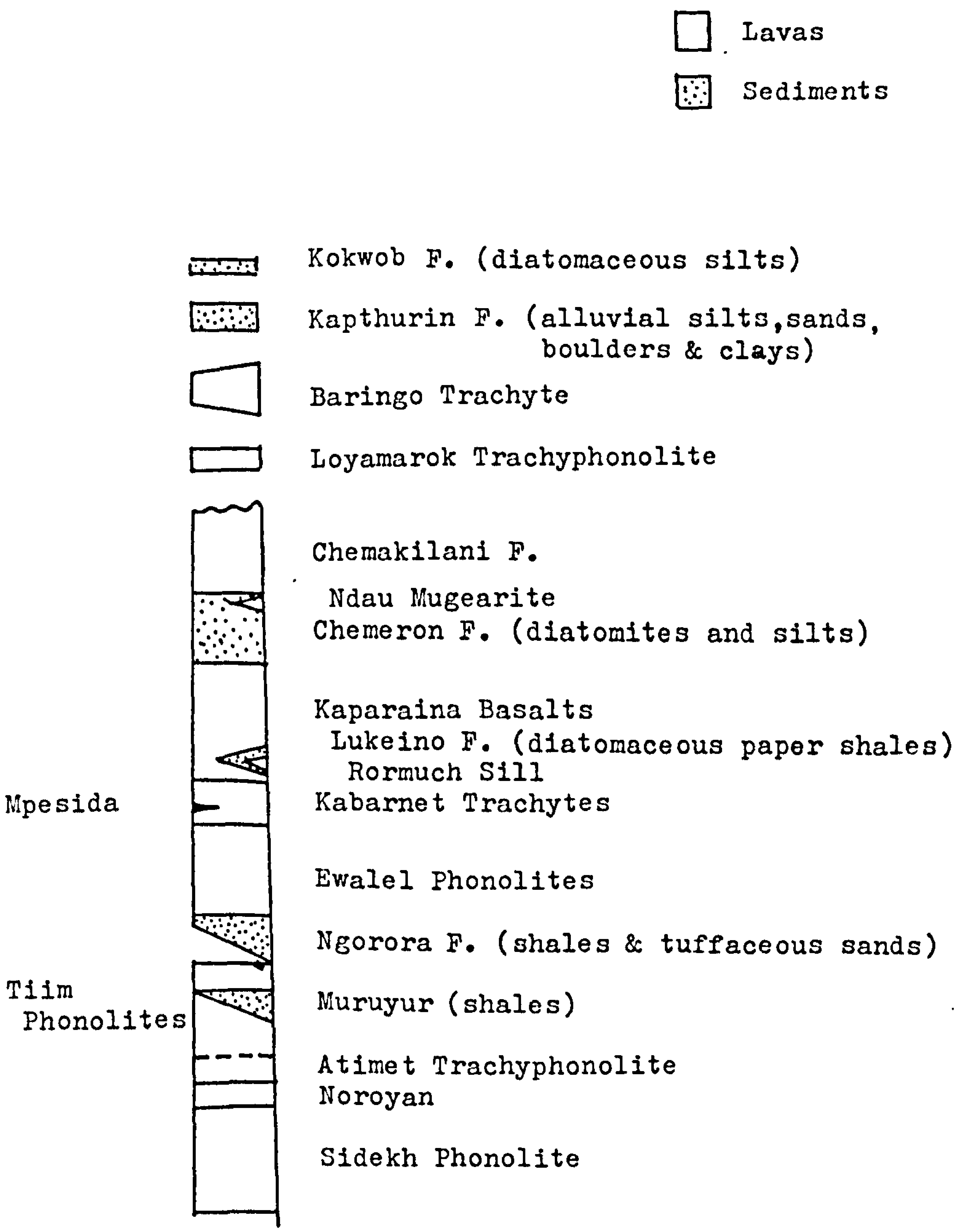
Volcanics

- Q Quaternary
- P Pliocene
- M Miocene

Metamorphic Basement

(after Chapman & Brook, 1978 and Pickford, 1978)

Fig. 1.7
Generalised stratigraphic succession in the Baringo district



N.B. not to scale. Lavas form by far the greatest thickness.

(ammended after Dagley et. al, 1978)

deposits examined in this study include the following.

(i) The Muruyur Beds (between 13 and 14 my old), which are dominantly shales interbedded with the Tiim Phonolites.

(ii) The Ngorora Formation (between 9 and 12 my old), which include shales, diatomites and tuffaceous sandstones that crop out on both sides of the Kamasia Hills.

(iii) The Mpesida Beds (ca. 7 my), which are local pockets of silts and shales between Kabarnet Trachyte flows. They have a maximum thickness of about 30 m.

(iv) The Lukeino Formation (ca. 6.7 my), which was formerly included in the Kaparaina Basalts Formation. These Formations were separated by Pickford (1975). The Lukeino Formation includes diatomaceous paper shales, pumice and silts.

(v) The Chemeron Formation (between 2 and 5.4 my old), which has a maximum thickness of about 200 m, and crops out at the foot of the Tugen Hills. Diatomites and tuffaceous silts predominate.

(vi) The Kapthurin Formation, which is a predominantly fluvial silt and boulder sequence of middle to late Pleistocene age.

(vii) The Kokwob Formation and the Loboi silts, which are largely of Holocene age, and consist of lacustrine and fluvio-lacustrine silts respectively.

The earlier lakes were centred on the Kamasia Hills area, but as the axial rift developed there was a lateral shift in basin foci until the middle to late Pleistocene Kapthurin Formation was deposited in approximately the same area as the present Lake Baringo.

The rift floor at Baringo is part of a general regional northward slope, that extends from Menengai in the south to the Suguta Valley in the north. The morphology of the rift in this part is distinctly asymmetric. The eastern side of the Kamasia Range (to the west of Lake Baringo), is steep and consists of a sequenoe of fault scarps, none of which exceeds a height range of 500 m.

During the Quaternary extensive flood lavas were erupted and caldera volcanoes developed along the median rift axis. In the south-west of the area, these include trachyphonolites (Hannington Formation; Griffiths, 1977) erupted between 1.6 and 0.3 my (Chapman and Brooke, 1978), while to the west of Lake Baringo the Baringo Trachyte is dated at 0.25 my. Quaternary trachytes and basalts were periodically erupted from Ol Kokwe, Korosi and Karau central volcanoes, which lie in the centre of, and to the north and east of Lake Baringo respectively. These lavas and Pleistocene sediments are interrupted by a dense network of late Pleistocene grid faults, which have substantially contributed to the present topography.

The late Pleistocene faulting, northward regional tilting and volcanic barrier to the north of Lake Baringo (Korosi) have together formed the latest of the series of structural basins in which lake sediments have been and are still accumulating.

1(vi) The geography and geological background of the Olorgesailie area

1(vi)a The geography of Olorgesailie

This area lies some 60 to 70 km to the south west of Nairobi, immediately to the north of Mt. Olorgesailie (plate 1.4) and within the Kenyan Rift Valley (fig. 1.1). It extends 20 km from north to south by 10 km from east to west and contrasts with the other study areas by the absence of a modern lake.

The climate is dry and hot. Rainfall figures for Magadi, the nearest town to the south, are given below:

	1950	1951	1952	1953	Average for 28 yrs.
	mm	mm	mm	mm	mm
Magadi 600 m O.D.	322	561	364	260	370

The bulk of the rain is concentrated into two seasons: March to April,and in December. It normally falls as isolated storms accompanied by strong winds from the east or north-east. Shade temperatures vary between 22°C in the cloudy seasons and 43°C (usually nearer 40°C) in the dry seasons.

The extreme climate has produced a semi-desert country. Vegetation is sparse,with Acacia savanna predominating. Plains to the east support grasslands. Dense woodlands on escarpment crests merge into montane forests on well-watered highlands. Forest belts are found at the foot of the Nguruman Escarpment to the west, where some limited cultivation is practised.

The area is thinly inhabited by the semi-nomadic Masai. Their economy is based on cattle herding. However, the grazing is poor and the lack of water for much of the year has led to an impoverished livestock.

Plate 1.4

Mount Olorgesailie. This mountain stands within the southern Kenya Rift, and rises to 1762 m. It consists of Pliocene volcanics, and during the middle Pleistocene acted as the southern limit of the Olorgesailie palaeo-lake. The light patches on the flat plain are diatomaceous silts that were laid down in this former lake.

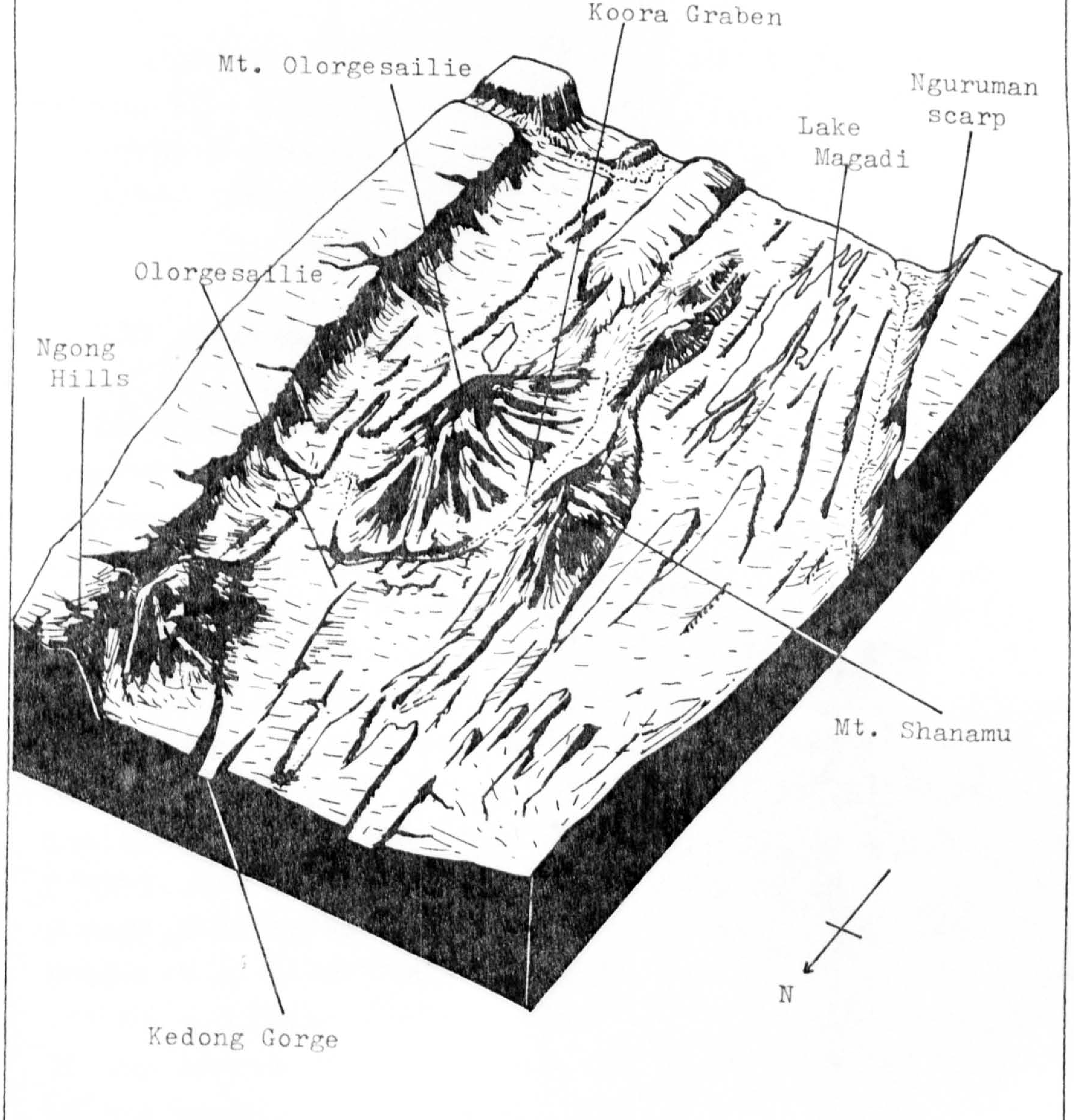
Small herds of zebra, hartbeest, wildebeest and gazelle occur, and as recently as 1967 lion, leopard and black rhino were reported as common. Today, these animals are rarely seen. Giraffe remain quite common between Lake Magadi and the Nguruman scarp. An avian fauna is still abundant and includes ostrich, guinea fowl, barbets, eagles, bustards and many others.

The topography of this part of the Rift Valley is illustrated in figure 1.8. The valley is bounded by the spectacular Nguruman Escarpment on the west, and by a series of scarps to the east. The valley floor rises from its lowest point at Lake Magadi (604 m) to its highest elevation at Gilgil (2070 m), some 130 km to the north of Olorgesailie. The terrain is rugged, consisting of a complex series of north to south trending horsts and grabens. Several isolated volcanic mountains occur and include Olorgesailie (1762 m), Ol Doinyo Nyegi (1169 m), Shanamu (1341 m) and Ol Doinyo Esakut. The oldest of the volcanics occur at Mt. Olorgesailie (Pliocene) and are strongly dissected.

Several perennial streams flow on both sides of the Rift Valley. The Uaso Nyiro passes along the foot of the Nguruman scarp having risen in the Mau Highlands to the north. It ultimately reaches Lake Natron in Tanzania. The Ol Keju Nyiro River descends several scarps east of Olorgesailie, passes to the north of Mt. Olorgesailie in a deep gorge, and into the Koora Graben before petering out on the Koora Plain. It maintains its flow over its whole course only during the wet seasons. Over most of this part of the Rift, surface waters persist only seasonally in rivers or ephemeral lakes such as Lake Kwenia. The largest of these lakes is Magadi, which contains extensive trona deposits.

To the north of Olorgesailie, the Kedong Gorge marks a former water course (Baker & Mitchell, 1976). The Olorgesailie area itself consists of the lower, Oltepesi

Fig.1.8 The physiography of the Olorgesailie area



Plain (to the east), and the higher, Legemunge Plain (to the west). They are separated by a north to south trending, east-facing fault scarp.

There is one main road into the area (numbered the C58). This runs from Nairobi to Magadi and has a tarmac surface, apart for a short section between Nairobi and the Ngong Hills.

A 1:250,000 scale map of the region is available in series Y503 (sheet SA-37-5). Shackleton (in Isaac, 1978) produced a geological map of the area at a scale of 1:10,000, which has been used during this work.

1(vi)b <u>History of research</u>

On a foot safari to the area in 1919, J.W. Gregory observed sediments which he attributed to a 'Lake Kamasia' (formerly thought to have spread over most of the Kenya Rift), and believed them to be of Miocene age (Gregory, 1921). L. Leakey examined the region in 1943 and found numerous Acheulian hand axes. R.M. Shackleton made the first detailed geological survey (Shackleton, 1955), and later Baker incorporated some of this data into his report on the Magadi area (Baker, 1958). Archaeological papers include those of Leakey (1955), Cole (1963) and Posnansky (1959). The sediments have been cited as indicators of a middle Pleistocene pluvial by Leakey (1955), and as evidence of climate-stratigraphy in East Africa by Cooke (1958) and Flint (1959). Isaac has studied the archaeology of the region and has worked on the spatial relationships of the various lithologies (1968, 1978).

1(vi)c <u>The geology of the Olorgesailie area</u>

The sediments investigated in this area belong to the middle Pleistocene Olorgesailie Formation. Its stratigraphic position is shown in table 1.5. The Formation is composed of a series of fluvial and lacustrine deposits laid down in a small graben. Climate, volcanism and tectonism all affected the pattern of deposition. The predominant lithologies are: diatomites, tuffaceous siltstones, tuffs and pumiceous sands, together with brown claystones. The purely lacustrine units tend to thicken towards the Koora Graben (to the south-west), into which the palaeolake retreated during phases of contraction. A generalised geological map of the area is given in figure 1.9.

Most of the sediments are exposed in a south-facing, erosional scarp near the base of Mt. Olorgesailie. In addition there are several small outcrops to the north-west of the Koora Graben. Exposures also occur along the north-eastern foot of Mt. Olorgesailie, and along the Ol Keju Nyiro River (where it crosses the Oltepesi Plain). Elsewhere exposure is poor.

Diatoms were previously examined qualitatively by J.L. Richardson (pers. comm.). This study was conducted independently of his work and extends it both qualitatively and quantitatively.

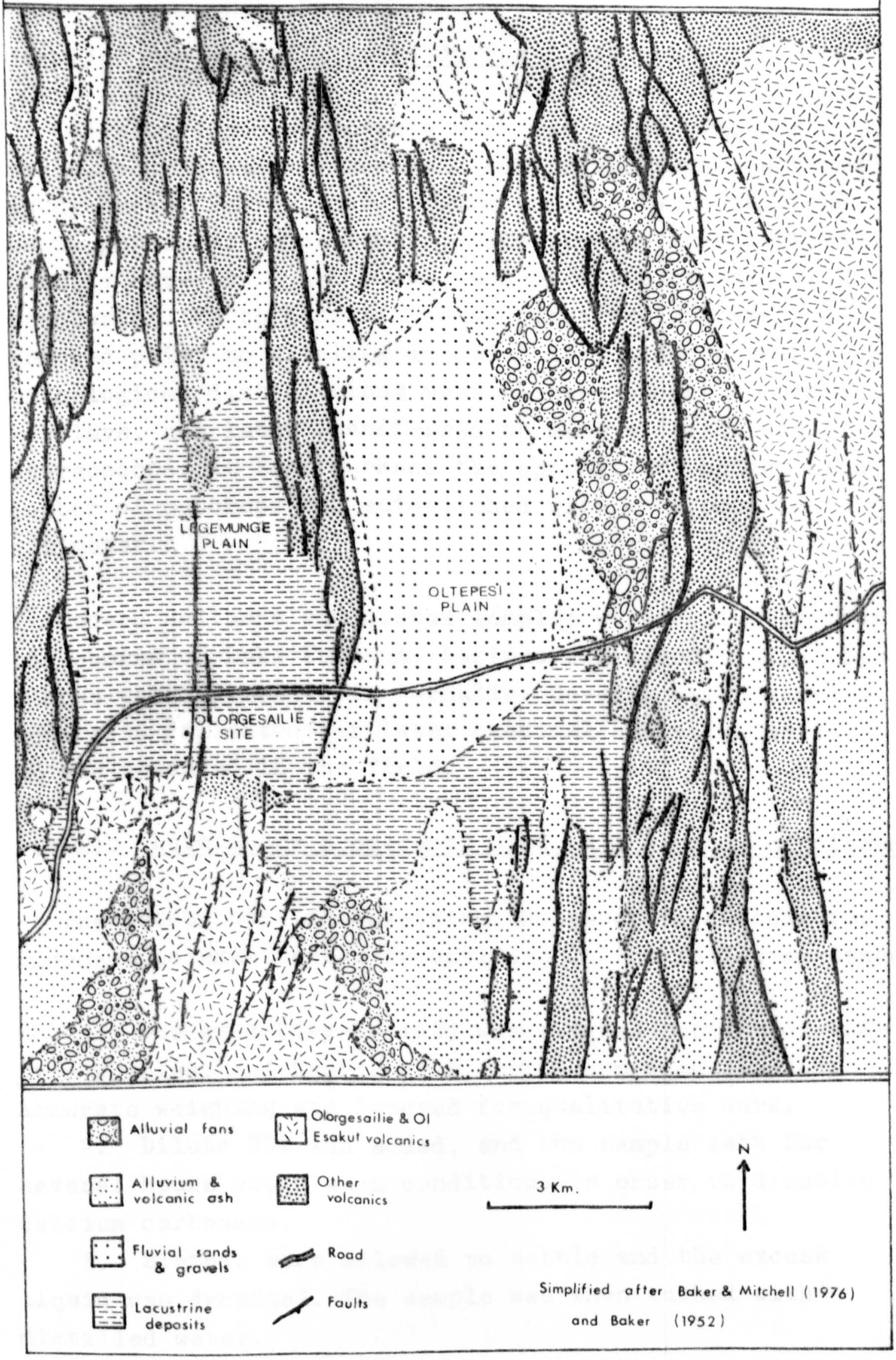
Table 1.5

Regional stratigraphy of the southern Kenya Rift Valley

	million years
Alluvium, travertines and swamp deposits	- ?
OLORGESAILIE FORMATION (Legemunge Beds)	- 0.42 & 0.48
Ol Doinyo Nyuki Volcanics	- 0.66
(Magadi) 'Plateau trachyte series'	- 0.66-1.25
Ol Tepesi basalts	- 1.4 -1.6
Ol Keju Nero basalts	- ?
Limuru trachytes	- 1.9
Singaraini basalts	- 2.3
Olorgesailie volcanics	- 2.2-2.8
Ol Esayeti volcanics	- 3.6-6.7

after Isaac, 1978

Fig. 1.9 Geology of the Olorgesailie Area



1(vii) Field and laboratory methods of study

1(vii)a Techniques adopted during fieldwork

The main approach to this work was to examine and record the details of sections (over 120) from the three study areas. Facies changes were noted between sections where possible. Samples were collected at fixed intervals, usually between 10 and 50 cm, and at lithological boundaries. Up to 5 cm of the sediment surface was removed prior to sampling in order to avoid contamination. Lithological distributions were plotted on aerial photo overlays, and later transferred to maps with the aid of a stereoscope. At East Turkana the approximate height of a number of outcrops was established with a barometric altimeter.

Modern sediment and diatom samples were collected from the shores of Lake Turkana, Baringo and Bogoria. The diatom floras were preserved in formalin. Several water samples were also collected for later chemical analysis, whilst pH was measured in the field.

1(vii)b Laboratory procedures used in the study of diatoms

The method used for cleaning and mounting diatoms for microscopic examination is outlined in the following stages.

1. One gram (dry weight) was weighed out for diatom-poor samples, and half a gram for diatom-rich samples. Accurate weighing was ignored for qualitative work.
2. Dilute HCl was added, and the sample left for several hours under warm conditions in order to dissolve calcium carbonate.
3. Diatoms were allowed to settle and the excess liquid was decanted. The sample was then washed with distilled water.
4. If organic matter was present, this was removed

by adding hydrogen peroxide and heating to 80°C for several hours. After settling and decantation, the sample was washed in distilled water.

5. If clay was present, sodium hexametaphosphate (calgon) was added as a def.loculent. The sample was later washed with distilled water.

6. The sample was then placed in 200 ml of distilled water and exposed to ultrasonic vibrations of 12,000 to 20,000 cycles/second for 20 to 45 seconds, in order to dislodge particles adhering to the diatoms.

7. 0.2 ml of the suspension was taken from different levels of the 200 ml beaker (in order to avoid bias due to differential settling rates), and placed on a slide. The slides were previously cleaned and degreased. After drying,the diatoms were mounted in styrax.

8. In qualitative studies, coarse and fine sediment particles were separated from the diatoms by using their different settling rates. This was not done in quantitative work (except to remove very coarse material) as this might have changed the percentage counts.

An alternative rapid method of examination involved the temporary mounting of sediment samples in high refractive index liquids (ca. 1.74).

For scanning electron microscopy stages 2 to 6 were used to clean the diatoms. After drying,the diatoms were placed on stubs using double sided sticky tape. A gold-palladium coating was applied. An Hitachi S450 electron microscope was used.

Diatom identifications were made using a Vickers 15c optical microscope at 1000x magnification, in conjunction with photographs taken on a Zeiss microscope (some are shown in appendix III). The main reference works for diatom identification have been: Bachmann (1938), Cholnoky (1954, 1956, 1957, 1959, 1960), Cleve-Euler (1952, 1953, 1955), Gasse (1974, 1975), Hustedt (1927-66), Muller (1905, 1911), Patrick and Reimer (1966) and Van Landingham (1967).

The diatoms have been studied by means of percentage analysis. The relative percentage of each species has been established after counting up to 300 individuals per sample at a magnification of 400x. Broken diatoms have only been counted if there is at least half of an individual surviving. However some diatoms are prone to damage due to their shape (viz. the long slender Synedra spp.). In these cases a subjective allowance has been made by counting specimens with at least a third of their frustule (skeleton) surviving. In quantitative work two complete traverses of the slide were made at 90° to one another when counting. Since during sample preparation fixed amounts of sample and water were used, it was possible to calculate the absolute number of diatoms per sample weight.

1(vii)c Laboratory procedures used in the study of sediments

Several approaches to sediment analysis have been used. These are briefly outlined below.

1. Optical microscopy.

Thin sections were made of sediments for microscope study. Many of the samples were unconsolidated and required impregnating with Araldite prior to sectioning.

2. Infra-red absorption analysis.

This technique was used in the qualitative study of fine-grained sediments. It is a rapid method needing very little sediment. Poor spectra were obtained where complex mineral assemblages were present, but the method was found to be particularly useful in detecting nitrate.

3. X-ray diffraction.

This method was adopted for the identification of minerals in fine-grained deposits. The samples were prepared in one of two ways.

a) Approximately 0.5 g of finely crushed sample was placed into the 'window' of a sample holder, which could then be placed in the diffractometer.

b) Where the clay percentage was high the crushed sample was mixed with distilled water, to form a basally-oriented slurry. This was spread evenly over a glass plate, and after drying could be placed in the diffractometer.

4. Grain size analysis.

A known weight of sample was placed in a column of distilled water (having been deflocculated with calgon). The sediment suspension was thoroughly mixed with the water column and allowed to settle. At set time intervals a quantity of the suspension was withdrawn to be dried and weighed. From the known weights, the time intervals, and settling rates of different particle sizes, the weight percentage of each size fraction could be calculated.

5. Chemical analyses.

The carbonate content of the deposits was determined by measuring the release of CO_2 upon the addition of HCl. Atomic absorption spectrophotometry was used in analysing modern lake waters. The main ions determined (expressed as oxides) were K_2O, Na_2O, CaO, MgO and SiO_2. Titration and gravimetry procedures were used in the examination of Cl^-, $CO_3^=$, HCO_3^- and $SO_4^=$.

CHAPTER 2

DIATOM ECOLOGY IN EAST AFRICA

2(i) Diatom assemblages and classifications in East Africa

The interpretation of fossil assemblages requires a knowledge of the existing ecological conditions of the group being studied. This chapter presents and reviews some of the basic information required, with particular reference to the ecological conditions as they exist in East Africa. The areas discussed include relevant classifications and the occurrence of diatoms in modern lakes, their relationship to water chemistry and physical parameters such as light, turbidity and temperature.

East African assemblages often differ in several respects from those of temperate regions. A classic example is the entry of species that occupy benthonic habitats in temperate areas, into the plankton of tropical lakes (eg. *Nitzschia frustulum*). Richardson (1968) suggests that these diatoms adapt by a reduction in size, or by a change of shape that maximises the surface to volume ratio and hence produces more frictional resistance to sinking.

Both Central and East Africa possess endemic species or diatoms that occur rarely in temperate zones. Many of these belong to the genera *Melosira*, *Nitzschia*, *Surirella* and *Thalassiosira*. Conversely, diatoms that are common in temperate regions may be almost absent from the tropics, eg. *Tabellaria flocculosa*.

Early diatom studies tended only to list the species present in a lake. Gradually more attention was given to the ecological setting in which the diatoms occurred, but even the most advanced studies still ignored the water chemistry. However, since the second world war and especially during the last decade, greater importance has been placed on the chemical and physical parameters controlling diatom populations.

In 1949, Hustedt set up an ecological classification based on alkalinity. This was developed from research in the Albertine Rift of Uganda. Lakes in this area are less alkaline than those of the Kenya Rift, reaching a maximum value of 16 meq/l at Lake Kivu. Hustedt's classification follows.

(i) Acid waters with a heavy representation of the genera Eunotia and Pinnularia, plus rare Nitzschia

(ii) More alkaline waters with a strong representation of the genus Nitzschia.

a) Lakes in which the genus Melosira predominates have alkalinities of about or less than 1.5 meq/l

b) Lakes in which the genus Nitzschia predominates have alkalinities above 1.5 meq/l

In 1965 Talling and Talling set up the following chemical classification of tropical and subtropical lakes based upon ionic content.

Class I - Conductivity less than 600 μmhos
Class II - Conductivity between 600 & 6000 μmhos
Class III - Conductivity greater than 6000 μmhos
(conductivity is closely and positively related to ionic content).

Talling and Talling noted that class I lakes were often dominated by Melosira and that class II types were dominated by Nitzschia.

The system established by Hustedt was improved by Richardson (1968, 1969) from his own research and that of

Evans (1962) and Kilham (1971). Richardson's classification is as follows.

(I) Dilute, often acid lakes with low phytoplankton productivity.

A. Cool montane lakes (less than 12°C)
Fragilaria pinnata, *F. bicapitata*, *F. strangulata*, *F. virescens* dominant

B. Warmer lakes (12 to 30°C)
Melosira ikapoeonensis dominant. *M. agassizi*, *M. ambigua*, *M. nyassensis* common

(II) Neutral or alkaline lakes, moderate to high phytoplankton productivity.

A. Heavy permanent or near permanent blooms of blue green algae; *Melosira granulata var. angustissima* usually predominates

B. Blue green algae less abundant than above, though sometimes common.

(i) Lakes of moderate alkalinity (0.9-4.5 meq/l).

a) SiO_2 relatively low (0.1-10 mg/l) in surface water.
Stephanodiscus astraea dominant. *Melosira agassizi*, *M. ambigua*, *M. granulata var. angustissima*, *M. nyassensis* & *var victoriae* common

b) SiO_2 mostly above 10 mg/l in surface water.
Synedra spp dominant. *Melosira ambigua*, *M. granulata var. jonensis*, *M. agassizi* common.

(ii) Lakes of higher alkalinity (2-18 meq/l)

a) SiO_2 low (0.1-10 mg/l) in surface water.
Nitzschia spp (warmer lakes); *Stephanodiscus spp.* dominant. *Melosira goetzeana*, *Thalassiosira rudolfii*, *Surirella engleri*, *Fragilaria harissoni*.

b) SiO_2 above 10 mg/l in surface waters. Nitzschia spp (warmer lakes), Thalassiosira spp. dominant. Cyclotella meneghiniana, Melosira goetzeana, M. granulata var. angustissima common.

Hecky and Kilham (1973) extended Richardson's work to lakes with higher alkalinities. Four diatoms were found to be dominant in the lakes studied. These replace each other as the alkalinity rises. Below about 50 meq/l Cyclotella meneghiniana is dominant. Between 50 and 80 meq/l Thalassiosira rudolfii or Navicula elkab become dominant. As the alkalinity rises above about 80 meq/l Nitzschia frustulum comes to dominate.

Diatom assemblages from many of the major lakes of East Africa are given in table 2.1, together with the ecological data presently available. Many of these assemblages can be placed into one or other of the classifications outlined above . At the present time, no single classification is available that can account for the whole range of East African diatom assemblages.

Interpretation is made easier if a species with specific known requirements occurs in abundance. These can be used as palaeoecological indicators, eg. the silica requirements of Stephanodiscus astraea. However, the whole assemblage must be considered in order to obtain a full story. Planktonic floras are often better than benthonic ones for determining major ecological changes in a lake, since they are not subject to the rapid environmental shifts of littoral zones. These environmental fluctuations are due to variations in lake level, proximity to water inflow and its nature, vegetation, water chemistry (eg. from lagoon to open lake), and local sediment type.

The ecology of individual species,found in the sediments of the Kenya Rift (during this study),are summarised in Appendix I (p. 433).

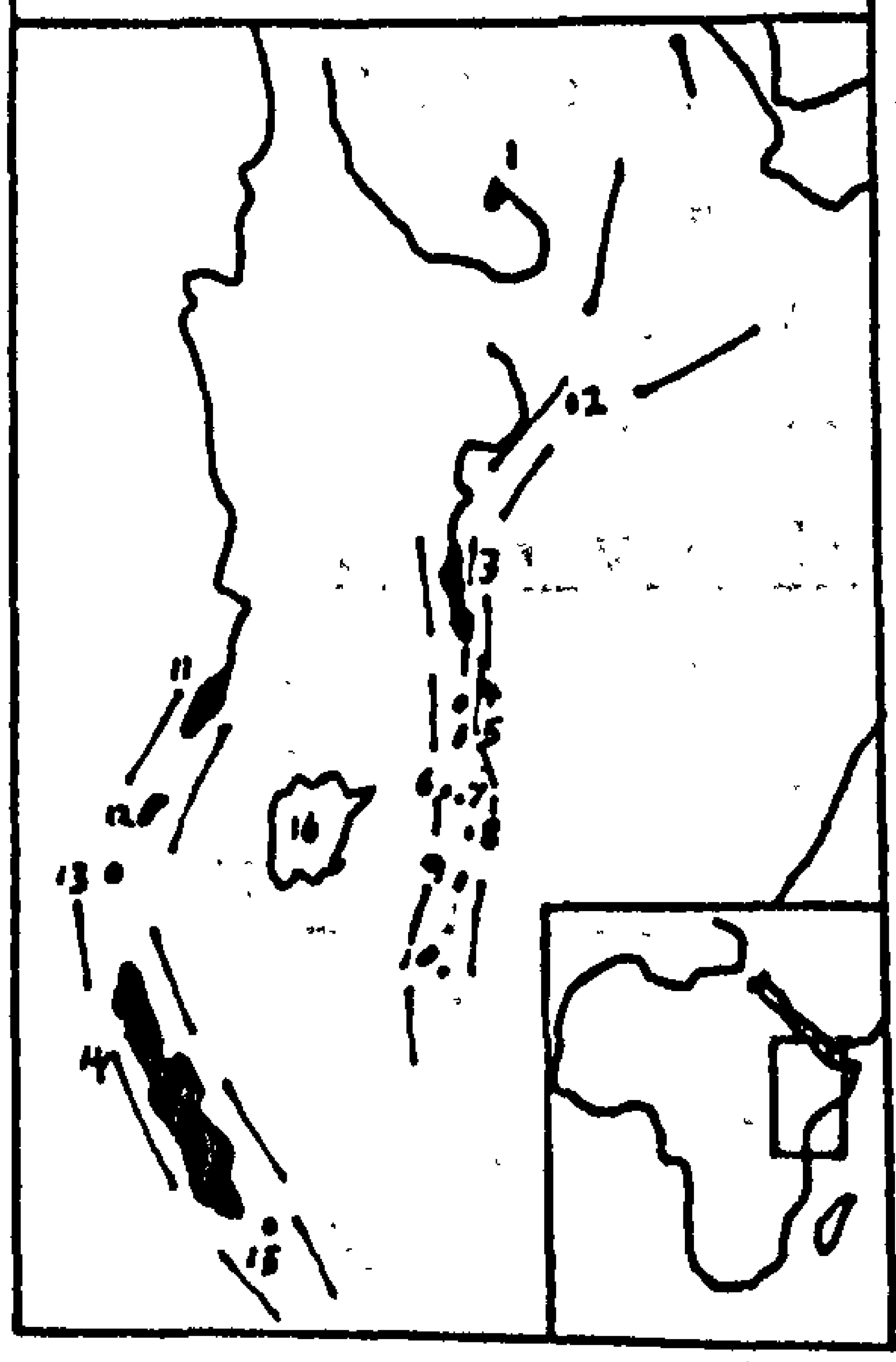
TABLE 2.1 THE PRINCIPLE DIATOMS IN SOME EAST AFRICAN LAKES.

LAKE	ABUNDANT DIATOMS (IN ORDER OF DECREASING IMPORTANCE)	REFERENCE
TANA	Melosira italica, & var. bacillegera, M. agassizi, Stephanodiscus astraea.	GASSE, 1975
	Surirella biseriata, S. fulleborni var. elliptica, S. robusta, S. turgida, Melosira italica var. tenuissima, M. ambigua, Synedra spp.	BRUNELLI & CANICCI, 1940
SHALA	Nitzchia frustulum, Thalassiosira rudolfi.	GASSE,1975
TURKANA	Nitzchia palea, Thalassiosira rudolfi, Rhopalodia vermicularis.	BACHMAN, 1938
	Cyclotella meneghiniana, Stephanodiscus astraea.	RICH,1932
	Cyclotella meneghiniana, Surirella biseiata,	WORTHINGTON & RICARDO, 1936
BARINGO	Melosira granulata var. angustissima, Nitzchia microcephala.	RICH,1933
	Amphora coffaeformis, Navicula rostrata.	WEST & WEST,1896
HANNINGTON	Nitzchia frustulum, Navicula sp.	HECKY & KILHAM,1973
NAKURU	Nitzchia frustulum, Navicula elkab, Thalassiosira rudolfi, Stephanodiscus astraea.	"
ELMENTEITA	Nitzchia sigma, Navicula elkab, Nitzchia frustulum, Anomoeoneis sphaerophora.	"
NAIVASHA	Melosira ambigua, Synedra acus, Surirella linearis, Cymbella spp. & Gomphonema spp..	RICHARDSON 1968
EMBAGAI	Nitzchia frustulum, Anomoeoneis sphaerophora, Rhopalodia gibberula.	HECKY & KILHAM?1973
ALBERT	Stephanodiscus astraea.	BACHMAN, 1933
	Melosira nyassensis, M. granulata, Cyclotella kutzingiana, Synedra sp..	WEST,1909
	Nitzchia bacata, Stephanodiscus astraea.	TALLING, 1965
EDWARD	Surirella engleri,	TALLING, 1965
	Nitzchia fonticola, N. lancettula, N. spiculum, Thalassiosira rudolfi, Stephanodiscus damas	HUSTEDT, 1949
GEORGE	Melosira granulata var. angustissima.	TALLING, 1955
	Nitzchia subacicularis, N. goetzeana.	MULLER,1911
	Coscinodiscus sp., Amphora veneta, Anomoeoneis sphaerophora.	VAN MEEL, 1954
KIVU	Nitzchia fonticola, Stephanodiscus astraea.	DEGANS,1973
	Nitzchia confinis, N. lancettula, N. tropica.	HUSTEDT, 1949
TANGANYIKA	Nitzchia lacustris, N. nyassensis, N. diserta, Stephanodiscus astraea.	VAN MEEL, 1954
(SOUTH BASIN)	Nitzchia lacustris, N. nyassensis, N. adapta, N. diserta, Stephanodiscus astraea.	RICHARDSON 1968
CHILA	Eunotia spp., Cymbella spicula, Gomphonema intricatum, Anomoeoneis sphaerophora, A. exilis.	"

TABLE 2.1 (cont.) ECOLOGICAL CONDITIONS

LAKE	pH.	SiO_2	ALK. meq./l.	T. °C	NEARBY PLANTS	DIATOM ABUNDANCE	REFERENCE
TANA	7.4	-	-	21-23	-	high	GASSE, 1975
SHALA	9.8	-	-	22.5-26	-	high	GASSE, 1975
TURKANA	9.5-9.8	-	-	29.6	-	high	BACHMAN, 1938
BARINGO	-	-	-	23	low	low	RICH, 1933
HANNING-TON	10.6	260	965	-	-	v. low	HECKY & KILHAM, 1973
NAKURU	9.8	208	121.6	-	-	low	"
ELMENT-EITA	9.4	177	107	-	-	low	"
NAIVASHA	7.5-8	-	-	19-21	moder-ate	moder-ate	RICHARDSON, 1968
EMBAGAI	10.1	111	183.3	-	-	-	HECKY & KILHAM, 1973
ALBERT	8.5-9.4	-	-	24-29	-	-	BACHMAN, 1933
EDWARD	8.9-9.3	-	-	-	-	-	TALLING, 1965
GEORGE	8.0-8.7	-	-	24-26	-	-	"
KIVU	8.4-9.4	-	-	23-26	-	moder-ate	DEGANS et.al. 1973
TANGAN-YIKA	8.5-9.1	-	-	24-27	-	moder-ate	VAN MEEL, 1954
(S. BA-SIN)	8.5-9.1	-	-	-	none	moder-ate	RICHARDSON, 1968
CHILA	-	-	-	20-23	moder-ate	high	"

LAKE LOCATION.



KEY

1. TANA
2. SHALA
3. TURKANA
4. BARINGO
5. HANNINGTON
6. NAKURU
7. ELMENTEITA
8. NAIVASHA
9. MAGADI
10. EMBAGAI
11. ALBERT
12. EDWARD & GEORGE
13. KIVU
14. TANGANYIKA
15. CHILA
16. VICTORIA

2(ii) The importance of water chemistry for diatom growth

The peculiar tectonic, volcanic and climatic history of the Kenya Rift has resulted in the formation of a series of alkaline lakes. Often these are centred on basins of internal drainage. While the flora is often dominated by blue green algae, diatoms are very common and sometimes predominate.

Hustedt (1939) developed an ecological classification of diatoms based on pH tolerance (table 2.2). Schoeman (1973) stated his belief that it is the pH optimum and not the range of tolerance that is important in controlling the presence or absence of diatoms. In the Kenya Rift pH is frequently high due to the introduction of alkalis from local lithologies and this has resulted in a species bias. Lakes with high alkalinities have been related to *Nitzschia* dominated phytoplankton, while *Melosira* dominated lakes are often correlated with water of lower alkalinity (Richardson, 1968). Richardson also pointed out exceptions to this pattern. Lake Naivasha is a *Melosira* type lake, but it has an alkalinity three times that of Lake Victoria, a *Nitzschia* type lake. It is clear that several factors are involved in determining the flora of any particular lake. Some of these factors are outlined in the following paragraphs.

Nitrogen and phosphorous are important nutrients for diatom growth. Several species show a preference for nitrogen in particular forms. Patrick (1961) found in several streams of the U.S.A. that *Melosira varians*, *Synedra ulna*, *Navicula viridula*, *N. mutica* and *Cocconeis placentula* were most common in waters of high nitrate concentration (2-3 mg/l). Bahls (1973) found an optimum growth for *Navicula epiphytica* in waters of high ammonia content. Schoeman (1973) has found that *Cyclotella meneghiniana*, *Gomphonema parvalum* and *Navicula muralis* prefer organic compounds as a source of nitrogen. Chu (1942) considered that nitrogen and phosphorous affected the numbers of

Table 2.2 Environmental spectra applied to diatoms

pH spectrum (Hustedt 1937-1939)		
(i)	Acidobiontic	: Found at pH values less than 7; optimum at or below pH 5.5
(ii)	Acidophilous	: Found at a pH of about 7; optimum below 7
(iii)	Indifferent	: Found at a pH of about 7
(iv)	Alkaliphilous	: Found at a pH of 7; optimum at a pH above 7
(v)	Alkalibiontic	: Appear only in alkaline waters.
Current spectrum (Hustedt 1937, 1939)		
(i)	Limnobiontic	: Especially found in stagnant water
(ii)	Limnophilous	: Optimum development in stagnant water
(iii)	Indifferent	: Common in stagnant and running water
(iv)	Rheophilous	: Optimum in running water
(v)	Rheobiontic	: Especially found in running water
Habitat spectrum		
(i)	Planktonic	: Free floating species
(ii)	Benthonic	: Species attached to a substratum
(iii)	Epilithic	: Species attached to rocks
(iv)	Epiphytic	: Species attached to plants
Nutrient spectrum		
(i)	Eutrophic	: Favoured by water rich in organic nutrients (eg. N and P)
(ii)	Oligotrophic	: Favoured by water poor in organic nutrients
(iii)	Dystrophic	: Favoured by water rich in humates and low in dissolved nutrients and oxygen

The table presents various spectra used in the text of this thesis with brief descriptions of the terms used.

diatoms present, and that the species composition of an assemblage is related to ions such as Ca, Na, K and Si.

Diatoms have been classified according to their salinity preferences by several researchers. Kolbe (1927) proposed such a system, based on the preference for NaCl. This was revised by Hustedt in 1953 and 1957 (table 2.3). The new version took account of NaCl and MgCl in solution. Cholnoky (1968) then set up a classification based on osmotic pressure. In his view, it is not the quantity of salts available, but the variability in the quantity of salts that is important (table 2.3). Other systems have used the quantity of total salts present, eg. Aguesse (1957) as modified to suit diatom studies by Gasse (1975; table 2.3).

Table 2.3 The Halobian spectrum

<u>Kolbe (1927)</u>

		NaCl in solution
(i) Euhalobes	:	30 to 40 ‰
(ii) Mesohalobes	:	5 to 30 ‰
(iii) Oligohalobes	:	Halophilous - slightly brackish
	:	Indifferent - fresh
	:	Halophobous - fresh, intolerant of salt

<u>Hustedt (1957)</u>

		NaCl & MgCl in solution
(i) Euhalobes	:	Polyhalobes - close to or greater than sea water
	:	Mesohalobes - 2 to 30 ‰
(ii) Oligohalobes	:	Halophiles - fresh but stimulated by a little salt
	:	Indifferent - salt in this range has little influence
(iii) Halophobes	:	Shun any salt

<u>Cholnoky (1968)</u>

(i) Freshwater diatoms	:	Incapable of supporting changes of osmotic pressure
(ii) Brackish diatoms	:	Capable of supporting changes of osmotic pressure

<u>Aguesse, as modified by Gasse (1975)</u>

(i) Stenohaline	:	Without strict limits
		Total salts in solution
(ii) Hyperhalobes	:	35 ‰ +
(iii) Euhalobes	:	Polyhalobes - 16 to 35 ‰
		Mesohalobes - 2 to 16 ‰
(iv) Oligohalobes	:	0.2 to 2 ‰
(v) Halophobes	:	0.2 ‰ -

The table shows some major salinity classifications. This thesis follows the system used by Hustedt (1957).

2(iii) The importance of physical factors for diatom growth

Three major physical factors can be considered that influence the species composition of an assemblage and the numbers of diatoms present. These are temperature, turbidity and light.

A. Temperature

Gasse (1975) noted that a tropical flora (reflecting high temperatures) could only become important where salinities were low, and even then salinity might exert a masking influence. Despite the confusion that can be caused by high salinities, Richardson (1969) found that Nitzschia-dominated lakes did not occur below 23°C in East Africa. However, he notes that this may be due to the indirect effect of high temperatures promoting organic decay and consequent release of nutrients.

It appears that large numbers of diatoms are able to withstand wide temperature changes, while others are temperature specific. Barker (1935) found that *Nitzschia palea* had its maximum rate of photosynthesis at 33°C, but was strongly inhibited when temperatures rose above 40°C. Wallace (1955), in contrast, observed that *Gomphonema parvalum* grew best at 20°C, but still grew fairly well at 34°C.

Temperature can also have several indirect effects on diatoms. As mentioned earlier, nutrient recycling may be accelerated with higher temperatures. Patrick (1961) has also suggested that high temperatures may lower the viscosity of water and hence increase diatom sinking rates. Warm water forms often have thinner silica walls, which might be a response to lower viscosity. Another indirect effect may operate through a decrease in oxygen with rising temperature. It is clear that relationships between diatoms and temperatures exist, but these are complicated.

B. Turbidity

This can be an important influence. Turbid water can encourage the recycling of nutrients essential for diatom growth. Certain species occur more often in agitated or flowing water, and a current spectrum into which they can be placed was established by Hustedt (table 2.2). High turbidity may favour the development of a strong plankton. Melosira granulata is often found in turbid water (Kilham and Kilham, 1975). In certain circumstances turbulence may support suspended sediment, which will reduce light penetration and restrict the numbers of diatoms.

C. Light

As a result of their photsynthetic requirements, light penetration is often of critical importance to the development of diatoms. Many species are favoured by high light penetration, eg. Cyclotella meneghiniana and Navicula cryptocephala (Rice, 1938). A number of diatoms are encouraged by low light levels, eg. Campylodiscus spp.. Benthonic and epiphytic diatoms (table 2.2) are confined to the margins of all but the shallowest lakes as a result of their light requirements.

Many of the factors outlined so far in this chapter, can vary over short distances, especially in the littoral environment. This makes diatoms particularly useful in palaeogeographical reconstructions.

2(iv) The contemporary ecology of Lake Turkana

2(iv)a The diatom content of Lake Turkana

The modern environment and diatoms of Lake Turkana have been studied by several researchers, and their work is briefly reviewed here. New data from the littoral environments of the lake are presented later (p. 80). An understanding of the modern environments helps in the reconstruction of palaeoenvironments.

F. Rich, as a member of a Cambridge expedition to several East African lakes, visited the western shore of Lake Turkana between December 1930 and April 1931. Most of the samples she collected were of planktonic algae. These were dominated by Hormidium subtile and Arthrospira subtile. Diatoms played only a minor role in these collections, being dominated by Cyclotella meneghiniana. She found diatoms to be more common on various waterweeds and organic debris, and these include: Rhopalodia gracilis, R. gibberula and its varieties rupestris and vanheurckii, R. hirundiformis, R. ventricosa, Surirella biseriata var. lanceolata, Cymbella grossestriata var. obtusioscula, C. helvetica, Gomphonema intricatum, Gomphocymbella brunii, Navicula pupula, N. cryptocephala, Anomoeoneis sphaerophora var. rostrata and Nitzschia hungarica.

Worthington and Ricardo (1936) sampled an area to the north-west of Central Island in water 48 m deep. Hormidium subtile and Botryococcus braunii were dominant. The diatoms Surirella biseriata and Cyclotella meneghiniana were recorded as 'occurring'.

Bachman (1938) reports several other species from the northern end of the lake. The shallow water floras were dominated by Rhopalodia gracilis, R. vermicularis and 'forma' perlonga. Less common were Thalassiosira rudolfii, a colonial group of _Nitzschia palea_, _Cymbella lanceolata_, _C. maculata_, _Anomoeoneis sphaerophora_, _Navicula placentula var. lanceolata_, _Surirella biseriata var. lanceolata_ and occasional _Gomphonema intricatum_. The blue green alga _Hormidium subtile_ was also recorded.

B.J. Harbott, in an unpublished 'Lake Turkana Fisheries' report, records that the most common genus is _Microcystis_. Other plankton include _Planktonema lauterbornii_, _Phormidium mucicola_, _Botryococcus braunii_ and several diatoms belonging to the genera _Navicula_, _Surirella_, _Nitzschia_ and _Rhopalodia_. He also recorded _Cyclotella meneghiniana_ as common.

A seasonal variability of diatoms has been shown by the Fisheries department. _Surirella biseriata_ became most numerous in September when 32 cells per litre were counted. A secondary peak occurred in June, while numbers were very low between February and April.

2(iv)b The physical and chemical parameters controlling diatoms in Lake Turkana

The floor of Lake Turkana divides it into northern and southern sub-basins. These tend to reinforce a chemical gradient caused by fresh waters being mainly introduced at the north end of the lake (by the River Omo). Ionic concentration is lower in the north basin than in its southern equivalent. The south basin exhibits almost vertical homogeneous conductivities of around 3600 µmhos, whereas the lowest values of 150 µmhos occur in the extreme north near the River Omo. Occasionally, enclosed bays attain higher conductivities. This occurs at Fergus ons Gulf, on the western shore, where values of 4500 µmhos have been recorded. Further data on the chemistry of Lake Turkana is given in table 2.4.

Table 2.4 The chemical composition of Lake Turkana.

Sampling date.	Conductivity (umho.)	pH.	Na mg/1	K mg/1	Ca mg/1	Mg mg/1	HCO_3 & CO_3 meq/1	Cl mg/1	SO_4 mg/1	SiO_2 mg/1	NO_3.N ug/1	PO_4.P ug/1	total P ug/1	ref.
Jan.1931	2860	-	770	23.0	5.0	4.0	21.7	429	56	4.2	-	-	-	1
Apr.1931	-	9.5	-	-	-	-	19.4	-	-	5.0	-	715	-	1
Jan.1953	-	9.7	-	-	5.8	-	21.6	320	57.6	24	-	-	-	2
Aug.1954	2900	-	-	-	-	-	23.0	-	-	-	-	-	-	3
Jan.1961	3300	-	810	21	5.7	3.0	24.5	475	64	18	-	-	2600	4
Aug.1973	3300	9.2	837	23.1	6.7	2.3	31.5	648	-	7.8	5	750	-	5

References:

1. Beadle, 1932
2. Fish, 1954
3. Fish, in Talling & Talling, 1965
4. Talling & Talling, 1965
5. Yuretich, in Harbott, 1973

Algal nutrients in the lake are low. This is especially true in the south basin, with regard to trace elements, which may partly account for the relative abundance of diatoms here, since they are less dependent on such elements than most other algae.

Yuretich provides the following chemical data relevant to diatom nutrition, in Harbott's unpublished report. Orthophosphate is generally less than 140 mg/l. The phosphate content is not likely to be a limiting factor anywhere in the lake. Nitrite was not recorded, while nitrate was not found in concentrations over 5.0 mg/l. Silicate was recorded as low, though mostly above 1.0 mg/l. He recorded surface ionic concentrations from the northern part of the lake as follows.

Na	:	760 - 890 ppm
K	:	18.3- 26.1ppm
Ca	:	4.5- 12.2ppm
Mg	:	2.0- 3.1ppm
Cl	:	585 - 655 ppm

The alkalinity was recorded as 20 to 23 meq/l. Organic carbon is highest in the north basin (1.1%), and decreases to the middle of the lake at Moiti (0.2%).

Light penetration into the lake also varies, being shallowest in the north, due to the influx of suspended solids from the Omo. This varies seasonally in response to the annual floods of the River Omo. Thermoclines tend to break down due to wind activity. Temperatures in the lake range between 25 and 30^{o}C.

2(v) The diatoms and water chemistry of the north-eastern shore of Lake Turkana

A number of diatoms and water samples were obtained from littoral environments along the north-eastern shore of Lake Turkana, between August and September 1977. These are described in the following paragraphs.

A series of lagoons exist along the Koobi Fora spit (fig. 2.1). These are seasonally inundated by rising lake levels, and often change their position. At the time of sampling most were separated from the lake, and rested on medium to coarse subarkosic sands. No rooted vegetation was present and water depths were mostly less than 50 cm. The pH values of ca. 9.6 were higher than the open lake figure of 9.1. The diatom flora from one of these lagoons (site 1, fig. 2.1) is described below.

DOMINANT (20% +)	:	*Anomoeoneis sphaerophora f. rostrata*, *Nitzschia palea*.
OCCASIONAL (10% -)	:	*Anomoeoneis sphaerophora*, *A. sphaerophora var. polygramma*.

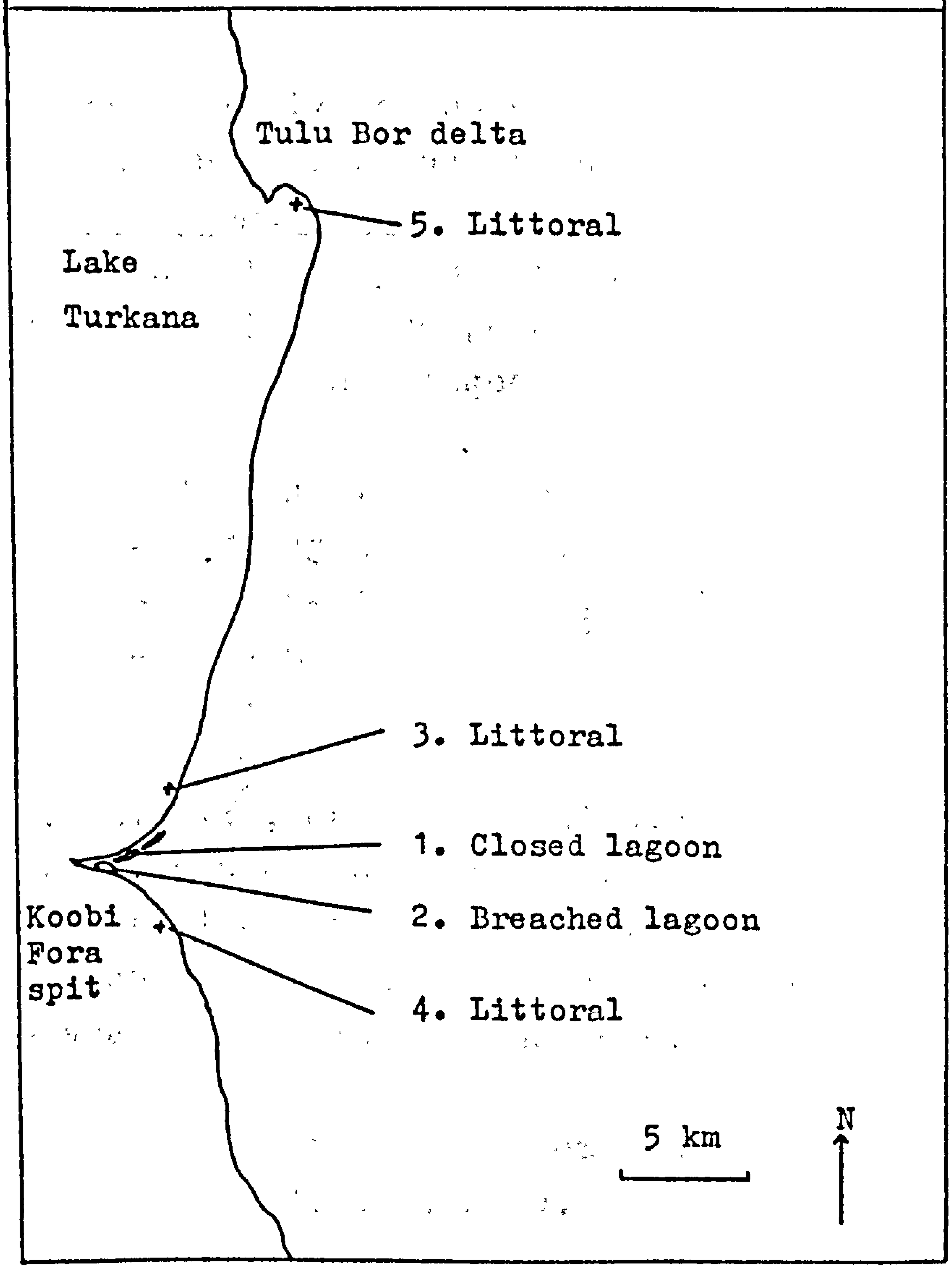
Water samples from the same lagoon have been examined, and the following results obtained.

Na	- 4810 mg/l	SO_4	- 68 mg/l
K	- 45 mg/l	Cl	- 2680 mg/l
Ca	- 8 mg/l	CO_3 & HCO_3	- 130 meq/l
Mg	- 1 mg/l		
SiO_2	- 0.7mg/l		

A breached lagoon was also sampled on the spit (site 2, fig. 2.1). The pH was the same as the lake. The lagoon again lacked any rooted macrophytes. The diatom flora was as follows.

Fig. 2.1

Location of diatom and water sampling sites



DOMINANT : Anomoeoneis sphaerophora f. rostrata, Nitzschia palea.

SUBDOMINANT : Nitzschia obtusa.

OCCASIONAL : Navicula cryptocephala var. veneta, Cyclotella meneghiniana, Thalassiosira rudolfii.

This is essentially the same flora as that of the closed lagoon, but the breaching has seen the introduction of Cyclotella meneghiniana and Thalassiosira rudolfii. Several other algal groups occur in these lagoons, but these are not within the scope of this work. The water chemistry of the breached lagoon is as follows.

Na	- 1100 mg/l	SO_4	- 45 mg/l
K	- 33 mg/l	Cl	- 830 mg/l
Ca	- 8 mg/l	CO_3 & HCO_3	- 26.5 meq/l
Mg	- 4 mg/l		
SiO_2	- 3 mg/l		

Sodium, chloride, carbonate and bicarbonate are less abundant than in the closed lagoon. Potassium has also decreased, but slight increases in magnesium and silica have been recorded. The dominant diatoms remain the same, but there are changes in the less common species.

A littoral open water area, dominated by reeds, was also examined (site 3, fig. 2.1). The diatoms differ from the lagoonal areas, and are as follow.

DOMINANT : Gomphocymbella brunii, Nitzschia palea.

SUBDOMINANT : Gomphonema intricatum, Anomoeoneis sphaerophora f. rostrata, Cymbella grossestriata, Navicula gastrum.

OCCASIONAL : Cyclotella meneghiniana, Navicula cryptocephala.

Littoral reed-dominated environments were also studied on the southern side of the Koobi Fora spit (site 4, fig. 2.1). A similar flora was found, with the exception of one area open to wave action. Here, the diatoms were heavily dominated by Nitzschia palea (95%) with Anomoeoneis sphaerophora f. rostrata also occurring.

A further series of samples were collected from the southern side of the Tulu Borr delta (site 5, fig. 2.1). A typical shallow water area with abundant reeds was sampled and the flora is shown below.

DOMINANT	:	Anomoeoneis sphaerophora f. rostrata Nitzschia palea.
SUBDOMINANT	:	Rhopalodia gibberula, R. ventricosa, Gomphonema brunii.
OCCASIONAL	:	Gomphonema intricatum, Cyclotella meneghiniana, Anomoeoneis sphaerophora var. guntheri.

Here, the lake waters are slightly more dilute than they are further south. This probably relates to the proximity of the Omo River. The data from this area follows.

Na	- 908	mg/l	SO_4	-	48 mg/l
K	- 22	mg/l	Cl	-	674 mg/l
Ca	- 7	mg/l	CO_3 & HCO_3	-	25.5 meq/l
Mg	- 6	mg/l			
SiO_2	- 4	mg/l			
Fe	- 0.4	mg/l			

Slight increases in silica and magnesium are detectable, while iron was recorded for the first time.

The most important features of the diatom floras are as follow.

A. The abundance of Anomoeoneis sphaerophora, especially in lagoons.

B. The abundance of *Nitzschia palea* in reedy zones.

C. The dominance of *Thalassiosira rudolfii* and *Cyclotella meneghiniana* in the plankton.

D. The absence of *Surirella biseriata var lanceolata*, which was often recorded by other researchers. It may have been 'missed', since it was usually found in the plankton and the samples collected here had a littoral bias.

All the diatoms recorded here are capable of living in alkaline waters. From this study it appears that:

(i) *Anomoeoneis sphaerophora* is favoured by high alkalinities (at least up to 135 meq/l).

(ii) *Nitzschia palea* is favoured by littoral reedy zones. No clear alkalinity preference could be detected within the range found here.

(iii) *Gomphocymbella brunii* is associated with littoral reedy zones and fresher waters.

(iv) *Rhopalodia gibberula* and *R. vermicularis* are most common in littoral regions, and in waters with alkalinities of less than about 35 meq/l.

(v) *Thalassiosira rudolfii* has a planktonic habit.

(vi) *Cyclotella meneghiniana* may live in both littoral and planktonic situations, but favours the latter in this lake.

Where data is available from other lakes, these tend to confirm the above observations.

PART II

THE EVOLUTION OF LAKE TURKANA

CHAPTER 3

THE DIATOM STRATIGRAPHY AND SEDIMENTS OF EAST TURKANA

3(i) Definition of the Holocene Galana Boi Formation

3(i)a The Galana Boi Formation

The Holocene sediments at East Turkana were informally termed the Galana Boi beds by Vondra, Johnson, Bowen and Behrensmeyer (1971). The name was derived from the Gabra word for Lake Turkana. These deposits form a distinct sequence both stratigraphically and spatially, and it is proposed here that they should be named the Galana Boi Formation.

The Galana Boi Formation lies with gross unconformity on Pliocene and Pleistocene sediments. Although over much of their distribution they are less than 10 m thick, in Area 103 (fig. 1.2) they attain a maximum thickness of 34 m. Commonly they crop out as discontinuous linear bodies that formed parallel to palaeoshorelines. The thickest individual sequences infill palaeovalleys. The deposits occur up to 80 m above the modern lake, which lies at _ca_. 375 m O.D.. Fluvio-lacustrine and aeolian sediments are present locally. Units are typically lenticular and exhibit rapid lateral and vertical facies variation. The sediments consist of grey, laminated, diatomaceous, quartzo- feldspathic silts, and littoral subarkosic and sublitharenitic sands. A simplified geological map showing the distribution of Holocene sediments is presented in figure 3.1.

The stratigraphy and the sediments of this area have been studied in detail in some 85 particular sections. However, these details are epitomised in one section, here numbered 72 (plate 3.1). This chapter gives a detailed

Fig. 3.1

Simplified geological map of East Turkana

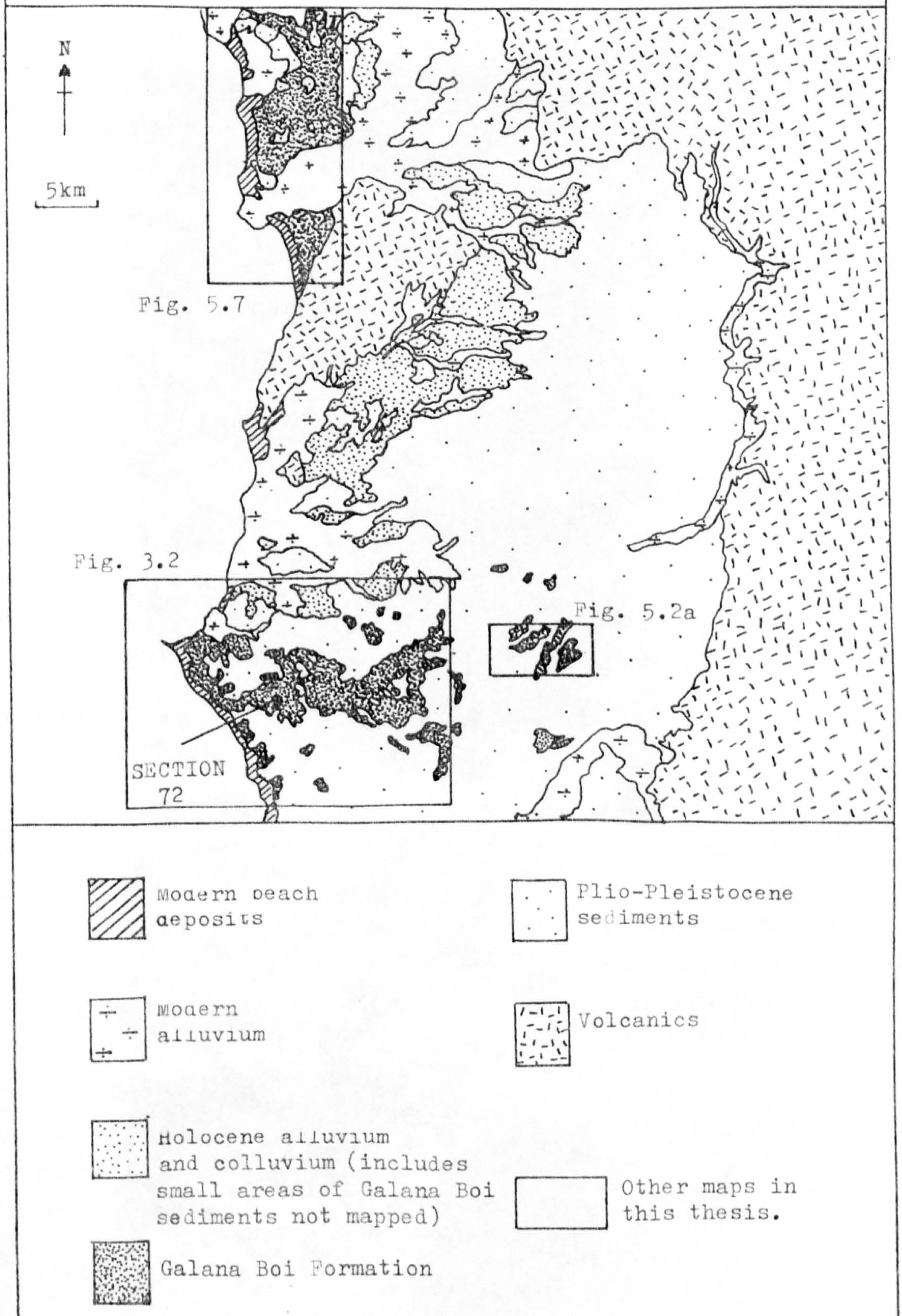


Plate 3.1

1 m

Section 72. Laminated diatomaceous silts can be seen. These contain diatoms that suggest several lake level fluctuations. Sandier deposits continue the sequence above that which can be seen in this photograph.

Diatomacous silt from the upper part of the section (x25, with photographic enlargement of x2.5). Several Rhopalodia can be seen. Quartz and feldspar dominate in the lower half of the photo.

account of the diatom stratigraphy and the lithological succession in section 72, while later chapters deal with the wider sediment distribution.

3(i)b The location and importance of section 72

Section 72 lies some 9 km to the south-east of Koobi Fora, in Area 103. Its location is shown in figure 3.1, and on the geological map of the area to the east of Koobi Fora, at the back of this thesis. This section was selected for a detailed examination for the following reasons.

A. Diatoms were found to be abundant in the silts of Area 103 during the first field season.

B. The thickness of these deposits, up to 30 m, suggested that a detailed history of Lake Turkana could be obtained. Using dates obtained by Raynolds (1972), a mean sedimentation rate of about 2 cm/ annum is indicated. However, in view of the grain size variability, this figure must be treated with caution.

C. These deposits lie adjacent to the Koobi Fora Ridge. This relatively high ground would have tended to establish shoreline conditions in this area. In turn, this would make the locality particularly sensitive to variations of lake level.

D. Section 72 does not occur in the area of maximum sediment thickness. Composite sections which represent a greater thickness were examined, but in less detail. Section 72 represents the thickest 'continuous' sequence available, and was chosen for this reason.

3(ii) The diatom stratigraphy of section 72

3(ii)a The diatom zonation of section 72

Samples for this study were collected at 10 cm intervals. In all, 128 slides were prepared from these samples, and were examined for their diatom content. The diatoms in this collection of slides reflect the early and middle Holocene history of Lake Turkana. Figure 3.2 illustrates all the diatom species that formed 1% or more of the total flora, in at least two samples. Species occurring at lower percentages have been ignored, since their presence is highly sensitive to reworking, transportation, contamination and count size. Emphasis has been placed on those diatoms that were abundant or common.

The zones established here are used in an informal sense, for descriptive purposes only. They are based on changes in the diatom flora and on variations in diatom abundance, and can be considered as loosely related to 'assemblage zones'. Since these zones are based upon diatoms, they closely reflect environmental changes and are not useful for correlation on anything other than a local scale.

Four of these 'zones' can be recognised from an inspection of figure 3.2. These will be dealt with in turn, but their major characteristics are summarised below.

ZONE D : Diatoms infrequent, often absent. When present *Rhopalodia vermicularis* and *Cocconeis placentula* dominate.

------------UNCONFORMITY--------------

ZONE C : Diatoms abundant, *Rhopalodia vermicularis* and *Cocconeis placentula* dominate

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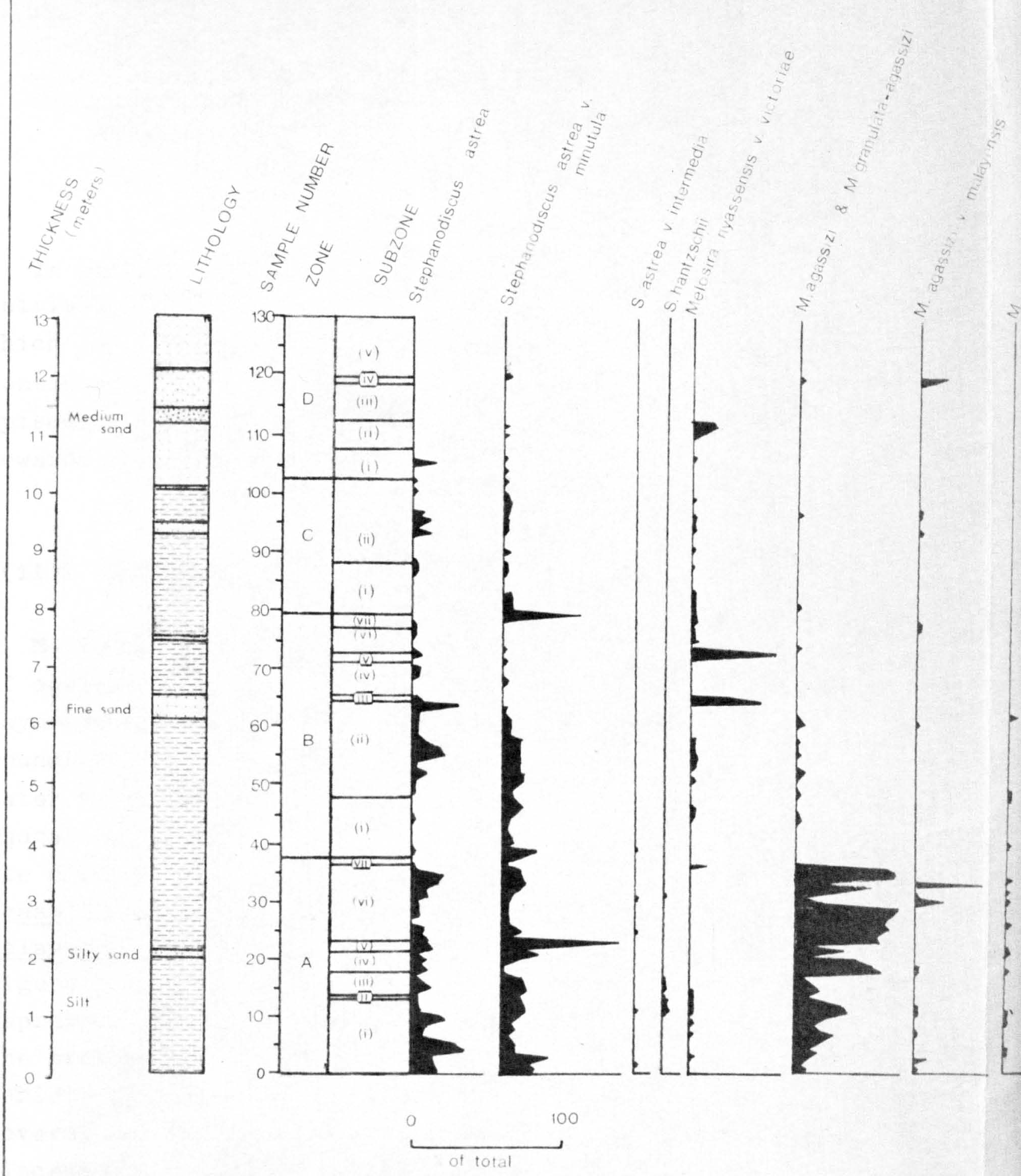
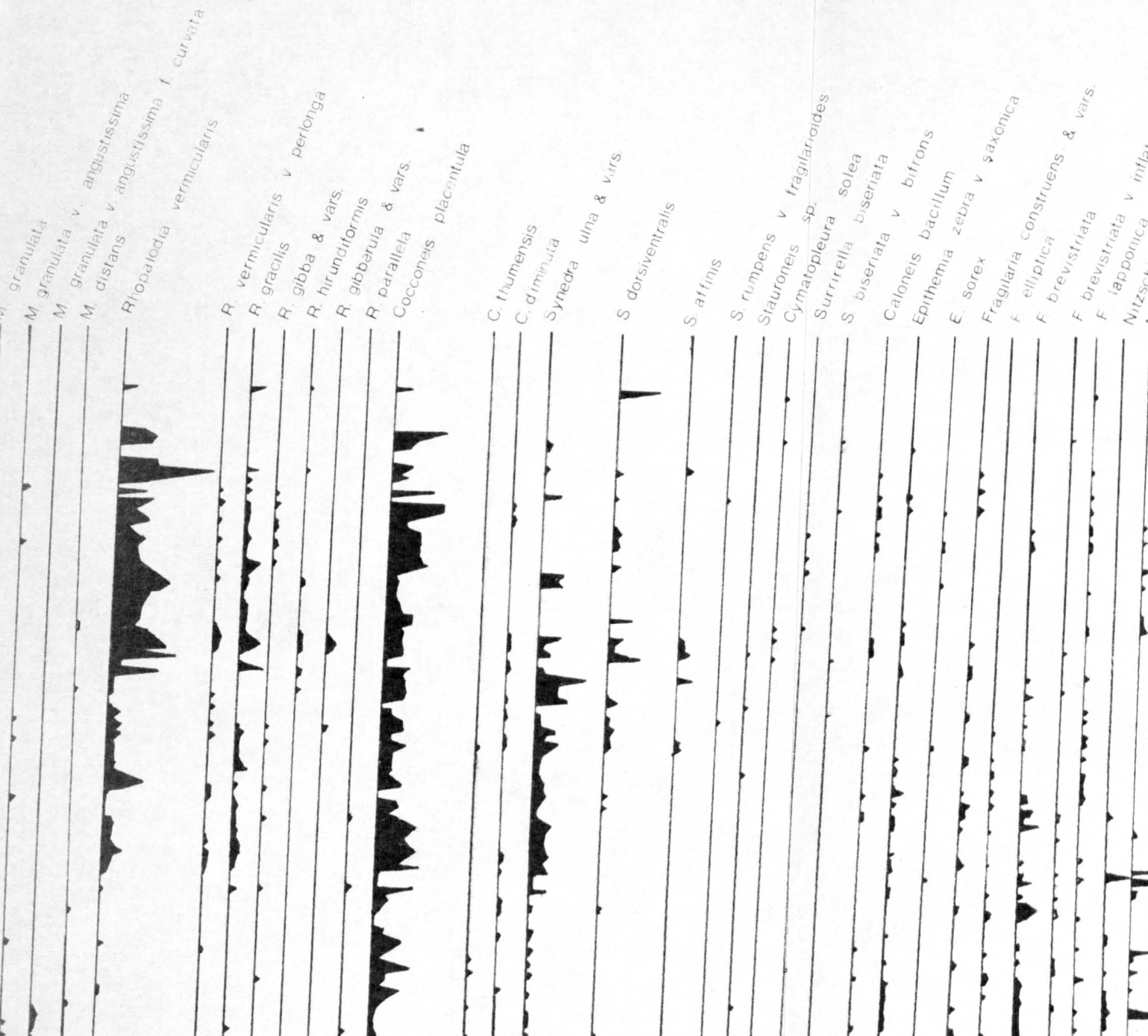
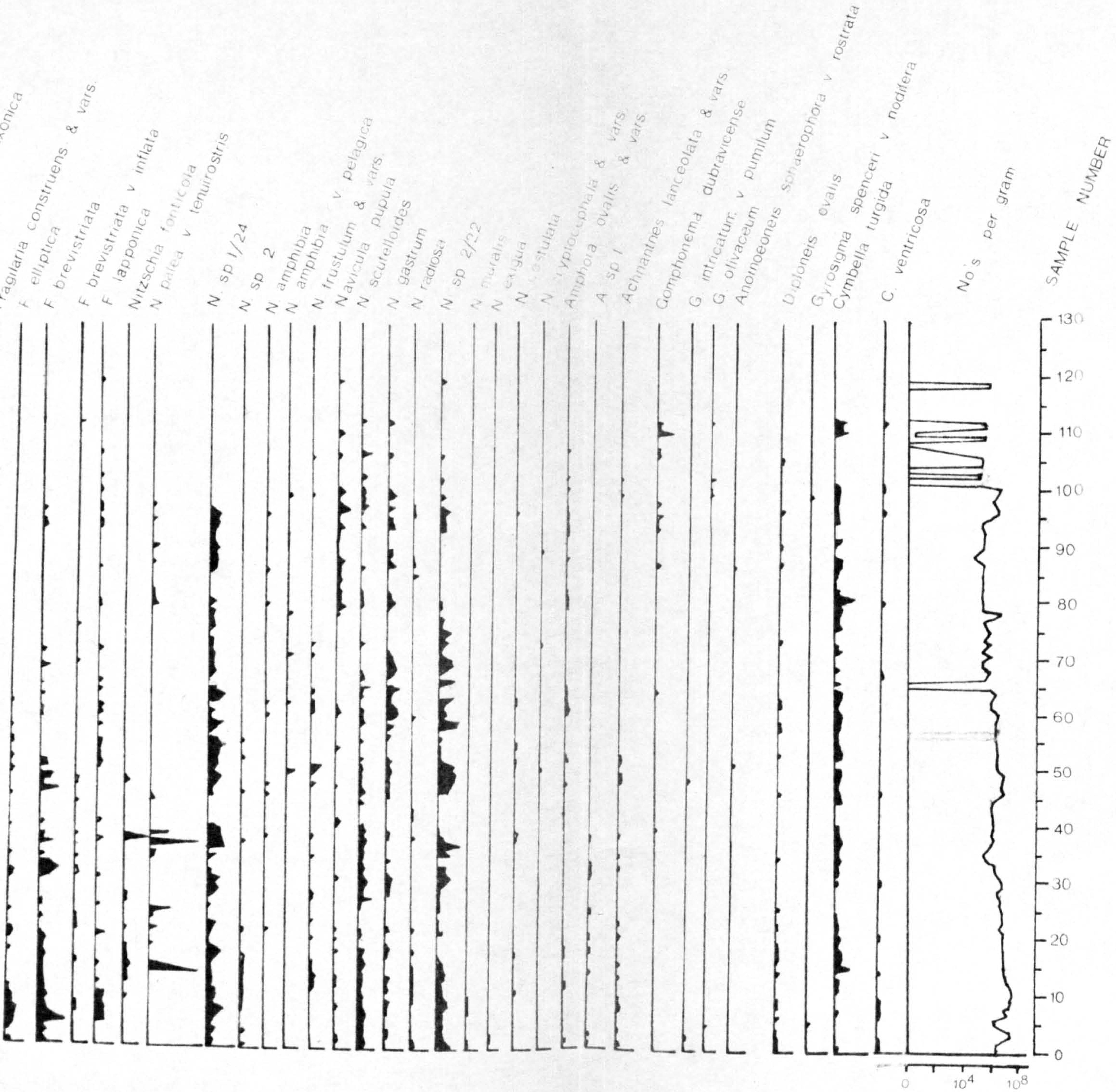
CONTAINS PULLOUTS

Fig. 3.2 The Dia



Diatom Stratigraphy Of Section 72, Area 103, East Turkana.





F. elliptica
F. brevistriata
F. brevistriata v. inflata
F. lapponica
Nitzschia fonticola
N. palea v. tenuirostris
N. sp 1/24
N. sp 2
N. amphibia
N. amphibia v. pelagica
N. frustulum & vars.
Navicula pupula
N. scutelloides
N. gastrum
N. radiosa
N. sp 2/22
N. muralis
N. exigua
N. costulata
Amphora ovalis & vars.
A. sp 1
Achnanthes lanceolata & vars
Gomphonema dubravicense
G. intricatum v. pumilum
G. olivaceum
Anomoeoneis sphaerophora v. rostrata
Diploneis ovalis
Gyrosigma spenceri v. nodifera
Cymbella turgida
C. ventricosa
No's per gram
SAMPLE NUMBER
0
10
20
30
40
50
60
70
80
90
100
110
120
130
0
10^4
10^8

ZONE B : Diatoms abundant, Synedra spp. and Cocconeis placentula common Rhopalodia vermicularis and Stephanodiscus spp. present. Melosira nyassensis var. victoriae occasionally abundant.

ZONE A : Diatoms abundant, Melosira spp. dominant, Stephanodiscus spp. common and occasionally dominant.

In general, the floral succession indicates an initially deep lake during the early Holocene, after which lake levels gradually fell. This fall was not continuous, but was interrupted by several transgressive episodes. A total regression from the area occurred towards the end of the middle Holocene.

3(ii)b The diatoms of Zone A

Mollusca occurring in Zone A sediments, some 100 m east of section 72, have been dated at 9880 ± 245 yr. B.P. by Raynolds (1972). This zone is characterised by an abundance of planktonic diatoms. The maximum possible water depth, based on topographic data and on the maximum shoreline heights recorded at East Turkana, is about 30 m. The most abundant of the planktonic species are Melosira agassizi, M. granulata-agassizi and M. agassizi var. malayensis. The first two have been grouped together in figure 3.2, since they are morphologically similar and may represent a single species. Stephanodiscus spp. form the second most important group, with S. astraea and its variety minutula becoming dominant at certain levels. Several other diatoms are important and include Cocconeis placentula, Fragilaria brevistriata, F. lapponica and Nitzschia palea var. tenuirostris.

For convenience of description, several subzones can be recognised, which are based on four diatom assemblages.

SUBZONE	DISTINCTIVE ASSEMBLAGE CHARACTERISTICS	DISTRIBUTION (cm)
(vii)	Nitzschia palea var. tenuirostris dominant	365-375
(vi)	Melosira spp. dominant	235-365
(v)	Stephanodiscus astraea var. minutula dominant	215-235
(iv)	Melosira spp. dominant	185-215
(iii)	Melosira/Stephanodiscus dominant	145-185
(ii)	Nitzschia palea var. tenuirostris dominant	135-145
(i)	Melosira/Stephanodiscus dominant	0-135

In the following description these subzones will be grouped together according to which of the four major assemblages is present.

A. Subzones (i) and (iii)

Subzones (i) and (iii) are characterised by a Melosira/Stephanodiscus flora, with roughly equal percentages of the two genera. However, the Stephanodiscus component is somewhat more common in the lower 50 cm of subzone (i). The dominant species are: S. astraea, S. astraea var. minutula, M. agassizi and M. granulata-agassizi. Other, less common, diatoms include: Cocconeis placentula, Fragilaria brevistriata, F. elliptica and Navicula scutelloides.

The Melosira/Stephanodiscus assemblage is planktonic, and as such suggests deep water, although proximity to a shoreline is suggested by the presence of benthonic and epiphytic diatoms. The flora is of oligohalobian nature (table 2.3, p. 73), and modern assemblages of this type are often found in slightly alkaline water.

B. Subzones (ii) and (vii)

The second assemblage, which occurs in subzones (ii) and (vii), is characterised by Nitzschia palea var. tenuirostris (40 to 50%). Other diatoms present include: Stephanodiscus spp., Melosira spp., Cocconeis placentula and Nitzschia fonticola. The dominant species is cited as a littoral type by Gasse (1975), and as such may reflect a shallowing of the lake.

C. Subzones (iv) and (vi)

A third assemblage occurs in subzones (iv) and (vi). This is dominated by Melosira agassizi, M. granulata-agassizi and M. agassizi var. malayensis. The percentage of each species varies, but together they form up to 98% of the total flora. Stephanodiscus astraea and its varieties form the second most common group of diatoms, but rarely exceed 10% of the total. Cocconeis placentula is the main benthonic contribution to the flora.

The high percentage of planktonic species suggests that deep water was prevalent. Melosira agassizi is endemic to the modern tropics and its abundance in these subzones and throughout Zone A, may reflect warm water. Today, M. agassizi occurs in dilute waters, such as those of Lake Victoria and Shiwa Ngandu. Its presence indicates much fresher waters than are found in modern Lake Turkana.

D. Subzone (v)

This subzone is characterised by the fourth diatom assemblage, which is dominated by Stephanodiscus astraea var. minutula (up to 90%). S. astraea and Melosira agassizi also occur. Benthonic species are at a lower percentage than at any other point in Zone A, which may suggest that the lake was at its deepest. Richardson (1968) has found that S. astraea and its varieties are only common in lakes with silica concentrations of between 0.1 and 10 mg/l. This suggests lower silica levels than other subzones dominated by Melosira spp. (which have higher silica requirements).

The large percentage of planktonic species in Zone A suggests that it represents a period of deep water, and therefore high lake levels. The zone terminates after a major decline in Melosira spp, and after the almost total disappearance of Stephanodiscus spp. and Nitzschia palea var. tenuirostris.

3(ii)c The diatoms of Zone B

The transition to Zone B occurs above a height of 375 cm from the base of section 72. Above this boundary there is an increased percentage of epiphytic and other littoral species (fig. 3.3). Rhopalodia spp. appear in significant numbers for the first time, while at several horizons Melosira nyassensis var. victoriae becomes important. Stephanodiscus spp. contribute significantly to the flora at many levels. A major feature of the zone is the presence of Synedra spp.. The upper boundary of the zone is less distinct than the lower. It has been placed above the last major bloom of Stephanodiscus astraea var. minutula, which also corresponds to a decline in Synedra spp.. This lies at 795 cm in section 72.

As with Zone A, several subzones can be recognised for descriptive purposes. In this case, seven subzones can be distinguished, and these are based on six diatom assemblages.

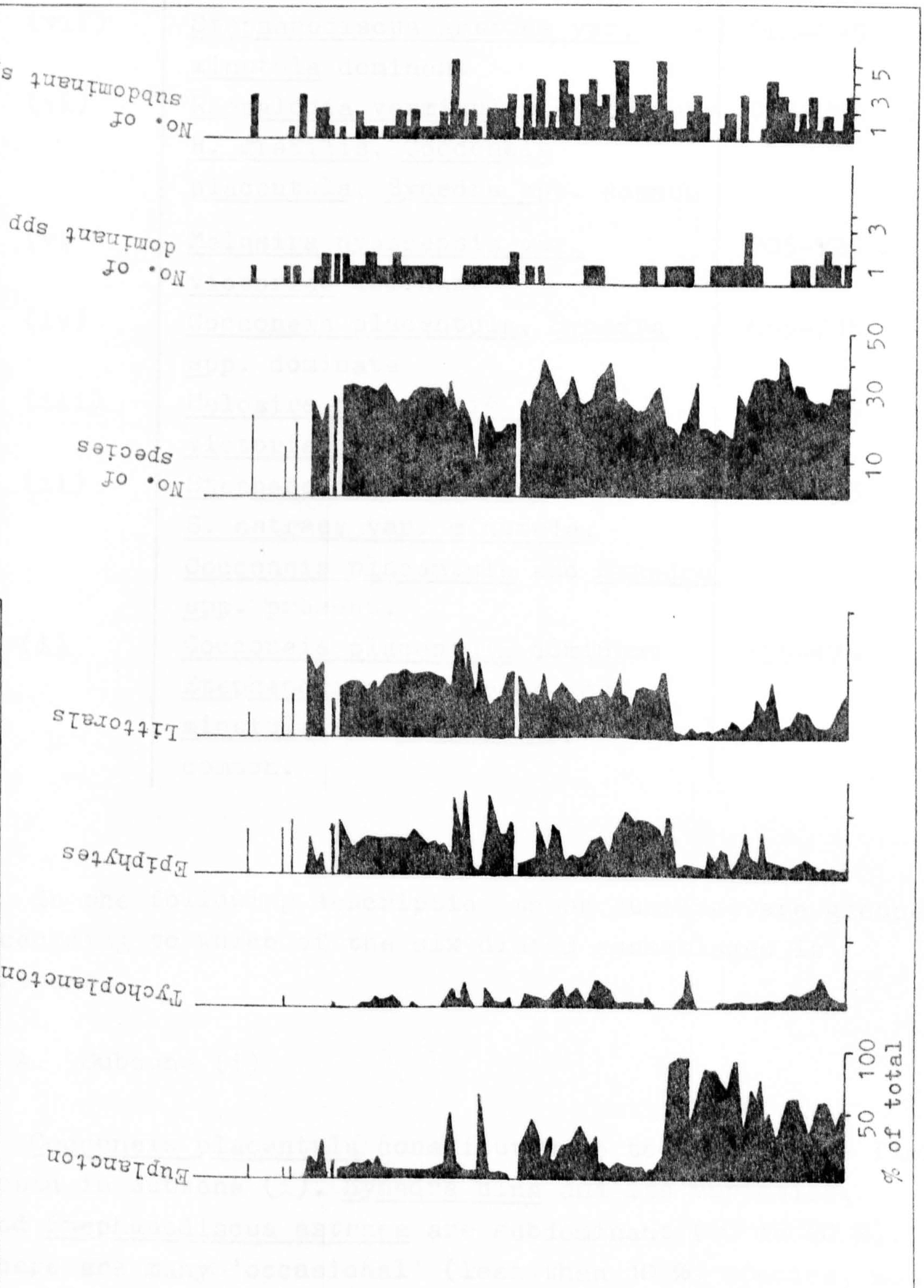


Fig. 3.3 Diatom evolution in section 72

SUBZONE	DISTINCTIVE ASSEMBLAGE CHARACTERISTICS	DISTRIBUTION (cm)
(vii)	Stephanodiscus astraea var. minutula dominant	765-795
(vi)	Rhopalodia vermicularis dominate R. gracilis, Cocconeis placentula, Synedra spp. common	725-765
(v)	Melosira nyassensis var. victoriae dominant	705-725
(iv)	Cocconeis placentula, Synedra spp. dominate	655-705
(iii)	Melosira nyassensis var. victoriae dominant	635-655
(ii)	Stephanodiscus astraea common, S. astraea var. minutula, Cocconeis placentula and Synedra spp. present.	475-635
(i)	Cocconeis placentula dominant Stephanodiscus astraea var. minutula and Synedra spp. common.	375-475

In the following description these subzones are grouped according to which of the six diatom assemblages is present.

A. Subzone (i)

Cocconeis placentula constitutes up to 30 % of the flora found in subzone (i). Synedra ulna and its varieties, and Stephanodiscus astraea are subdominant (10 to 20 %). There are many 'occasional' (less than 10 %) species, most of which belong to the genera Epithemia, Navicula and Cymbella. All, except S. astraea, occur in littoral areas of modern lakes. The large number of epiphytes suggests the presence of aquatic plants. Talling and Talling (1965), and Richardson (1968) have observed that Synedra ulna dominates or is common in lakes that have a dissolved silica range of 15 to 30 mg/l. This suggests a high silica content in the palaeolake.

B. Subzone (ii)

In the second assemblage of Zone B, which occurs in subzone (ii), Stephanodiscus astraea becomes important (up to 25 %), while its variety minutula constitutes about 10 % of the total flora. Synedra spp. remains common, but Cocconeis placentula declines in comparison to subzone (i). Important 'occasional' species include Melosira agassizi and M. nyassensis var. victoriae. The rise in planktonic species (fig. 3.3) since subzone (i) suggests a deepening of the lake.

C. Subzones (iii) and (v)

These two subzones are characterised by the same flora. There is a strong dominance of Melosira nyassensis var. victoriae (50 to 70 %). The flora resembles that found in the deeper water of Lake Victoria. It differs in the higher percentage of Melosira nyassensis var. victoriae found here, and by an absence of Melosira ambigua. The assemblage suggests deep waters, possibly the deepest indicated by the Zone B record.

D. Subzone (iv)

Diatoms are absent, other than as fragments from the base of this subzone. This may reflect a period of emergence or near emergence. The flora in the remainder of the subzone is dominated by Synedra ulna (30%), and by Cocconeis placentula (20%). The strong epiphytic component suggests an abundance of macrophytes, although these decline at the top of the subzone. All the diatoms occur in shallow waters of modern lakes, and probably reflect a regression between subzones (iii) and (iv).

E. Subzone (vi)

The dominant species in this subzone are Rhopalodia vermicularis (45%) and R. gracilis (20%). Subdominant diatoms include Cocconeis placentula and Synedra spp.. These are all found in littoral situations today. The Rhopalodia spp. occur in modern Lake Turkana at its fresher, northern end, and are often associated with littoral reeds. Planktonic species occur, but in very low percentages, and include Melosira nyassensis var. victoriae and Stephanodiscus astraea.

F. Subzone (vii)

Stephanodiscus astraea var. minutula (60%) dominates in this subzone. It is a planktonic diatom and indicates the last major rise in lake level, as reflected in the record of section 72. Rhopalodia vermicularis and other littoral diatoms remain common and suggest a proximity to a shoreline.

Zone B represents a period of lower lake levels than Zone A. Evidence exists for emergence or near emergence at several horizons. It should be noted that by the end of Zone B times the lake floor was some 8 m higher than it had been at the commencement of Zone A times.

3(ii)d The diatoms of Zone C

Zone C begins at a height of 795 cm. It is typified by a reduction in the percentage of Synedra spp., except at one or two horizons, and by a dominance of Rhopalodia vermicularis (15 to 45%) and Cocconeis placentula (10 to 40%). Other diatoms include: Rhopalodia gracilis, R. vermicularis var. perlonga, Synedra ulna, S. dorsiventralis, Navicula pupula and Cymbella spp. Planktonics are rare.

Two subzones have been recognised and these are as follows.

SUBZONE	DISTINCTIVE ASSEMBLAGE CHARACTERISTICS	DISTRIBUTION (cm)
(ii)	Cocconeis placentula dominant	885-1025
(i)	Rhopalodia vermicularis dominant	795-885

The assemblages of both subzones are similar. They have been separated, for descriptive reasons, on the basis of the dominant diatom.

A. Subzone (i)

Subzone (i) is characterised by Rhopalodia vermicularis (20 to 45%), with Cocconeis placentula occurring as a subdominant. Rhopalodia gracilis (5%) is also present. The dominance of Rhopalodia species suggests a water chemistry similar to that at the north end of Lake Turkana, where the genus is common today. The predominance of littoral species suggests shallow waters, probably rich in reeds.

B. Subzone (ii)

In this subzone Cocconeis placentula becomes dominant (25 to 40%), and Rhopalodia vermicularis declines. Gomphonema dubravicense appears in the flora, while the genus Synedra is represented only by S. dorsiventralis. This flora suggests shallow littoral areas, possibly rich in reeds. In the middle of the subzone a minor transgression is reflected by a slight increase in planktonic species. These include Stephanodiscus astraea, S. astraea var. minutula and Melosira nyassensis var. victoriae.

Zone C represents a period when littoral conditions prevailed across the area of section 72. The upper boundary occurs at a minor unconformity at 1025 cm.

3(ii)e The diatoms of Zone D

Zone D lies above a minor unconformity at 1025 cm. It differs from the other zones in that it is based on rapid changes in diatom numbers (0 to 10^7 valves/g sed.). The flora is dominated by littoral species.

The subzones recognised, including two separated because they lack diatoms, are as follows.

SUBZONE	DISTINCTIVE ASSEMBLAGE CHARACTERISTICS	DISTRIBUTION (cm)
(v)	No diatoms	1195-1300
(iv)	*Synedra*/*Melosira* dominant	1185-1195
(iii)	No diatoms	1125-1185
(ii)	*Cocconeis placentula* dominant	1075-1125
(i)	*Rhopalodia vermicularis* dominant	1025-1075

The main features of these subzones are as follows.

A. Subzone (i)

The bottom and top of this subzone consists of only rare diatoms and occasional fragments. Between these two levels *Rhopalodia vermicularis* dominates (20 to 60%), with *Cocconeis placentula* forming between 10 and 25 % of the flora. Stephanodiscus astraea is the most common planktonic species, but does not exceed 10% of the flora.

The fragmentation, low numbers of diatoms, and littoral species suggest shoreline conditions at this time.

B. Subzone (ii)

Cocconeis placentula dominates (30%), with Rhopalodia vermicularis forming less than 25%. Melosira agassizi var. malayensis occurs at the top of the subzone, but forms less than 15% of the flora. Shallow waters are probable, although there may have been a slight deepening by the end of the subzone.

These sediments lie at a height of about 70 m above the modern lake, indicating that while the lake was shallowing at this site (partly due to sediment infilling), the lake still stood well above modern lake heights.

C. Subzones (iii) and (v)

No diatoms occur in these subzones. The sediments are composed of subarkosic, cross-bedded sands that resemble modern beaches around lake Turkana.

D. Subzone (iv)

This subzone is dominated by Synedra dorsiventralis (25%) and Melosira agassizi var. malayensis (15%). Other common species include: Rhopalodia vermicularis, R. gracilis and Cocconeis placentula. Synedra dorsiventralis occurs in littoral and planktonic habitats today. Its association with M.agassizi var. malayensis suggests a slight deepening, and the final transgression recorded by section 72.

Several minor unconformities occur in Zone D. These, and the rapid changes in diatom numbers suggest proximity to a shoreline and fluctuating lake levels.

3(iii) The palaeoecological implications of the diatoms of section 72

3(iii)a The chemistry of the palaeolake

Floristic changes in section 72 have resulted mainly from the effects of lake level fluctuations on planktonic and benthonic diatoms. However, certain palaeoecological inferences can be made.

The varying dominance of diatoms favoured by low silica concentrations (Stephanodiscus spp.), and species favoured by higher silica levels (Melosira spp., Synedra spp.), suggests that the silica content fluctuated. Throughout this period silica was probably equal to or greater than it is today.

The pH of the lake appears to have remained fairly constant during the deposition of section 72. Alkaliphilous (table 2.2, p. 71) species dominate, while 'indifferent' and alkalibiontic diatoms occur much less often. The flora suggests a pH of about 7.5 to 8.5 (the modern lake has a pH of 9.2, at Koobi Fora).

The flora is dominated by oligohalobian diatoms (tolerant of total salinities of 0.2 to 2.0‰). Occasional mesohalobian (2 to 16‰) species, such as Rhopalodia gibberula, reflect an increasing salinity towards the top of the section.

The large numbers of diatoms may reflect nutrient-rich water. Diatoms such as Cocconeis placentula are often suggestive of high nitrate levels (Patrick, 1961).

3(iii)b The physical aspects of the palaeolake

The diatoms in section 72 include species that are confined to the modern tropics, and wider ranging cosmopolitan forms. The tropical diatoms reach their highest percentages in Zones A and D. However they occur throughout the section and suggest warm waters.

In the lower part of the section, alternating light diatom-rich, and dark diatom-poor, laminated silts, suggest periodic water and sediment input to the lake. This in turn may reflect a periodicity (possibly seasonal) to the palaeoclimate.

Two major high lake level periods can be recognised from the diatoms of section 72, together with many, probably shorter-lived, transgressive episodes. However lake levels probably did not fall below about 50 m during deposition. The highest lacustrine sediments representative of this period occur between 75 and 80 m above the modern lake.

3(iv) The geology of section 72

3(iv)a The lithology of section 72

The lithological succession is shown in figure 3.4. The sediments are poorly consolidated, and dominated by diatomaceous silts and sands.

Grain-size analyses have confirmed the dominance of silt grade deposits in the lower ten metres (fig. 3.5). Fine to medium silts (5 to 8.5 phi) form up to 65 wt.%, and coarse silts (3.5 to 5 phi) up to 30 wt.% of sediment samples. The grain size distribution of the silts is unimodal and skewed to the right in samples from the lower six metres. Clays from these lower six metres constitute up to 28 wt.% of the sediments. Fine sands (2 to 3.5 phi) make up to 75 wt.% of samples from the upper three metres. Coarser sands never occur above 5 wt.%, except between 1120 and 1140 cm, where they form about 60 wt.% of the sediment.

The silts are rich in diatoms and laminated throughout. Varying diatom numbers in the lower two to three metres result in alternating light and dark bands about 0.5 cm thick. At higher levels varying shades of grey and brown occur, but not in distinct bands.

Excluding diatoms, which may form up to 80 % of a silt sample, feldspars are the dominant constituent. Albite is usually the most common mineral (up to about 50 %), with microcline and orthoclase also common (up to about 30 % each). Quartz may form up to 25 % of the silts, but is usually less than about 15 %. Montmorillonite is the only common clay mineral and contributes from <u>ca</u>. 5 to 28 %. Biotite and muscovite contribute small amounts to the sediment (and are best observed in hand specimen). Other minerals detected by X-ray diffraction include: chlorite, hornblende, magnetite, haematite and ilmenite.

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Fig. 3.4

The Lithology of Section 72 - Area 103, East Turkana.

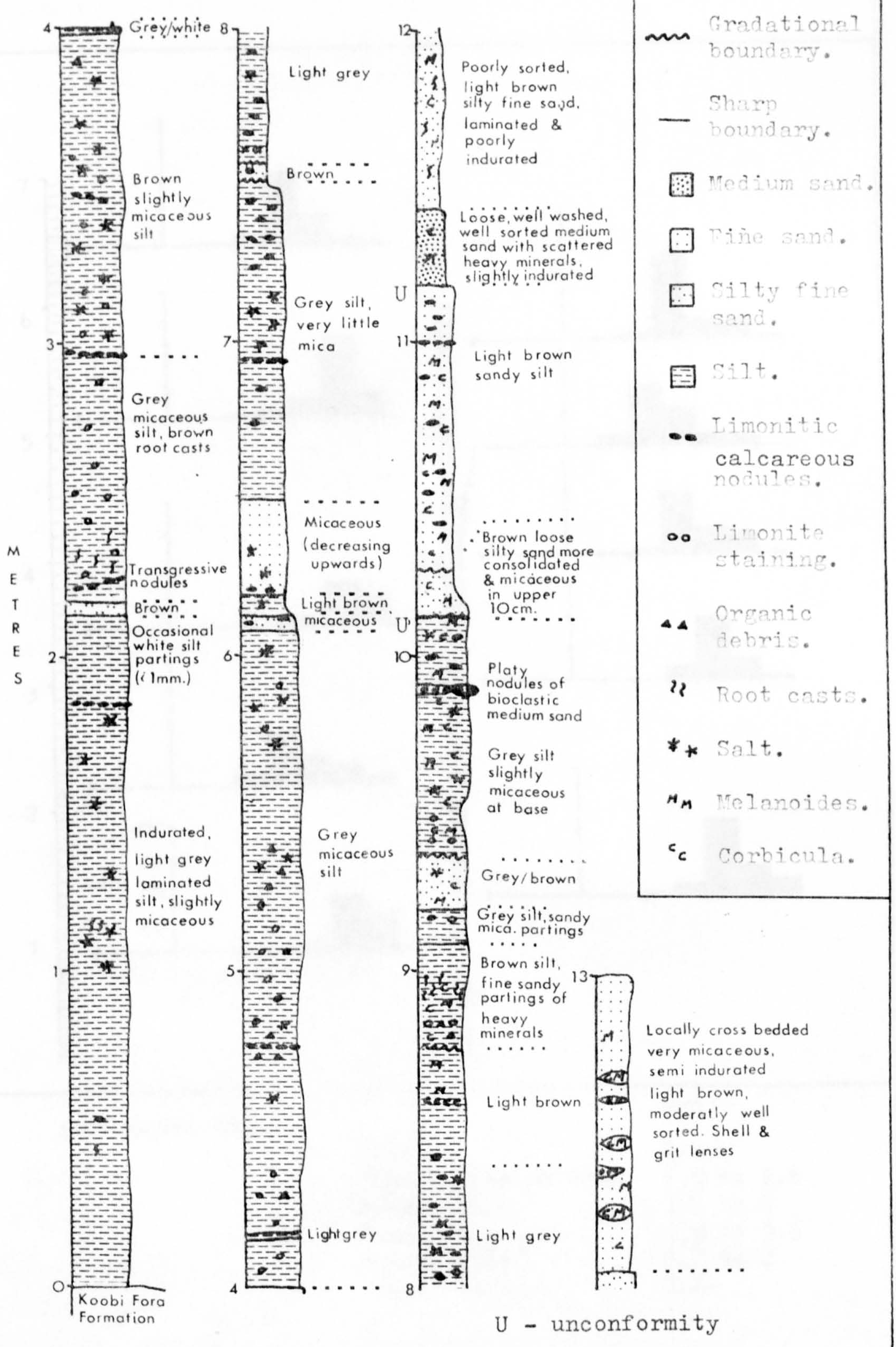
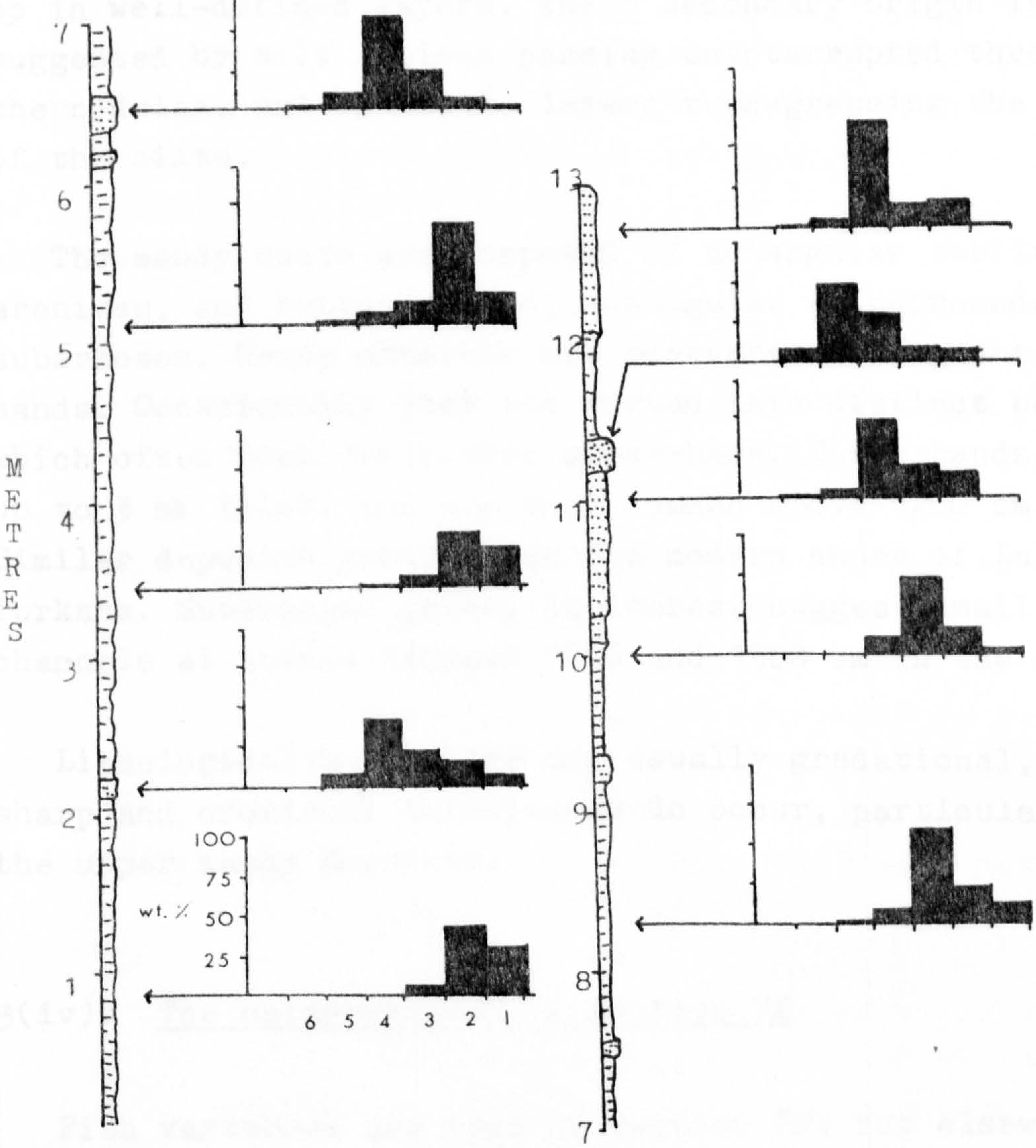


Fig. 3.5

Grain size frequency distributions in section 72



Horizontal axis:

		PHI
1:-	clay.	8.5+
2:-	fine to medium silt.	5.0 to 8.5
3:-	coarse silt.	3.5 to 5
4:-	fine sand.	2.0 to 3.5
5:-	medium sand.	0.2 to 2
6:-	coarse sand.	0.2-

Calcite is also present, mostly as shell debris, in a few samples. A typical X-ray diffraction of the silts of section 72 is shown in figure 3.6.

Limonite-stained, carbonate-cemented, siltstone nodules are common in the silts and fine sands. These are a flattened ovoid shape with a long axis of up to 12 cm. They occur scattered through the deposits, and also line up in well-defined layers. Their secondary origin is suggested by silt laminae passing uninterrupted through the nodules, and by nodule layers transgressing the laminae of the silts.

The sandy units are composed of subangular sublitharenites, and better sorted, subangular to subrounded subarkoses. Heavy minerals are scattered throughout the sands. Occasionally they are sorted into distinct bands, which often pick out planar cross-beds. These bands are up to 3 mm thick, and are most common above 1200 cm. Similar deposits occur along the modern shore of Lake Turkana. Subangular grits, in lenses, suggest small channels at levels between 1200 and 1300 cm in the section.

Lithological boundaries are usually gradational, but sharp and erosional transitions do occur, particularly in the upper sandy deposits.

3(iv)b The palaeontology of section 72

Fish vertebrae are rare in section 72, but elsewhere are common in silts, and include *Lates*, *Tilapia* and *Clarius*.

Molluscs are abundant, and are found both scattered and in 'pockets'. *Mutela emini*, *Etheria elliptica* and *Pila ovata* occur in the sandier units. *Melanoides tuberculata*, *Corbicula africana*, *Cleopatra pirothii* and *Caelatura sp*. are found in both sands and silts. Several other species occur in the sediments lateral to the section, but these are dealt with in chapter 4.

Carbonised root marks and plant debris occur at several levels within the silts, and are also found in the silty sands between 1140 and 1200 cm.

3(iv)c <u>The nitrate and carbonate content of section 72</u>

Salts occur at several levels within the silts. A chemical analysis showed this to be sodium nitrate (nitratine). A semi-quantitative estimate of the percentage of nitratine present in section 72 was established using the following method.

(i) A reference collection of samples with 5, 10, 25, 50 and 90 wt. % sodium nitrate was made by adding this compound to nitrate-free silt.

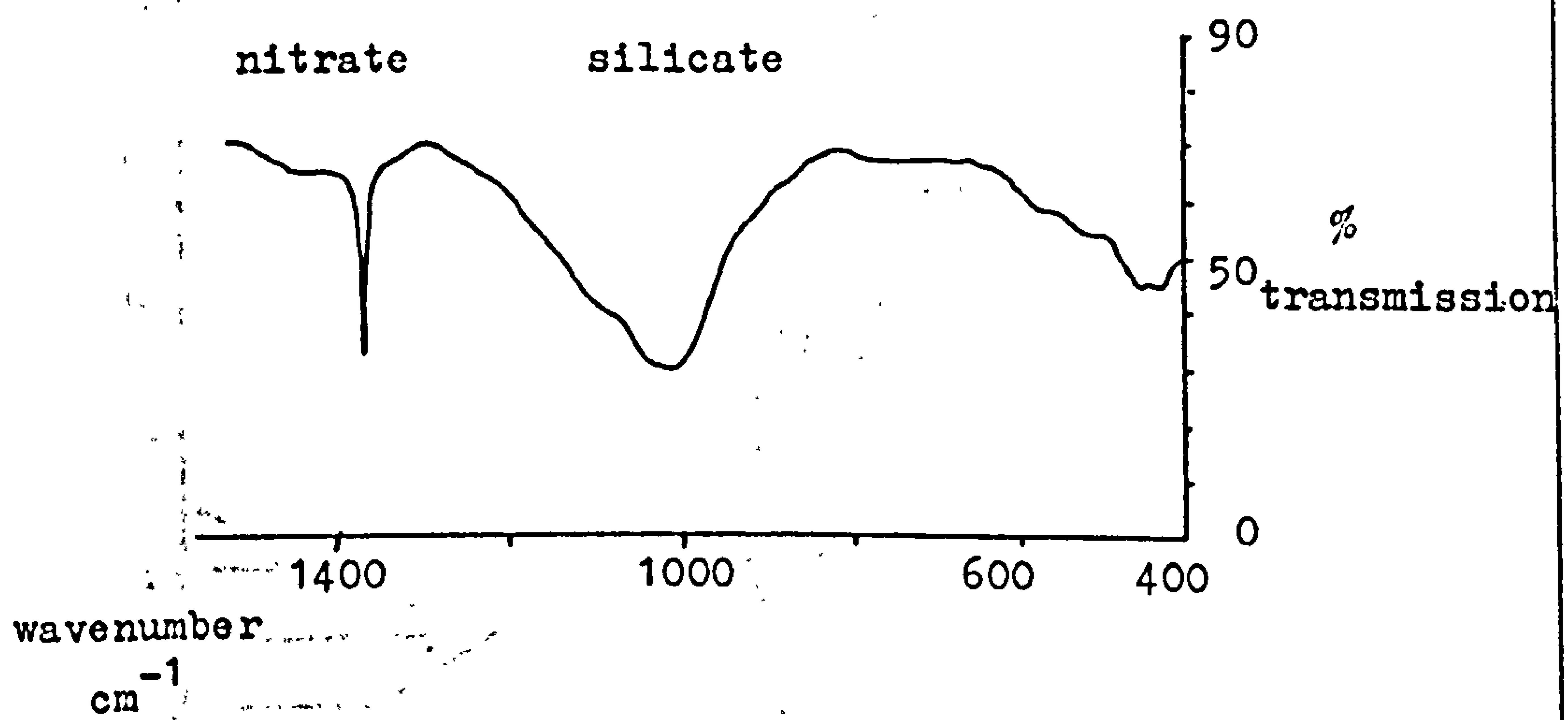
(ii) The infra-red spectrum of these samples was obtained. Using the % transmission readings at the side of the chart, the log of the reciprocal of the top of the silicate peak was subtracted from the log of the reciprocal of the base of the silicate peak. Having done the same for the nitrate peak, the ratio between the two was established.

(iii) The ratio obtained from stage (ii) was then calibrated against the known wt. % of sodium nitrate for each of the specially prepared samples. The data from this procedure could then be used to estimate the wt. % of sodium nitrate from the infra-red charts.

A typical example of the infra-red spectrum of the nitrate rich silts is shown in figure 3.6, while the percentage of nitrate in section 72 is shown in figure 3.7. Here, the sodium nitrate fluctuates between 0 and 8 wt % up

Fig..3.6 Typical infra-red spectrum and X-ray diffraction of the silts from section 72

Infra-red spectrum of silts
70 cm from base of section 72



X-ray diffraction of silts
120 cm from the base of section 72

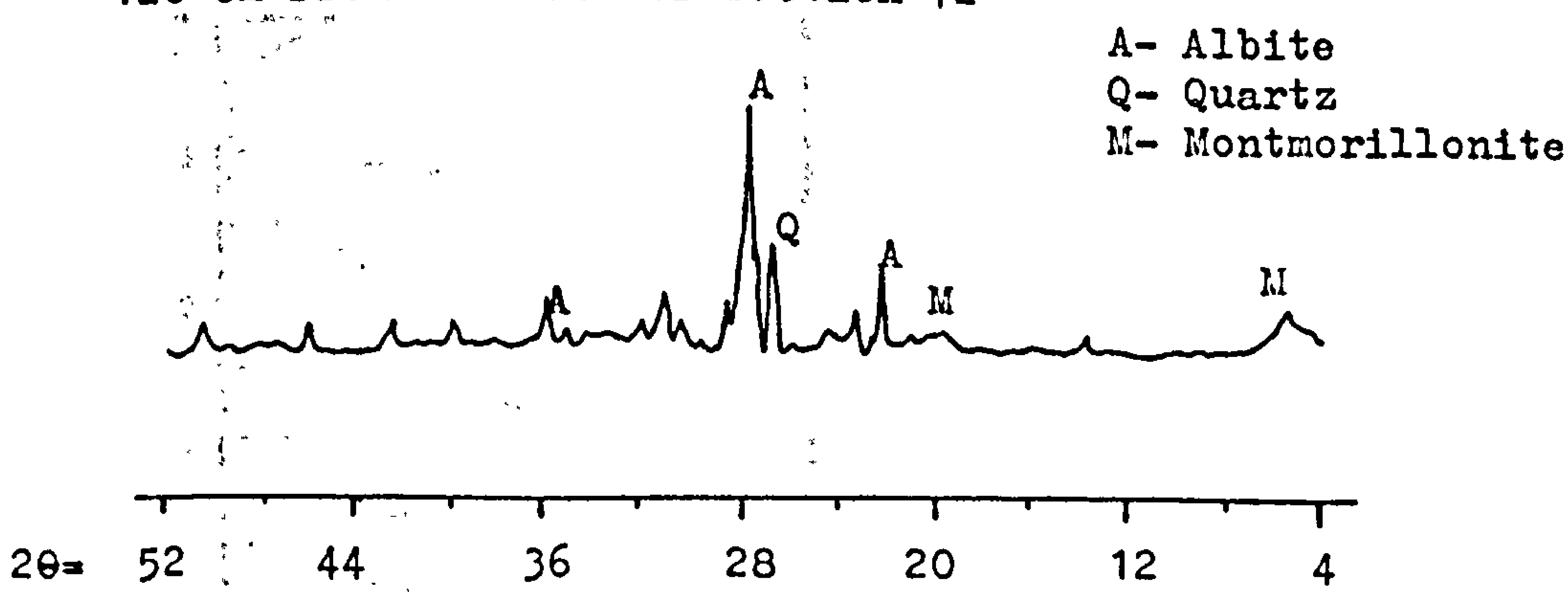
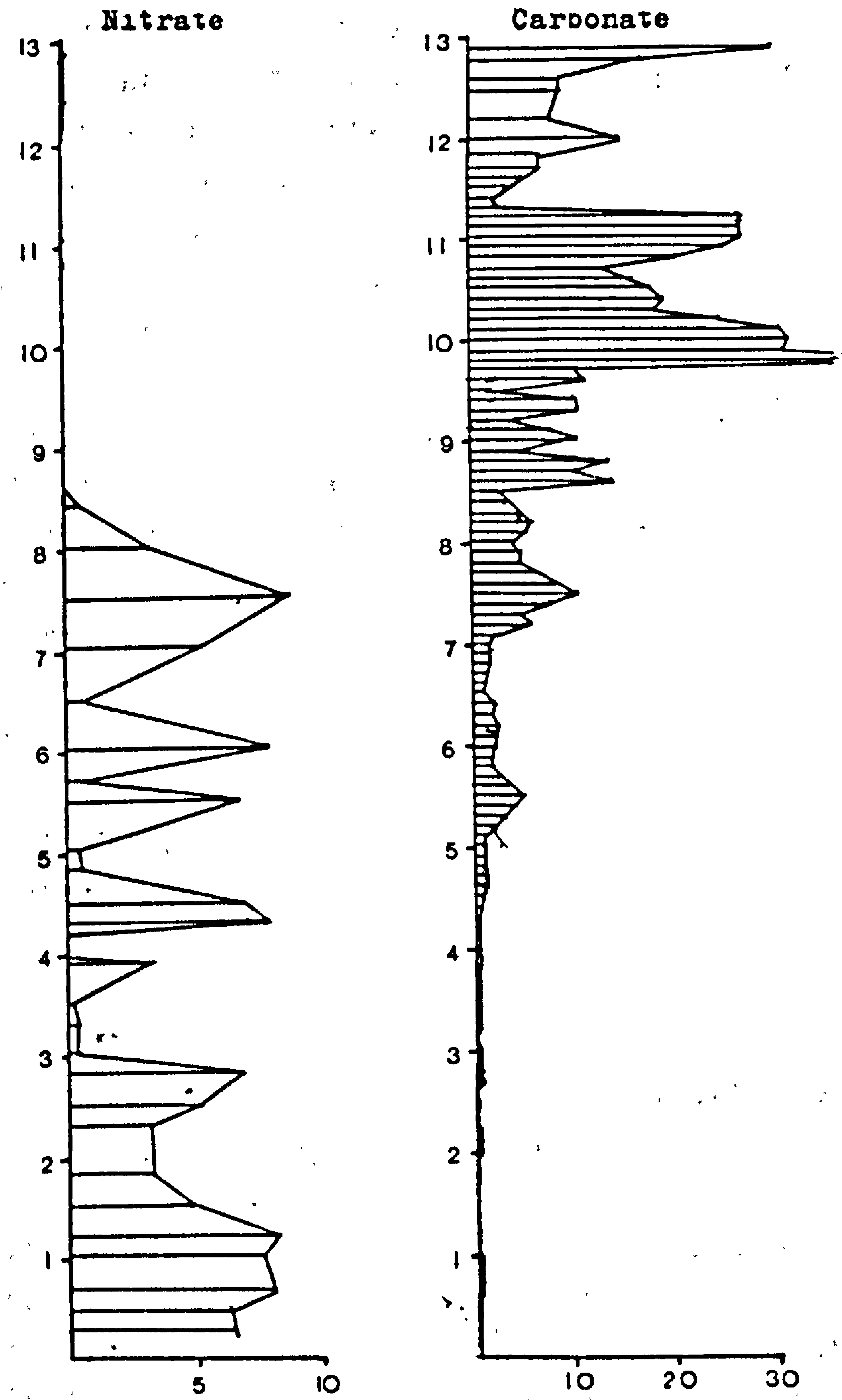


Fig. 3.7

The stratigraphic development of Nitrate and Carbonate in section 72.



% of total rock

mg. CO_2 released/g. sed.

1) Nitrate determined by infrared methods (semi-quantitative)

2) Carbonate determined by calcimeter (based on release of CO_2)

to a height of 850 cm.

Two possible origins of the nitratine can be considered.

(i) It may be primary and reflect a lake rich in nitrate (modern Lake Turkana has little nitrate). However, nitrate is easily dissolved and it seems unlikely that it would form while the area was covered by a freshwater lake. A later Holocene period of volcanism from North Island is indicated by lavas stepping over high lake level erosional benches. This activity may have provided a source of nitrate to the lake.

(ii) At Eliye Springs near Fergusons Gulf (western Lake Turkana), nitrate-rich waters are associated with leaching from nearby soils. An explanation such as this, involving a local origin is better than the one above, since the nitrate is confined to the silts of Area 103. This leaching process would probably have operated since lake regression.

The carbonate content was established by adding HCl and measuring the release of CO_2 (fig. 3.6). The carbonate increases from the bottom to the top of the section, but irregularly. The carbonate appears to be associated with shell material (whole or fragmentary). The increase in carbonate probably reflects greater proximity to littoral areas, in which molluscs thrived.

Primary precipitates probably contribute little to the carbonate content in view of the neutral to slightly alkaline pH of the palaeolake. In contrast, the modern high alkalinity and pH cause the lake to be saturated with Ca and Mg carbonates (Yuretich, 1979). As a result calcite is apparently precipitated, much of it biologically by ostracods in the southern basin of Lake Turkana. Carbonate rich cores have been recovered from the lakes northern basin (Barton, pers. comm.), which may be of a primary chemical origin.

CHAPTER 4

THE GEOLOGY AND DIATOM STRATIGRAPHY OF AREAS 102 AND 103

4(i) The sedimentology, palaeontology and dating of the Holocene deposits of Areas 102 and 103

4(i)a Introduction to the geology and location of Areas 102 and 103

Areas 102 and 103 lie some 5 to 10 km to the east and south-east, respectively, of Koobi Fora (fig. 1.2, p. 29). For descriptive reasons, these areas have been split into smaller sectors, which will form the framework for discussing the sediment distribution.

Holocene lacustrine and fluvio-lacustrine sediments (plate 4.1) are widely distributed throughout Areas 102 and 103, and represent a series of former, higher lake levels. Figure 4.1 shows a map of the major lithofacies present. Many of the facies indicated are diachronous, or formed during one or more distinct time periods. No time implications should therefore be drawn from this map. The general sedimentological, palaeontological and dating aspects of these deposits will be discussed in the rest of this section, before going on to describe the sediment distribution in more detail.

4(i)b The sedimentology of the Galana Boi Formation to the east of Koobi Fora

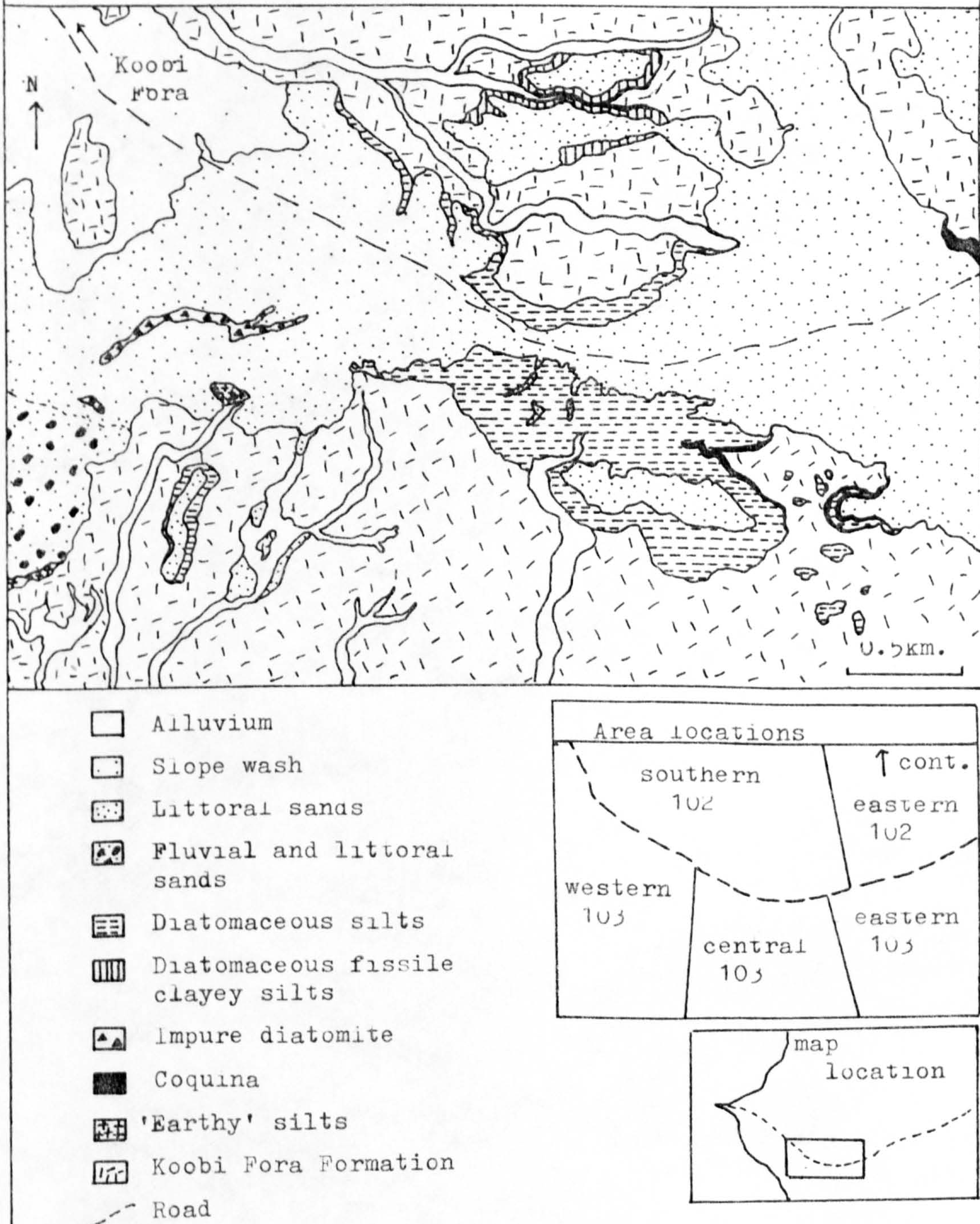
The sediments of Areas 102 and 103 display rapid facies changes, both vertically and laterally. These changes are related to variations in grain size, structure and mineralogy (mainly differences in the quartz to feldspar

Plate 4.1

Area 103, looking north. Early and middle Holocene lacustrine, diatomaceous silts and sands can be seen. These are up to 35 m thick, and stand up to 80 m above the modern lake. The lighter deposits contain a higher percentage of diatoms. The sediments generally dip lakewards (to the left of the photo), and are deeply incised. Note the Landrover (arrowed) for scale.

Fig. 4.1

Facies map of Areas 102 and 103, East Turkana.



N.B. Aeolian cover sands ignored.
The boundaries separate the facies both vertically and horizontally. The sediments are often time transgressive and no time relationships should be drawn from this map.

plus lithics ratio). The complexity of the sediments is due to numerous shifts of environment during their formation. These environmental shifts were a response to the interaction of lake level fluctuations and a much eroded topography.

As in section 72 (chapter 3), fine sands (2.0 to 3.5 phi) and silts (3.5 to 8.5 phi) dominate. Coarser units are less common, except in the western sector of Area 103 (fig. 4.1). Twenty sediment samples, representing both silts and sands, all possessed a unimodal grain size distribution. Sorting ranged from good to poor.

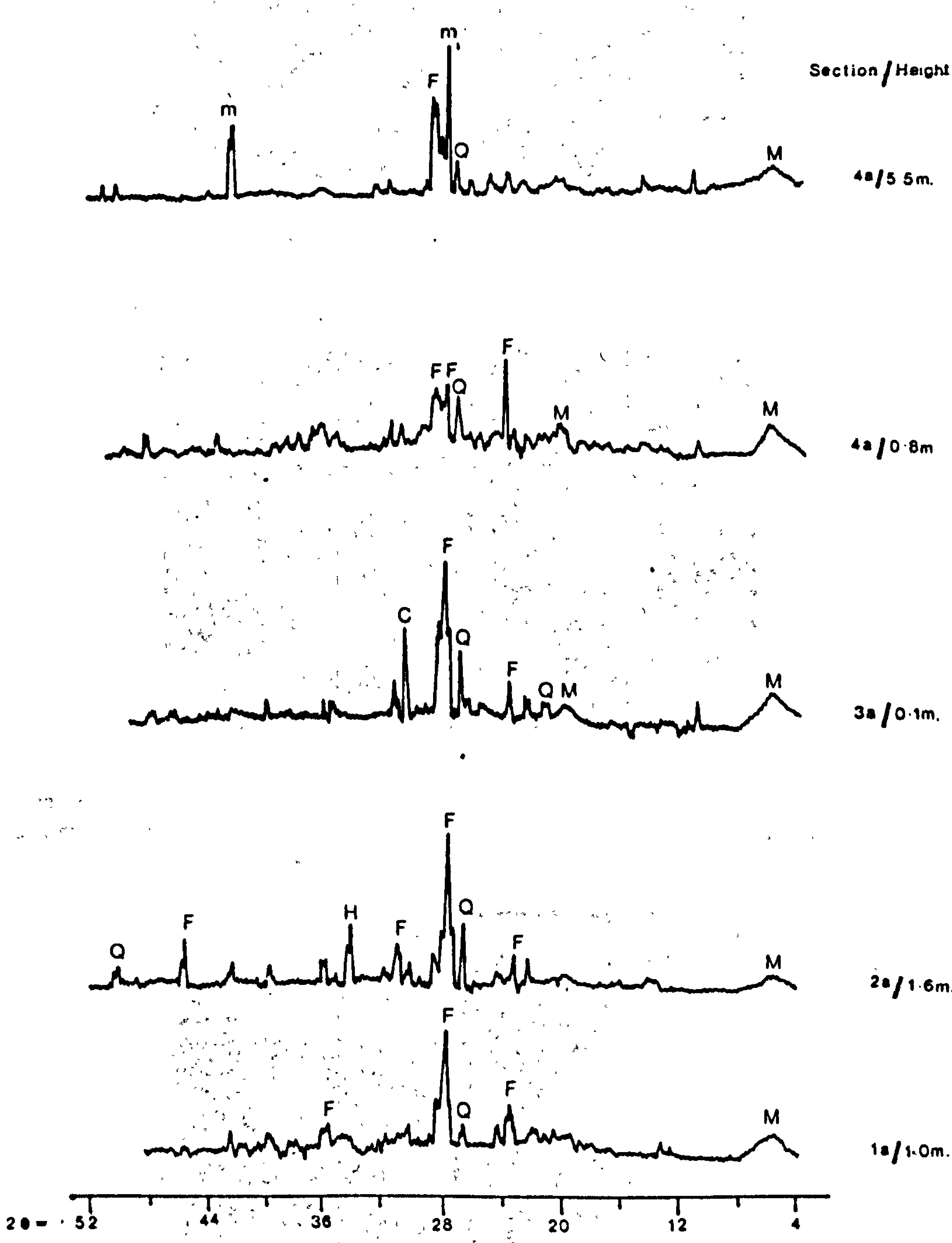
Deposition was closely related to the palaeotopography. Bedding or laminae in the silts closely parallels the pre-existing surface. Initial dips of up to 15^{o} are common at the base of many sections. As the flooded palaeovalleys were gradually infilled, topographic surfaces became gentler and dips declined. Disconformities and minor unconformities (related to lake level changes) are common in the sands, but also occur in the silts.

X-ray diffraction of the silts show them to be similar to those in section 72 (p.105). Several typical diffraction spectra are shown in figure 4.2, and a thin section is shown in plate 4.2.

Sands were examined in thin section (plate 4.2), and by X-ray diffraction. They are dominated by moderately to well sorted, subrounded, subangular and angular, sublitharenites, subarkoses, arkosic arenites and litharenites. The mineralogy and descriptive terminology of the sands is shown in figure 4.3. Most units are loose, although a few are weakly cemented with calcite. Often, calcareous cementation was best developed in the surface of outcrops. Arkosic arenites and litharenites tend to be found today on the floors of ephemeral rivers, and at their point of entry into the lake. The better sorted subarkoses and sublitharenites are more common along the modern

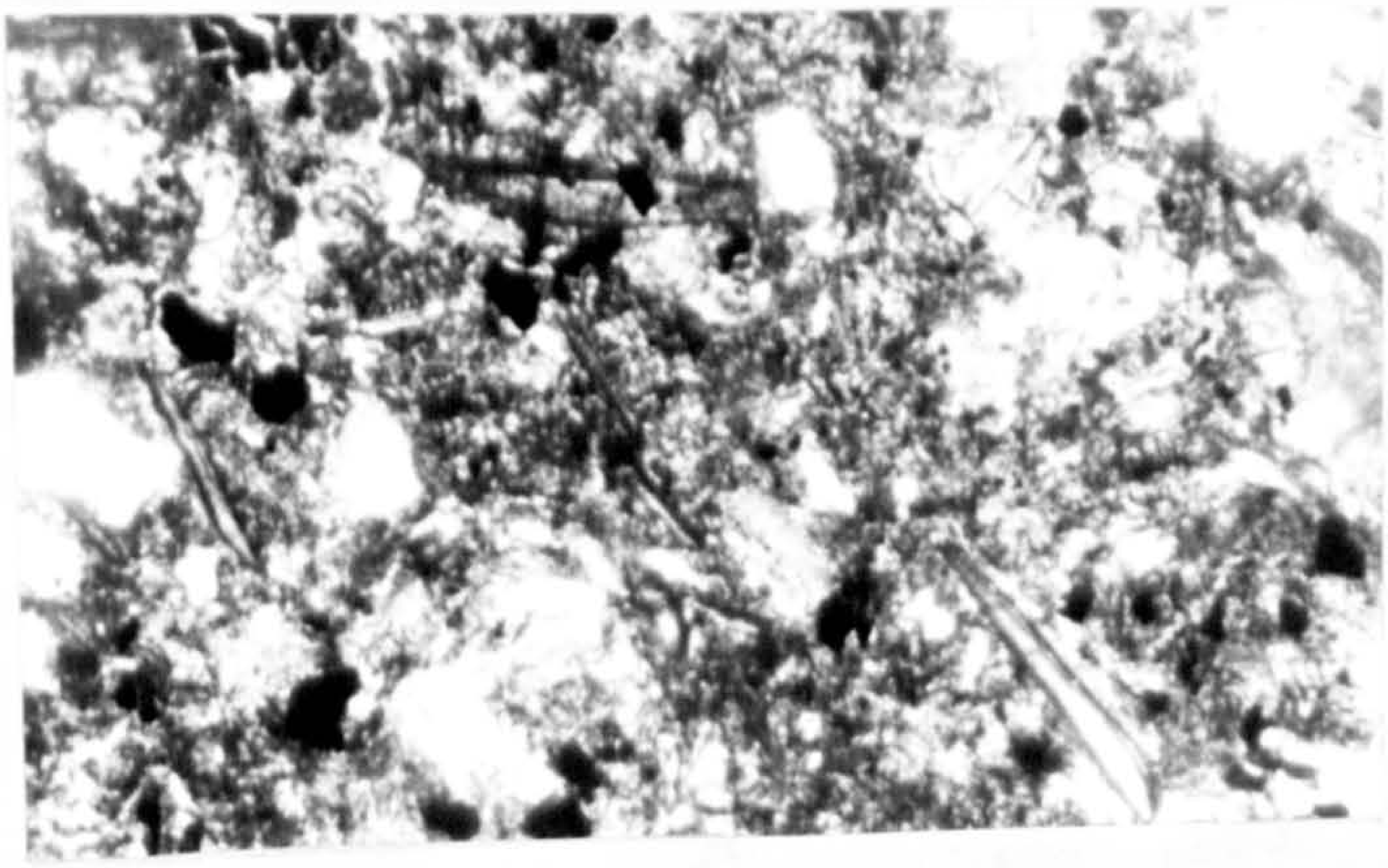
Fig. 4.2

Area 103 : X-Ray Diffraction Spectra

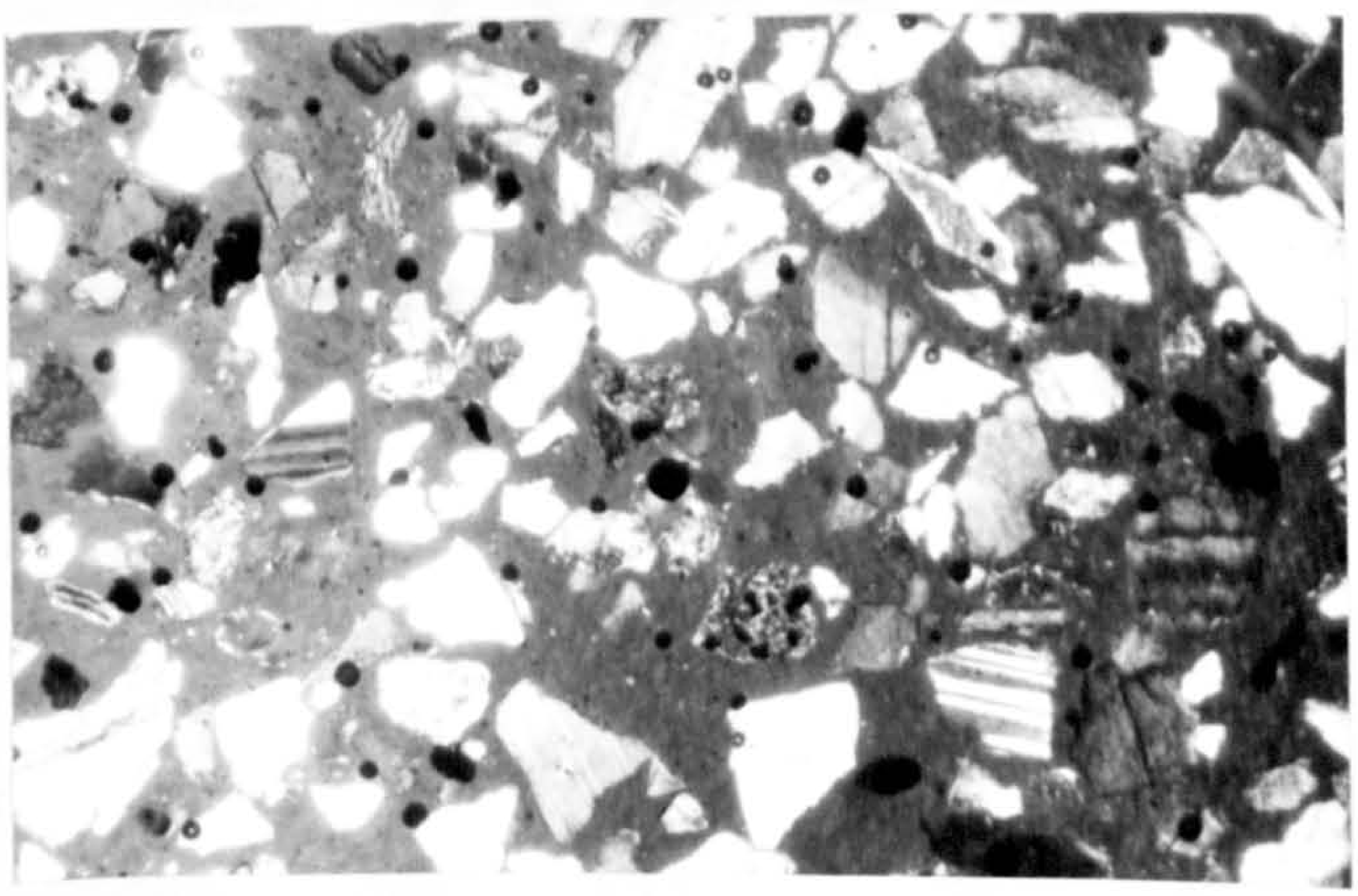


Q – QUARTZ
m – MICROCLINE
F – FELDSPAR
M – MONTMORILLONITE
C – CALCITE
H – HORNBLENDE

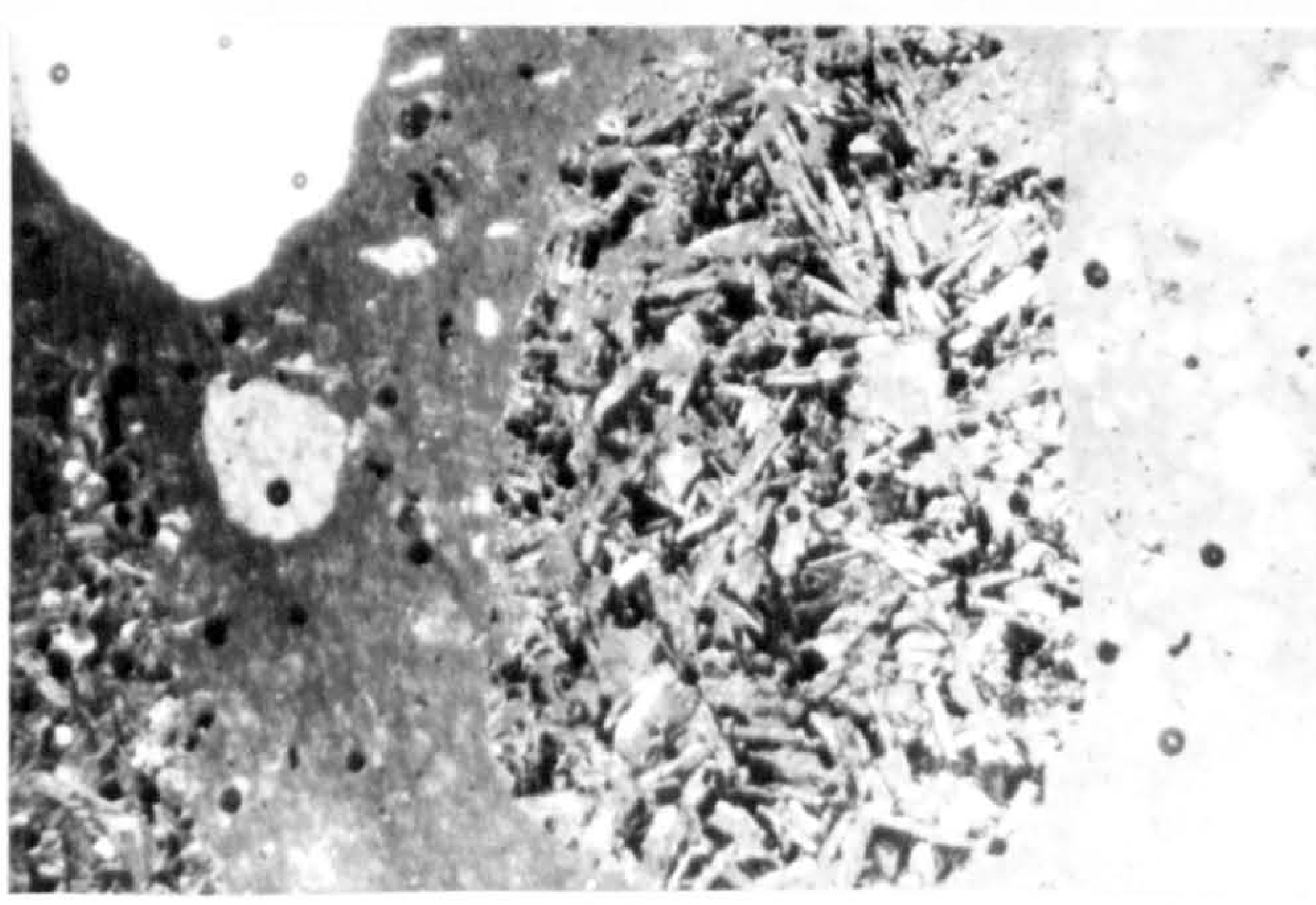
Plate 4.2
Galana Boi sediments



Diatomaceous silt. x 63 (photographic enlargement x 3.5). Poorly-sorted quartzo-feldspathic silt, which includes several Rhopalodia. (araldite-impregnated thin section).



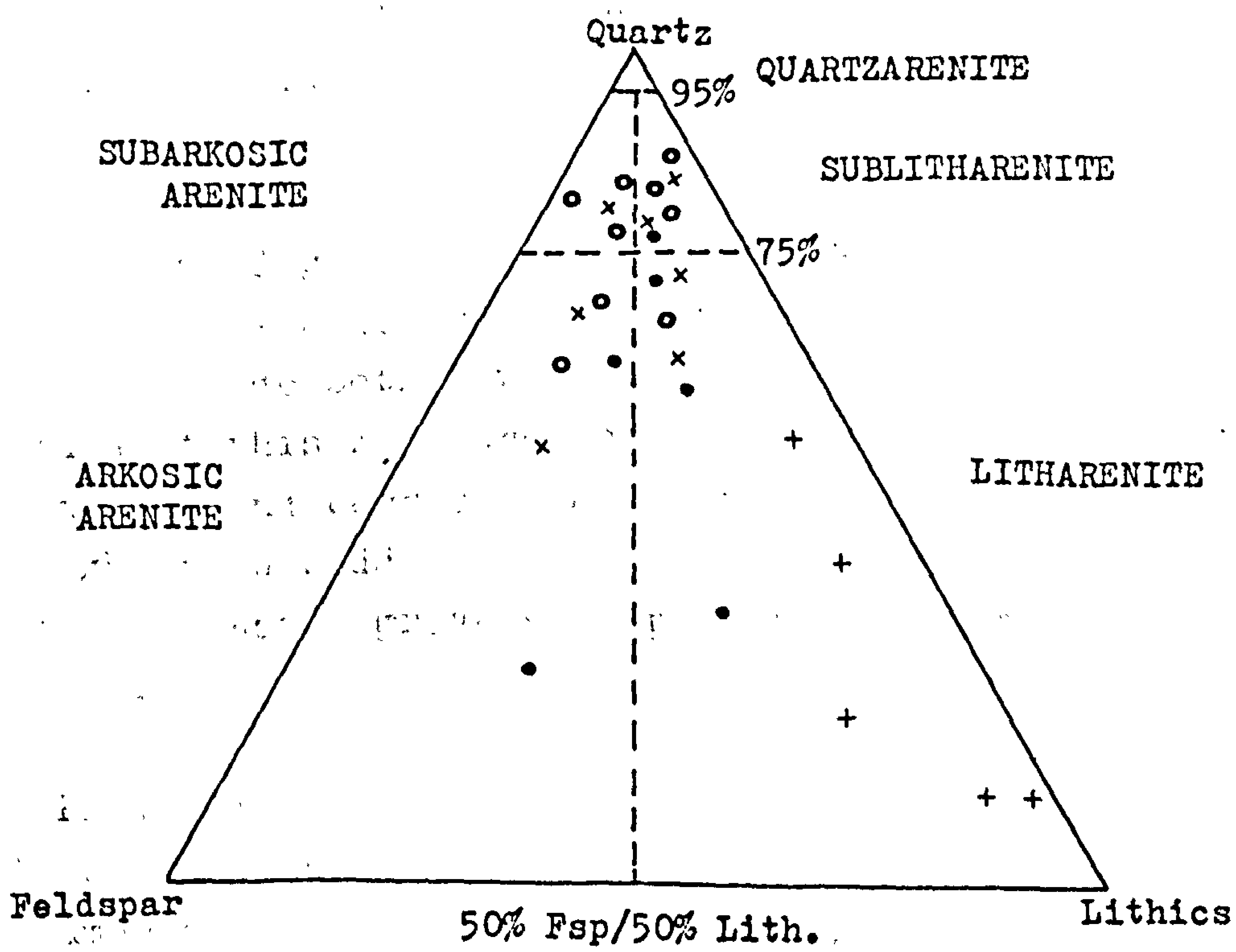
Moderately-sorted, angular, arkosic arenite. x 25 (photographic enlargement x 2.5). Feldspar dominates with less common quartz and occasional, more rounded, lithics (araldite-impregnated).



Poorly-sorted litharenite. x 25 (photographic enlargement x 3). Rounded lava occurs with smaller and more angular quartz and feldspar (araldite-impregnated thin section).

Fig. 4.3

Sand terminology and mineralogy of the Holocene deposits of East Turkana



Modern beach sands .... o

Modern river sands (at the point ...... •
of entry to Lake Turkana)

Galana Boi Formation:

Cross bedded beach units .... ×

Local channels and basal sand units ... +

shoreline. The presence of either sediment type may therefore have a palaeoenvironmental significance. Heavy minerals are also present in the Holocene sediments, and often pick out cross-bedding (plate 4.3). Similar heavy mineral layers occur along the Koobi Fora shoreline today, where they are sorted by wave activity.

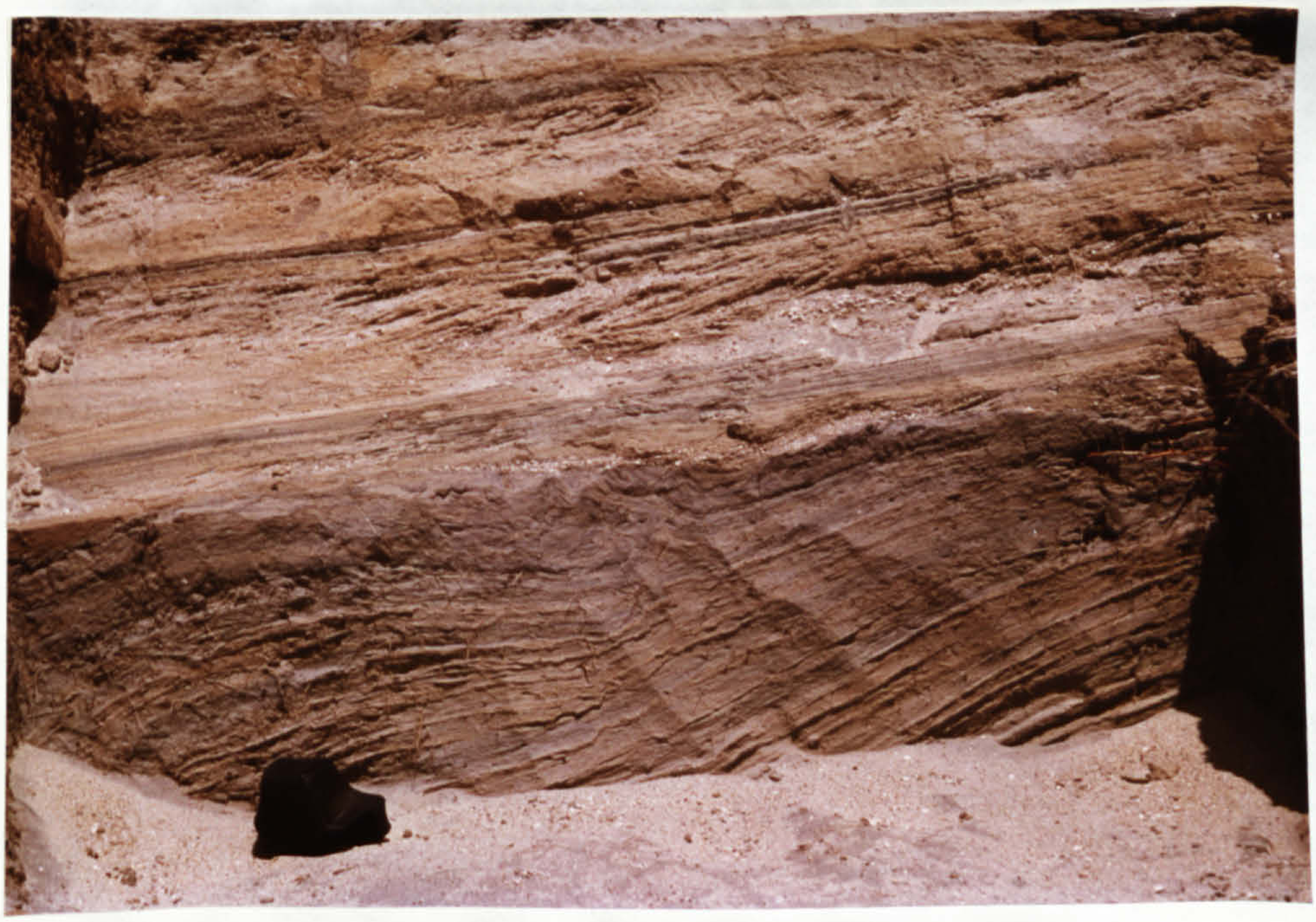
Cross-stratification is often well developed in the sandy units (plates 4.4 and 4.5). This includes non-erosional 'alpha' types, and smaller scale structures similar to 'kappa' and 'nu' cross beds that indicate linguoid ripples (terminology after Allen, 1963). 'Lambda' types, that are formed by the migration of straight crested sand ripples, also occur. Well sorted, medium to coarse sands often show larger scale planar cross-beds. These include both low and high angled types. Cross-strata of this kind are forming today in response to beach formation and barrier migration on the Koobi Fora spit. Trough cross bedding is uncommon, being mostly found in sands and sandy gravels of probable aeolian and fluvial origin.

Plagioclase (predominantly albite), orthoclase and microcline, together with quartz (both volcanic and metamorphic types) are the most common minerals in the sands. The percentage contribution of each mineral varies considerably. Beach sands (as indicated by cross-strata and heavy mineral bands) commonly contain a high percentage of quartz (up to <u>ca</u>. 80%). Quartz grains range from angular to subrounded, and occasionally have secondary silica overgrowths. The feldspars may be partially altered to clays and may form up to about 65% of a sand sample. Lithic fragments are usually less than 40% of the beach deposits, and are mostly well rounded. However, they may constitute up to 90% of sands in basal and channel units. The lithics consist of lavas such as basalt, and reworked sandstones. Hornblende, chlorite, biotite, muscovite, magnetite and ilmenite are all common. The heavy minerals may be sorted into distinct

Plate 4.3

Heavy mineral bands are common in the early and middle Holocene sands of East Turkana, as can be seen in this photograph. Similar layers are forming along the modern beaches of Lake Turkana.

Plate 4.4



Middle Holocene sands. The lower part of the section resembles beach bar sediments forming along the edge of the modern lake. The upper part, with its planar cross beds, and heavy mineral bands, is similar to low angle beach shorelines.

Plate 4.5

Laminar silty-sands giving way to ripple drift laminated units. The photograph was taken in the upper part of a 2 m sequence of middle Holocene beach type deposits.

layers, where they may make up to 95% of the sediment.

The mineralogy of the Galana Boi Formation is similar to that of the Pliocene and Pleistocene Koobi Fora Formation, for which Findlater (1976) gives the following list.

Metamorphic	Volcanic
quartz (undulose extinction)	basalts, ignimbrite,
K feldspar (microcline)	acid tuffs and
biotite	amorphous silica
amphibole	K feldspar (sanidine,
rutile	anorthoclase)
apatite	amphibole
tourmaline	plagioclase
zircon	pyroxene
opaques	olivine (& serpentine)
	zircon
	opaques

The source of the metamorphics in the Koobi Fora Formation appears to be the west Amar Kokke Highlands (west of Lake Chew Bahir). The volcanics were derived from these and other highlands that surround East Turkana. The Holocene deposits may have derived their minerals from reworking of the older sediments, and from renewed erosion of the surrounding volcanics.

Siltstone nodules of the type described in chapter 3 (p.108) occur throughout the silts and fine sands of Areas 102 and 103 (plate 4.6). These are often centred on molluscs and are usually limonite-stained. Limonite (diffuse and banded) is found in interdistributary regions of the modern Omo delta (Butzer, 1971). Butzer states that "ferric concretions and more continuous limonitic bands are theoretically possible among these interdistributary clays at depth". He did not observe any concretions, but stated that quite long periods of suitable conditions may

Plate 4.6

Early to middle Holocene diatomaceous silts. Note the distinctly white, highly diatomaceous unit at the top. Limonite-stained, calcareous-cemented, siltstone nodules can be seen at the base of the slope.

be needed. While the silts of 102 and 103 are not of interdistributary character, they may have provided suitable conditions of stability.

Gypsum occurs along several fracture planes. Cerling (1979) suggests that its presence in the older Formations may be due to sulfuric acid (released from pyrite by oxidation) attacking calcite. The gypsum in the Holocene units is secondary, but its origin must remain speculative since no evidence of pyrite has been found.

Nitratine is widely distributed throughout Area 103, but has not been recorded in Area 102. It decreases in the fine sands and is absent from coarser units. This may reflect the permeability of the sands and the ease with which nitratine can be leached. It is absent from the younger silts that crop out in the western sector (fig. 4.1) of Area 103.

Syndepositional, precipitated carbonate appears to be rare. Carbonate found in the sediments is probably derived from comminuted shell debris. Secondary deposits occur in various nodular forms, as a cementing agent and as calcrete.

4(i)c Palaeontological aspects of the Holocene sediments

Fish vertebrae are common in the silt units. *Tilapia sp.* comprise about 75 % of the fauna, while *Lates niloticus* (Nile Perch) and *Clarius lazera* (catfish) account for about 20% and 5% respectively.

Occasional crocodile teeth occur and hippo bones have been reported by Raynolds (1972). A sparsity of terrestrial vertebrates reflects the dominance of lacustrine environments in Areas 102 and 103. Further east, in Area 127, equid teeth have been recovered from alluvial and beach deposits. Archaeological digs by J. Barthelme (1978) have revealed the presence of warthog, equids, hippo and rhino in Area 102 and throughout East Turkana.

Archaeological evidence indicates that during the Holocene,human occupation was based on two economic traditions (Barthelme, 1978). The earlier was based on fishing and the manufacture of barbed bone harpoon heads. The second, later economy,was based on domestic animals and has left a distinctive suite of pottery fragments.

Mollusca are abundant in the Holocene sediments. In contrast, today they are rare and confined only to a few species. Cerling (1979) states that the upper limit of alkalinity tolerance is about 16 meq/l. Mollusc identifications have been based on Williamson (pers. comm.), Mandahl-Barth (1954) and Adam (1957).

The gastropoda include: Melanoides tuberculata, Pila ovata, Cleopatra pirothii, C. bulimoides, Bellamya unicolor, Gabbia semaareniensis, Lymnaea exserta and Biomphalaria stanleyi. Raynolds (1972) also reports the presence of Gabbia walleri, G. kichwambae, Cleopatra nyanzae, Biomphalaria sudanica, Gyraulus costulatus and Bulinus trigonus.

Bivalves include: Caelatura hautecoeuri, C. monceti, C. bakeri, C. rothschildi, Etheria elliptica, Corbicula africana, C. fluminalis, C. artini, Mutela nilotica and M. emini. Raynolds also reports the presence of Byssanodonta parasitica.

Molluscs are both scattered through the sediments and occur in laterally extensive coquinas. The most common molluscs in the sandier units are Mutela emini, Etheria elliptica and to a lesser extent Pila ovata. Often they are partially reworked. In the silts, Melanoides tuberculata and Corbicula africana dominate, with Cleopatra pirothii. Laterally extensive coquinas or mollusc -rich horizons tend to be dominated by Melanoides tuberculata and/or Corbicula africana.

Root marks are common and consist of two main types. In the siltier units a carbonised film has been left by the decay of aquatic vegetation. These cut through and lie parallel to the laminae. The second type forms calcareous tubular casts in sands. These are often better cemented than the surrounding matrix, and occur as dense concentrations in growth position.

Ostracods are present in several units. Rather tentative identifications, based on Carbonel and Peypouquet (1979), suggest the presence of Hemicypris kliei and Limnocythere africana. Other species occur but identifications were not attempted. More rarely, pollen and siliceous phytoliths were observed. A. Vincens (pers. comm.) states that although uncommon when compared to diatoms, pollen is still significant.

4(i)d The dating of the Galana Boi Formation

No radiocarbon dates were obtained during this study, but several earlier workers have established a series of dated units. Raynolds reports three dates from Area 103 (eastern sector). These are 9880 ± 670, 4390 ± 235 and 5060 ± 245 yr. B.P. The latter two are anomolous in that they are stratigraphically in the wrong order. One or both may be based on derived material.

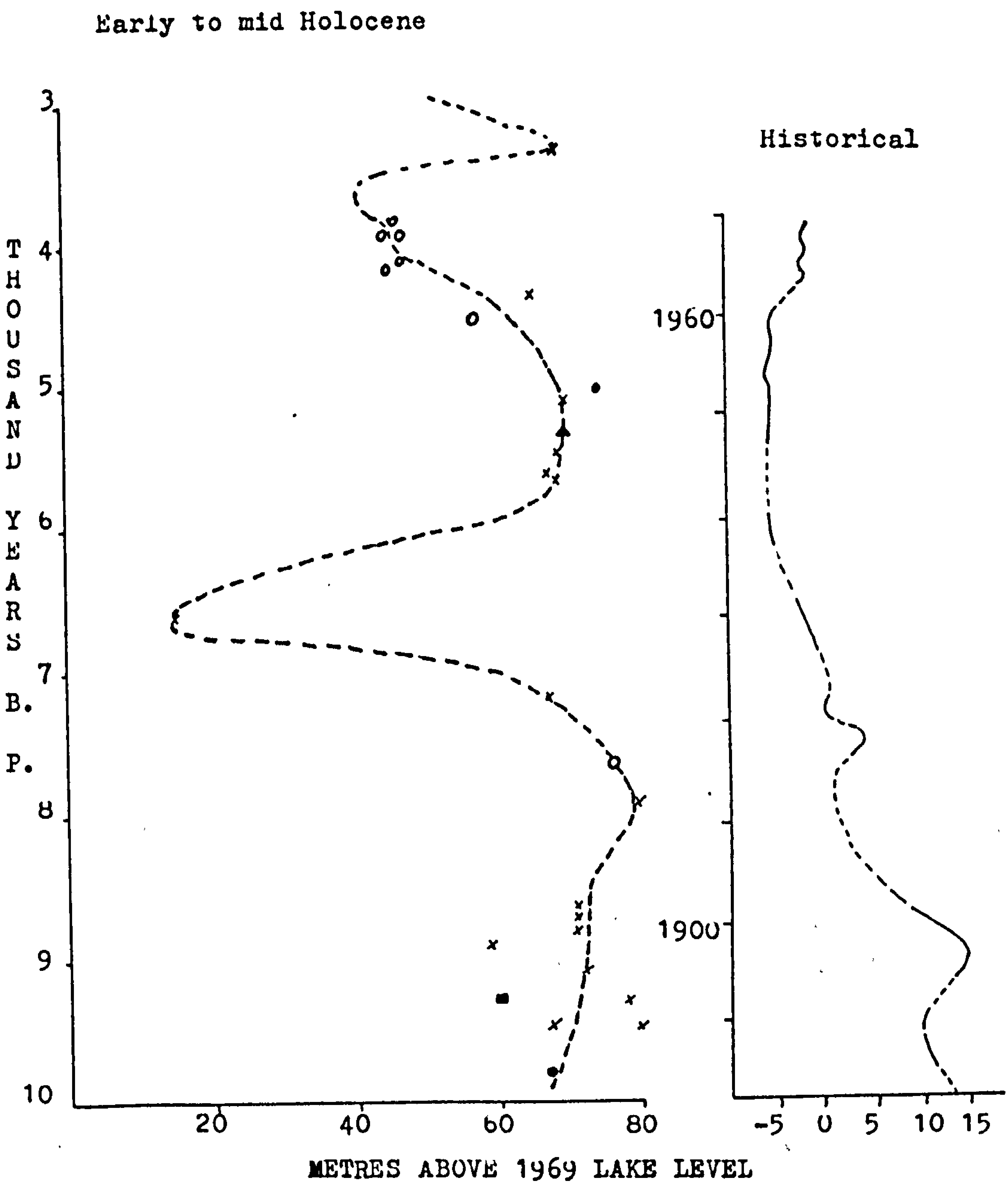
J. Barthelme (pers. comm., 1978) has obtained a series of dates between 3890 and 9660 yr. B.P. (table 4.1). They suggest that the lake stood about 75 to 80 m above modern levels between ca. 10,000 and 7,700 yr. B.P., and from about 5,500 to 4,000 or 4,500 yr. B.P. Dates from a number of localities around Lake Turkana are plotted against height in figure 4.4. This gives a crude curve of lake level fluctuations for the Holocene.

Table 4.1 Carbon-14 dates from Holocene high level sediments in the Turkana Basin.					
East Turkana (N.E. Lake Turkana)					
Source	^{14}C date (years)	Nature of sample	Context	Lake level (m.)	Sed. unit
Raynolds, 1972	5060 ± 245	Charcoal	Littoral	?	GALANA BOI FORMATION
	4390 ± 235	Mutela	Beach	?	
	9880 ± 670	Mixed shell	littoral	+ca.68	
Vondra et. al, 1971	9360 ± 135	Shell?	Beach?	-	
Barthelme (pers. comm.)	3970 ± 60	Charcoal	Beach	+43-46	
	4160 ± 110	Charcoal	Beach	+43-46	
	3890 ± 60	Charcoal	Beach	+45-47	
	3945 ± 135	Charcoal	Beach	+45-47	
	4100 ± 125	Humic acid residue	Beach	+45-47	
	4560 ± 185	Mammal bone	Beach	+55-56	
	7855 ± 160	Fish bone	Littoral	+73-75	
	8355 ± 235	Mammal bone	Spit	+95-	
	8395 ± 270	Mammal bone	Spit	uplift	
	9660 ± 235	Mollusc shell	?	"	
	9940 ± 235	Mollusc shell	?	"	
Lowasera (S.E. Lake Turkana)					
Philiipson 1978	3970 ± 120	Bone apatite	Terrestrial	?	UNNAMED
	5120 ± 135	Bone apatite	Stabilised beach	?	
	4460 ± 110	Bone apatite	Beach	?	
	3650 ± 155	Bone apatite	Beach	?	
	7785 ± 150	Bone apatite	Beach	+75	
	9470 ± 200	Shell	Littoral sand	+74	
Lothagem (S.W. Lake Turkana)					
Robbins, 1972	7960 ± 140	Shell	Littoral ?	?	unnamed
	8420 ± 165	Shell	Beach ?	?	
	8230 ± 180	Mollusc	Shell bed	?	
	6010 ± 155	Mollusc	Shell bed	?	
	6200 ± 125	Charcoal	Hearth?	?	
1978	6300 ± 80	Shell	Shell bed	?	
	7000 ± 800	Charcoal	Hearth?	?	

Table 4.1 (cont.) Carbon-14 dates from Holocene high level sediments in the Turkana Basin.

Source	^{14}C years	Nature of sample	Context	Lake level (m.)	Sed. unit	
Omo Region (N. Lake Turkana)						
Butzer et. al. 1972	3250 ± 150	Mixed shell	Beach ridge	+70	IVb	KIBISH FORMATION
	4400 ± 100	Etheria	Littoral	+66		
	5150 ± 350	Mixed shell	Beach ridge	+70		
	5450 ± 100	Mixed shell	Littoral	+69		
	5700 ± 100	Mixed shell	Littoral	+67		
	5750 ± 100	Unionidae	Channel fill	+69		
	6600 ± 150	Mixed shell	Trans-gressive sandstone	+15		
	7160 ± 80	Unionidae	Littoral	+66	IVa	
	7900 ± 150	Etheria	Littoral oyster bank	+80		
	8650 ± 150	Corbicula	Littoral	+72		
	8700 ± 200	Corbicula	Littoral	+72		
	8800 ± 200	Corbicula	Littoral	+72		
	8900 ± 300	Mixed shell	Littoral	+59		
	9100 ± 300	Mixed shell	Channel fill	+72		
	9300 ± 400	Unionidae	Littoral	+78		
	9500 ± 150	Unionidae	Channel fill	+80		
	9500 ± 150	Corbicula	Littoral	+67		
Kangatotha (W. Lake Turkana)						
Livingst-one & Kendall 1969	4800 ± 100	Etheria	Beach	+66	unnamed	

Fig. 4.4 Holocene lake level fluctuations of Lake Turkana.



Data from Butzer, 1971 (Historical); Butzer et. al., 1972 (x); Livingstone et. al., 1969 (▲); Vondra et. al., 1971 (■); Raynolds,1972 (•) ; Barthelme, pers.comm. (o).

4(ii) The distribution of Holocene sediments and their diatom stratigraphy, in Area 102

4(ii)a The lacustrine sediments in the south of Area 102

Area 102 has been divided into southern and eastern sectors for descriptive purposes (fig. 4.1).

Three main outcrops can be recognised in the southern sector of Area 102. These are:

(i) The high level silts
(ii) The low level silts
(iii) The clayey-silts

Each of these sediment outcrops will be discussed in turn.

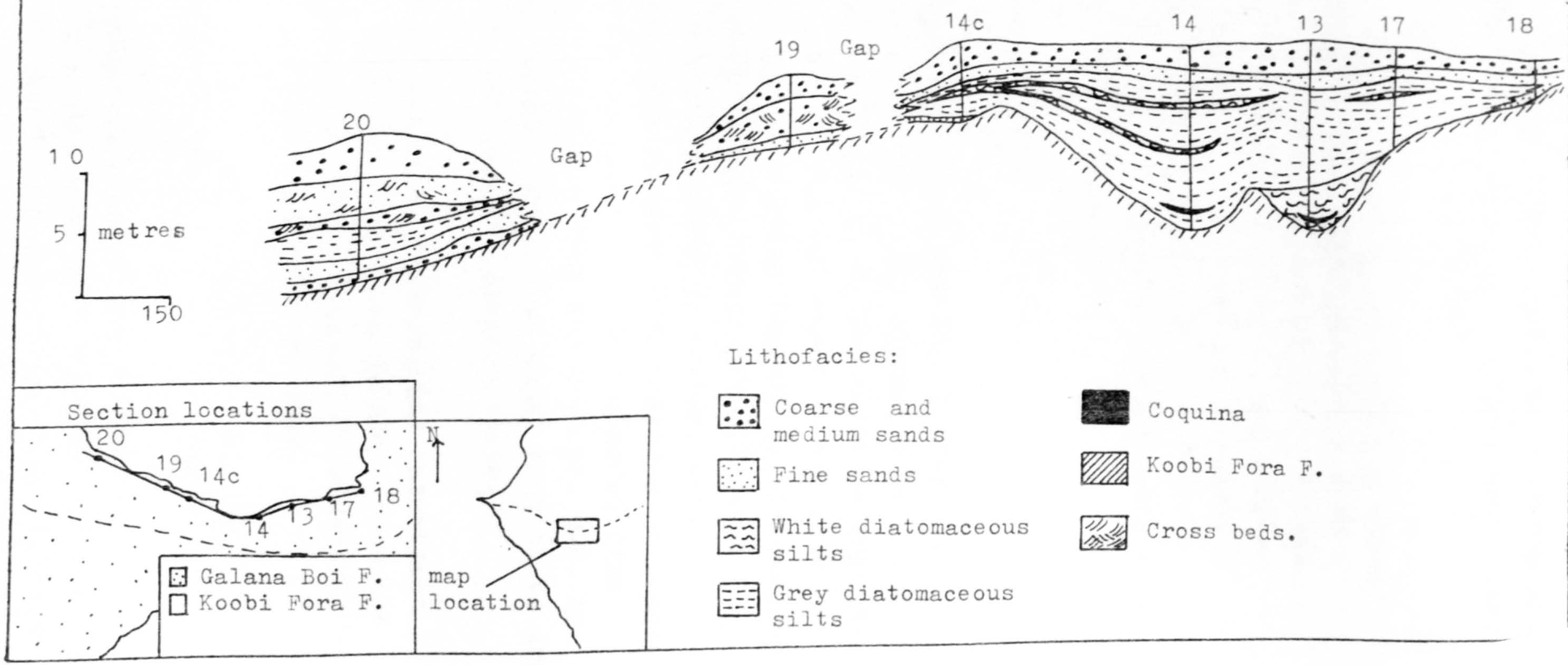
(i) The high level silts

Lacustrine silts, at heights of up to ca. 75 m above the modern lake (barometric altimeter reading), form a north-facing, arcuate scarp in the extreme south of Area 102. Sections 13 to 18 (fig. 4.5, and map of the Koobi Fora area at the back of this thesis) all lie along the line of this scarp. These deposits can be traced southwards a short distance into Area 103, where they have been dated at between 10,000 and 5,000 yr. B.P.(Raynolds, 1972).

The pre-Holocene surface on which these sediments unconformably sit is a shallow depression with a central ridge of slightly higher ground (fig. 4.5). This ridge separates highly diatomaceous white silts (to the east) from diatomaceous grey silts (to the west). As the depression was gradually infilled, initial dips became gentler and the grey silts spread across the central divide. Two distinct horizons of white silt, towards the

Fig. 4.5

Major lithofacies relationships in southern 102



the top of the silty units, merge westwards at a topographic high. The silts pass vertically and laterally into fine, medium and coarse, mollusc-rich sands.

Section 19, in figure 4.5, lies in sediments whose lateral relationships are obscured by aeolian sand and vegetation cover. Fine sands at the base of this sequence give way to planar cross-bedded and ripple-laminated, medium to coarse, well sorted, subarkosic sands. Heavy mineral bands are present. The deposit probably represents a beach, possibly contemporary with the second group of lacustrine silts.

(ii) The low level silts

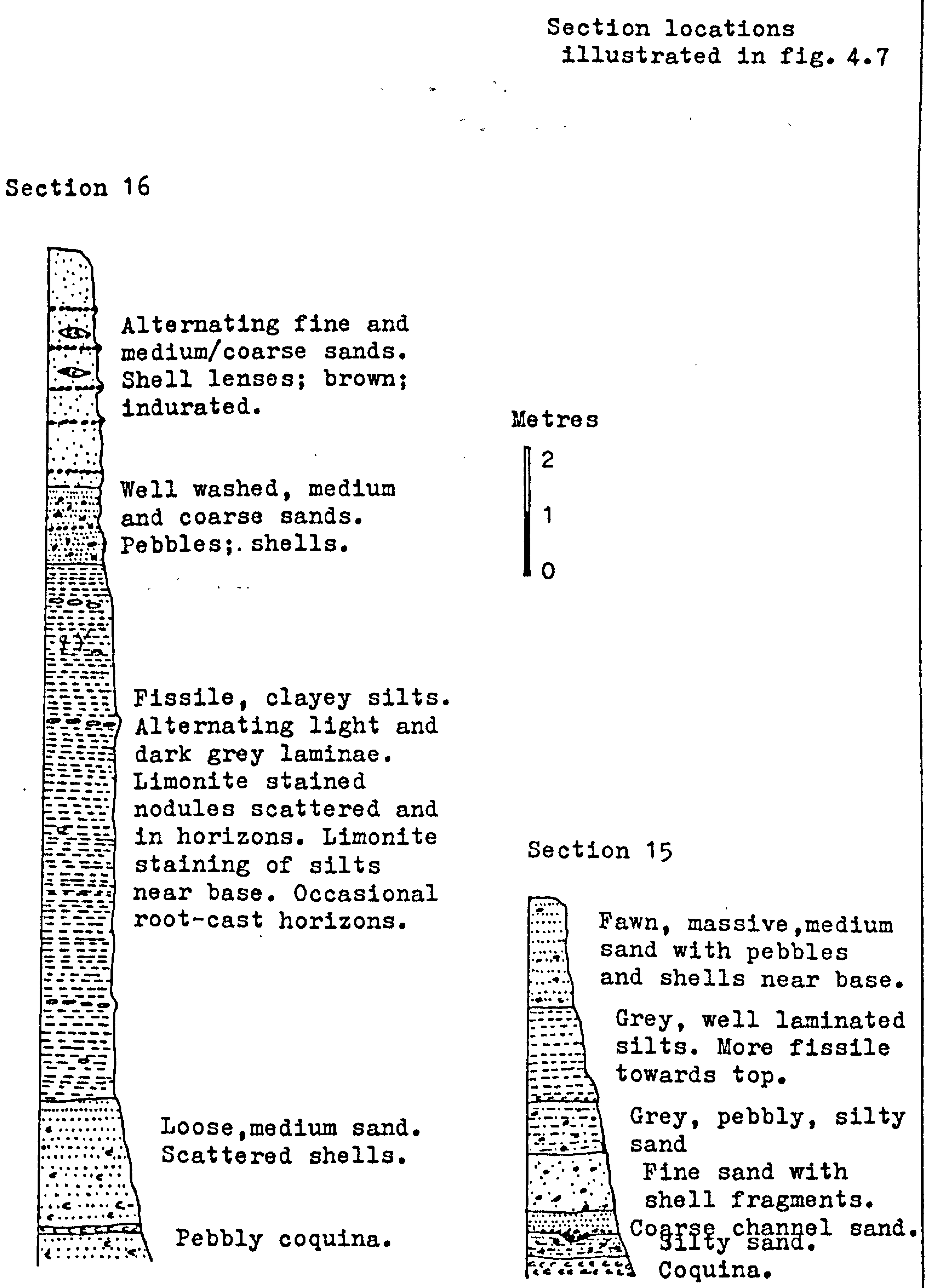
Lacustrine silts crop out at section 20 (fig. 4.5), to the north-west of the high level silts. These lie at a maximum elevation of ca. 65 m. The sequence begins with coarse and medium, subarkosic sands, which give way to finer units. The succeeding laminated, diatomaceous silts and clayey silts suggest a transgressive event. A subsequent regression is marked by coarse, well sorted, planar cross-bedded sands with numerous molluscs. This latter unit, and a sequence of cross-bedded fine sands have been dated between 3890 and 4160 yr. B.P. by J. Barthelme (pers. comm.). Calcified sandy root casts are common in the sands and suggest littoral reeds.

Coarse to medium, reworked (bioturbated) subarkosic sands of probable littoral origin are spread across the top of all the sections so far discussed. This deposit may be related to a final regressive episode.

(iii) The clayey-silts

Lacustrine sediments also crop out to the north of those discussed above (sections 15 & 16, fig. 4.5). At the base of sections 15 and 16 are sublitharenitic (littoral ?) sands, with litharenites in channels. Molluscs are common,

Fig. 4.6 Holocene sections in the south of area 102.



consisting mainly of Corbicula spp.. A deeper-water, clayey-silt lithofacies succeeds the sands of both sections. These silts are about 7 m thick in section 16, and 2 m thick in section 15. They are highly fissile and resemble paper shales. Alternating light and dark laminae (ca. 1 cm thick) are common. Limonite-stained, calcareous, siltstone nodules are abundant. Root casts are common, particularly at the top of section 16. Resting with a sharp boundary on top of the silts are massive, medium, brown subarkosic sands and arkosic arenites with pebbles and molluscs. In section 16, the latter units give way to alternating fine and pebbly coarse sands. These sandy units indicate a return to shallow-water, high-energy environments. The age relationships and height of these sediments are uncertain.

4(ii)b The lacustrine sediments in the east of Area 102

This area lies along the western flanks of the Koobi Fora Ridge (fig. 4.1). The maximum elevation of the deposits is about 80 m above the modern lake. The sediments are mostly of littoral character and they lack the deeper water facies of southern 102. Figure 4.7 shows a series of sections in these deposits, and these are referred to in the following account.

Section 34 lies in the northernmost of the outcrops. It is also the thickest at 15.5 m. The sequence begins with conglomerates and coarse to medium, poorly-sorted litharenites, which are locally cross-bedded. These give way to lacustrine silts and a coquina, that probably formed during a high lake level. A regression is indicated by the succeeding poorly-sorted litharenites which contain root casts. Above an 80 cm thick fine sand is an alternating sequence of fine and coarse sandy units, which might reflect a fluctuating lake level. About 7 m of mollusc rich, fine to medium, moderately well sorted litharenites completes the succession (apart for

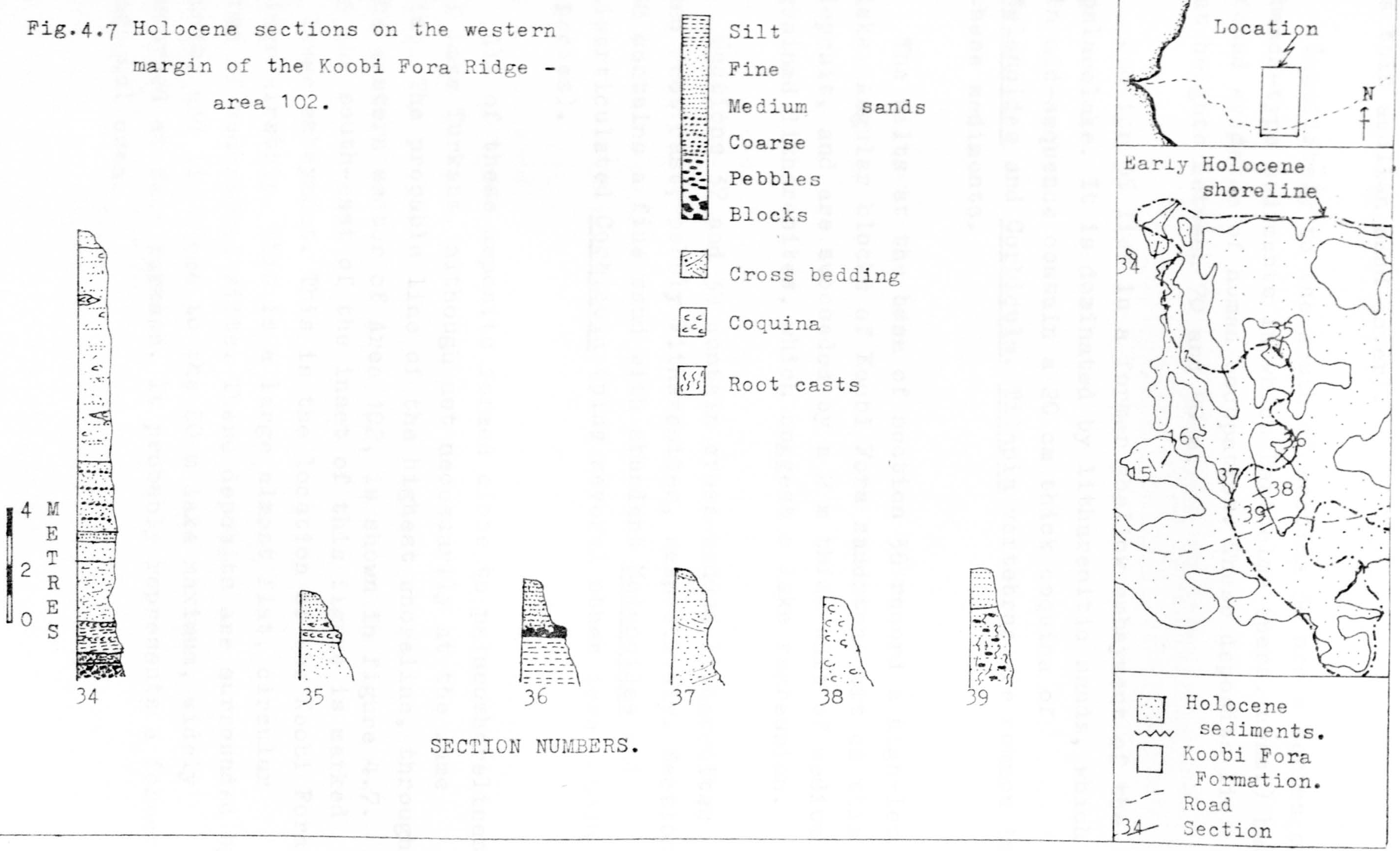


Fig.4.7 Holocene sections on the western margin of the Koobi Fora Ridge - area 102.

a thin aeolian sand cover).

Immediately to the south of section 34 are a series of beach-type sediments in which Barthelme (pers. comm.) has found evidence of human occupation. These deposits lie at heights between 70 and 80 m.

Section 35 lies in a former shallow embayment of the palaeolake. It is dominated by litharenitic sands, which in mid-sequence contain a 20 cm thick coquina of Melanoides and Corbicula. Tilapia vertebrae are common in these sediments.

The silts at the base of section 36 record a high-level lake. Angular blocks of Koobi Fora sandstone sit on this deposit, and are succeeded by a 2 m thick unit of medium grained litharenites, which suggest a lake regression.

Sections 37 and 39 contain cross-bedded litharenites and root cast, pebbly litharenites, respectively. Section 38 contains a fine sand with abundant Melanoides and disarticulated Corbicula (plus several other less common species).

All of these deposits formed close to palaeoshorelines of Lake Turkana, although not necessarily at the same time. The probable line of the highest shoreline, through the eastern sector of Area 102, is shown in figure 4.7. In the south-east of the inset of this figure is marked a large embayment. This is the location of the Koobi Fora Ridge airstrip. This is a large, almost flat, circular area of mudcracked silts. These deposits are surrounded by sands, and lie close to the 80 m lake maximum, widely recorded at East Turkana. It probably represents a former lagoonal area.

4(ii)c The diatom stratigraphy of Area 102

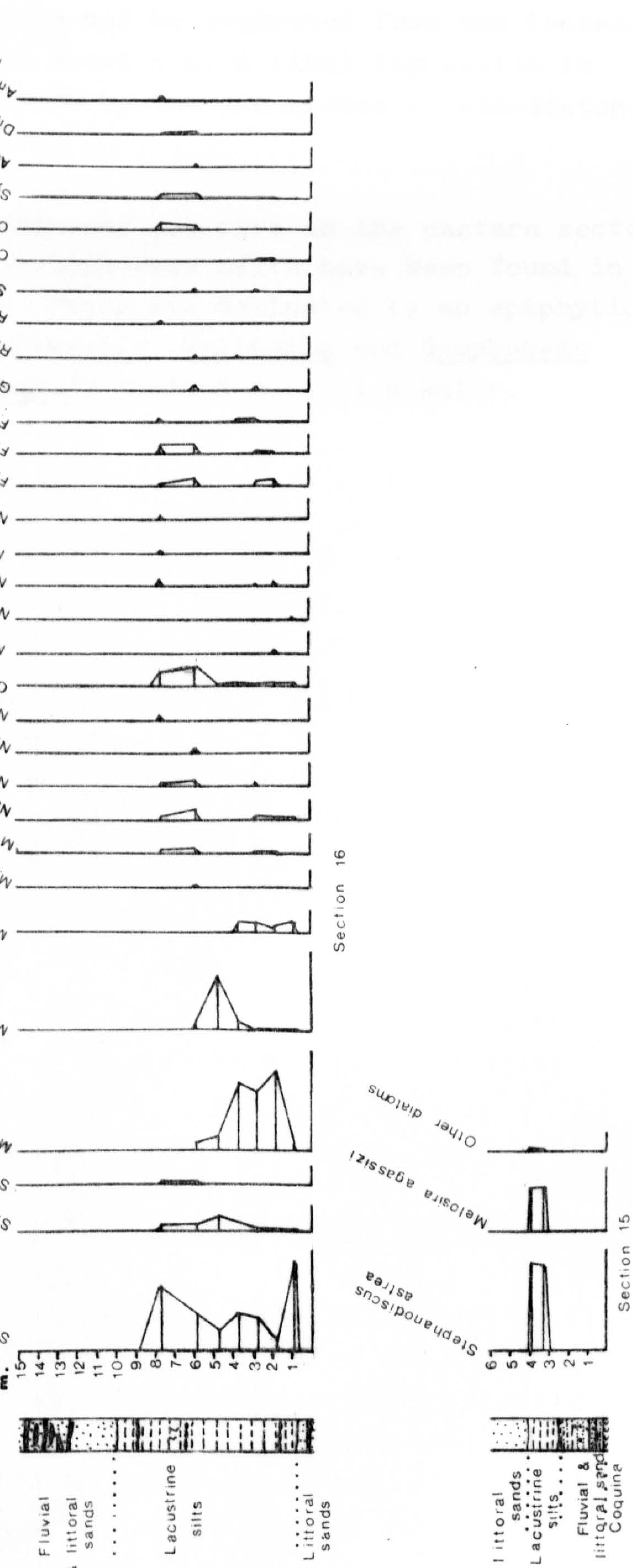
Diatoms are uncommon and often fragmentary through much of the high-level silts of southern 102. However, diatom -rich horizons do occur. Near the base of section 14 (fig. 4.6) is a benthonic flora dominated by *Rhopalodia* and *Surirella* species. *Rhopalodia vermicularis* is the most common diatom and is favoured by slightly alkaline, littoral waters. It is oligohalobian and endemic to East Africa. Planktonics are rare, except in two horizons in the middle of the succession. Towards the top of section 14, benthonic forms become increasingly common.

An abundant planktonic flora was only observed in the low level silts of section 20, and in the clayey-silts of sections 15 and 16.

In section 20 (fig. 4.6), *Stephanodiscus astraea* dominates in the lower 50 cm of the silt sequence. Today, this planktonic, oligohalobian diatom is recorded from lakes low in dissolved silica (Richardson, 1968), with a low alkalinity (0.9 to 4.5 meq/l), and a moderate to high phytoplankton content. The remainder of the silts are dominated by *Melosira agassizi*, which is another planktonic diatom favoured by low alkalinities. Although *M. agassizi* has a broad salinity tolerance, it is most often found in dilute water. It often occurs in shallower water than *Stephanodiscus spp.*, and usually indicates higher silica concentrations.

The diatom stratigraphy of sections 15 and 16 are shown in figure 4.8. Section 15 includes about 1 m of diatomaceous clayey silts. The flora is dominated by *Stephanodiscus astraea* with less common *Melosira agassizi*. Section 16 contains about 9 m of clayey silts. *S. astraea* dominates in the lower 1 m, after which *M. agassizi* predominates up to about 5 m. At this level there is an increase in the littoral diatom *Cocconeis placentula*. This marks a probable fall in lake level. A second

Fig. 4.8 The Diatom Stratigraphy of Sections 15 & 16, Area 102



transgressive episode can be suggested from the increase in S. astraea above about 6 m. A final regression is recorded in section 16 by the occurrence of non-diatomaceous littoral sands.

Diatomaceous sediments are rare in the eastern sector of Area 102, but diatomaceous silts have been found in sections 34 and 36. These are dominated by an epiphytic flora (Cocconeis, Cymbella, Epithemia and Gomphonema species), which suggest shallow reed-rich water.

4(iii) The geology and diatoms of Area 103

4(iii)a Introduction to the geology of Area 103

The Holocene sediments in Area 103 are the thickest and most extensive deposits of this age at East Turkana. Here, the Galana Boi Formation rests unconformably on a highly dissected Pleistocene surface. This surface exerted a strong influence on Holocene sedimentation.

Figure 4.9 shows an east to west cross-section through Area 103. This diagram shows the thickest sequences occurring in low parts of the Pleistocene surface. These correspond to palaeovalleys. A series of isopachytes (ignoring local incised river valleys) in figure 4.10 shows the location of the thickest Galana Boi sequences.

Contemporary or post-depositional faulting was not observed. At present the poorly-consolidated Holocene sediments of Area 103 are being rapidly eroded, mainly by wind deflation.

Area 103 has been split into three sectors, following the system used by Raynolds (1972), for descriptive purposes (fig. 4.1). These sectors will be described in the following parts of this chapter.

4(iii)b The distribution of lithofacies in central 103

The deposits of the central sector are shown in figure 4.11. They reach a maximum thickness of about 33 m. To the east and north they thin into the silts of eastern 103 and southern 102, respectively. Westwards they thin and give way to sandier units in western 103, while to the south the sediments are eroded, leaving isolated outliers.

Section 72, which was discussed at length in chapter 3,

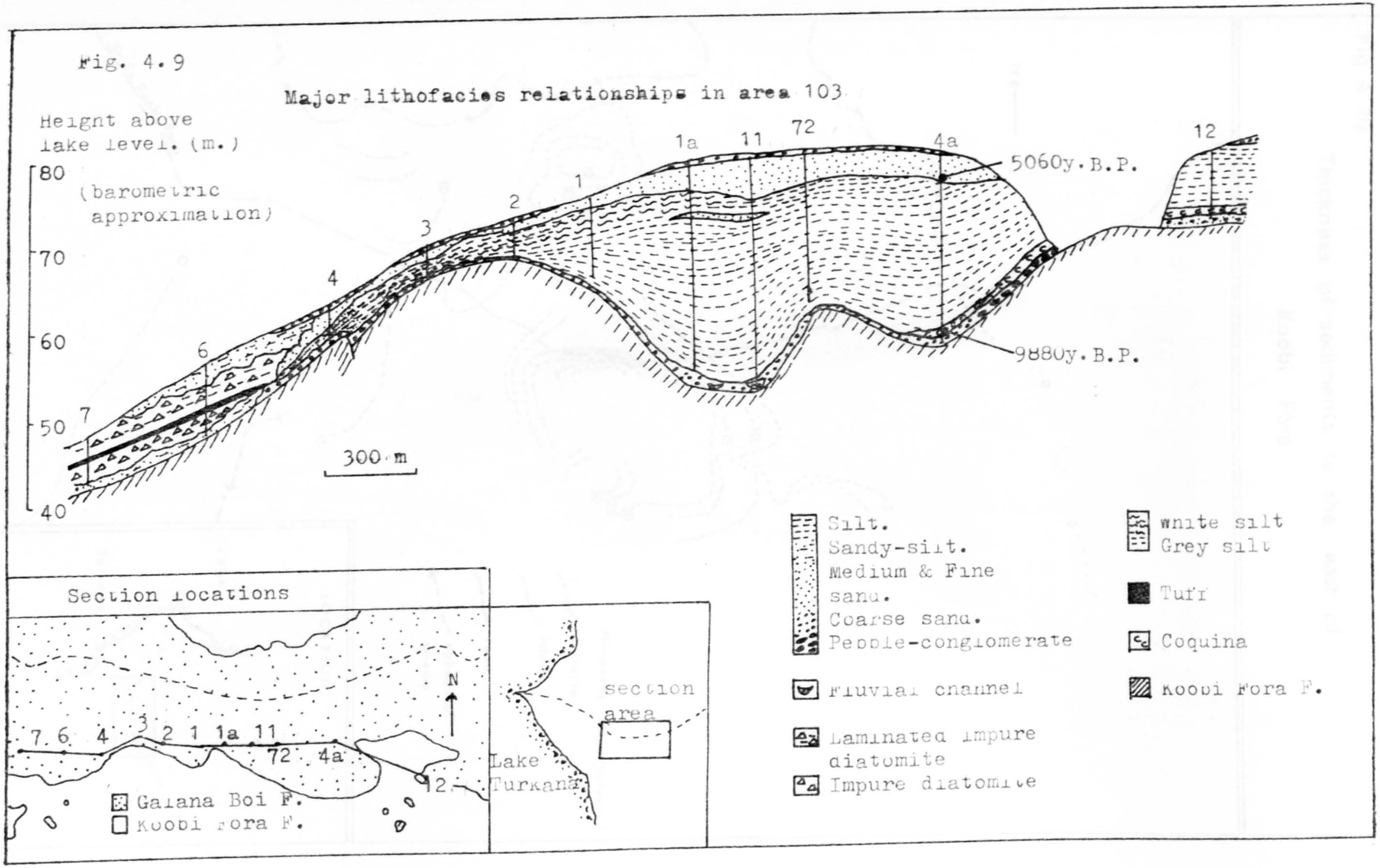
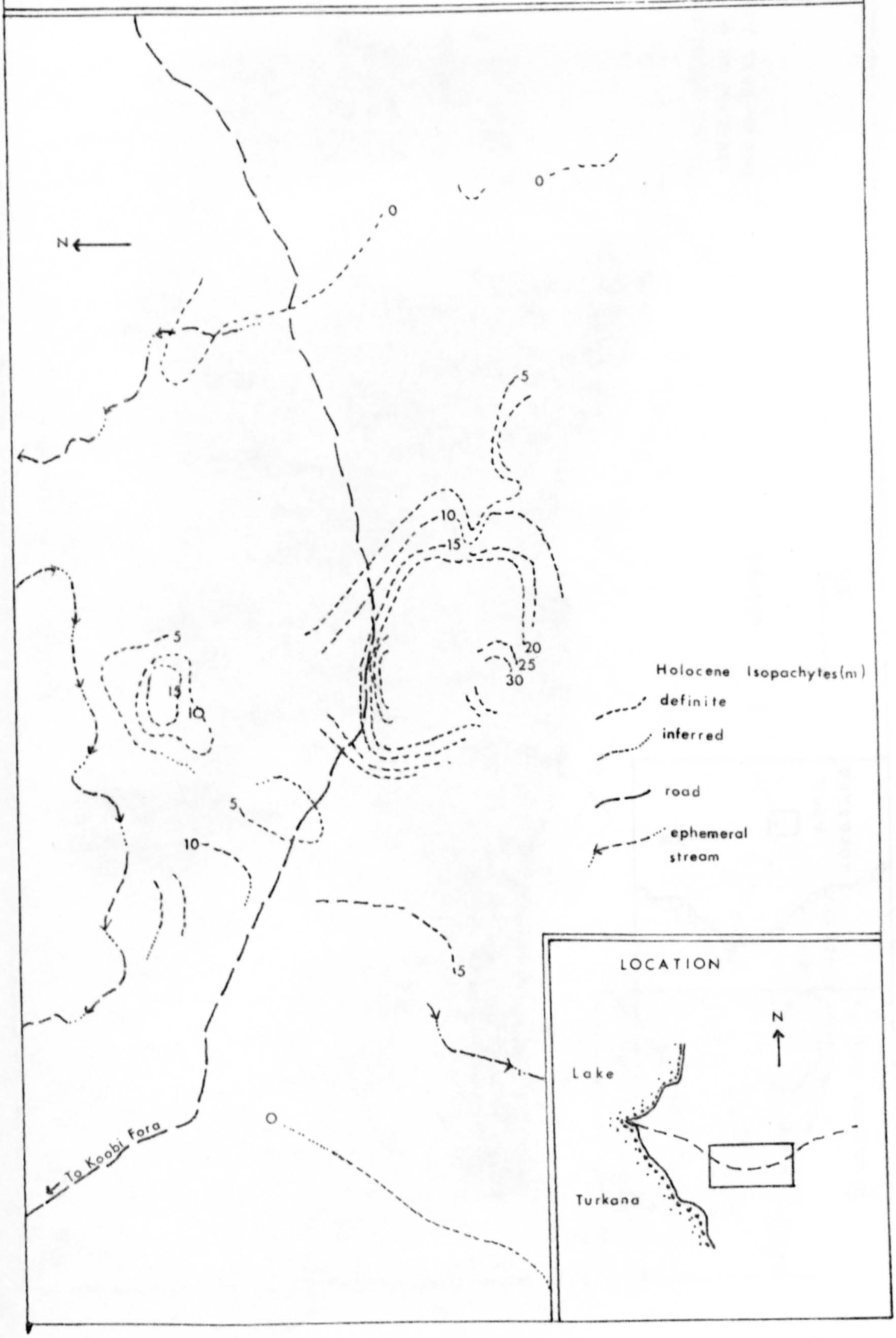


Fig. 4.9

Major lithofacies relationships in area 103

Fig. 4.10

Thickness of sediments to the east of Koobi Fora



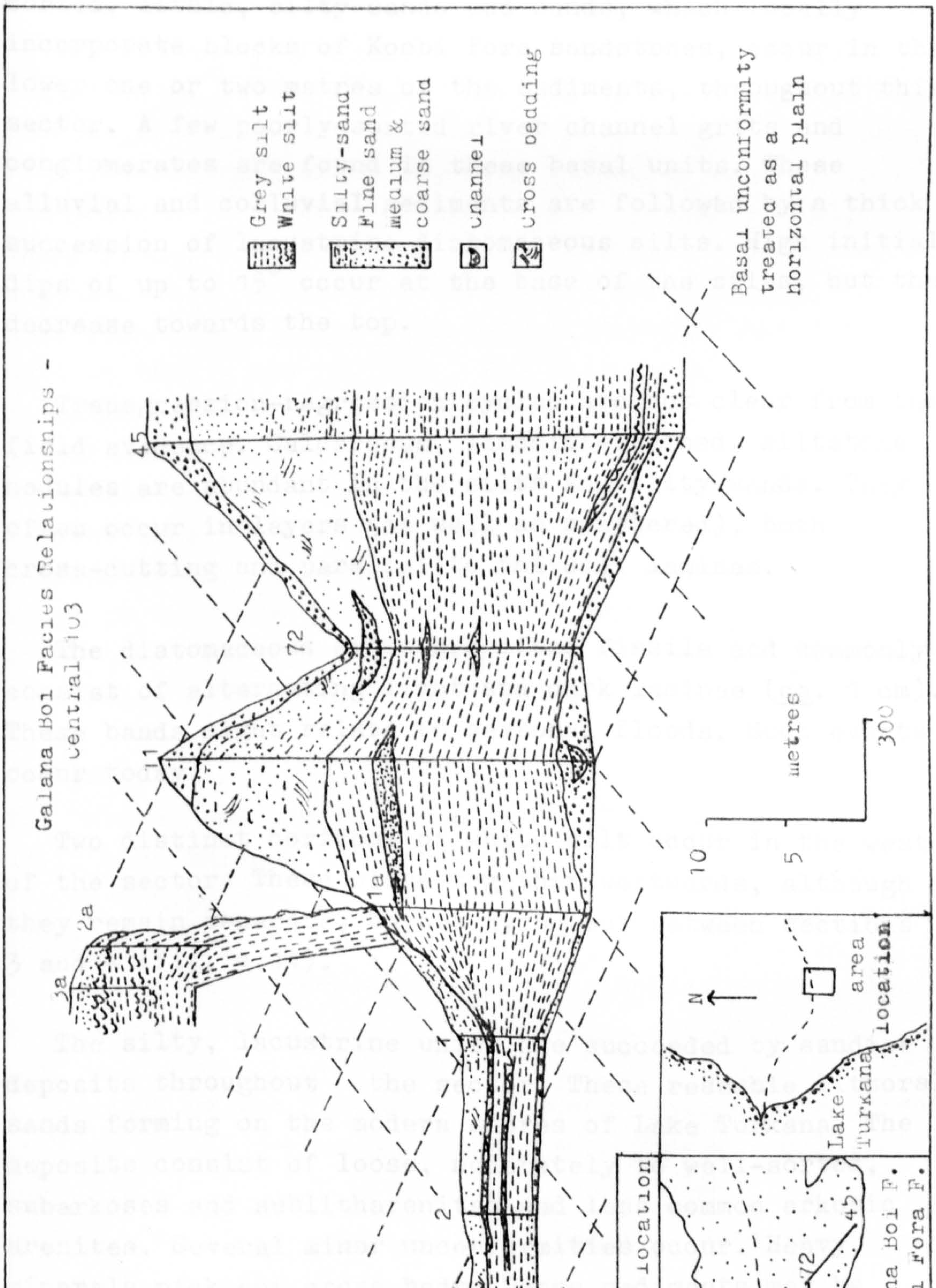


Fig. 4.11 Galana Boi Facies Relationships - central 103

lies at the eastern margins of this sector. Poorly-sorted, lithic, silty-sands and sands, which locally incorporate blocks of Koobi Fora sandstones, occur in the lower one or two metres of the sediments, throughout this sector. A few poorly-sorted river channel grits and conglomerates are found in these basal units. These alluvial and colluvial sediments are followed by a thick succession of lacustrine diatomaceous silts. High initial dips of up to 15° occur at the base of the silts, but these decrease towards the top.

Transgression-regression cycles are not clear from the field evidence. Calcareous, limonite-stained, siltstone nodules are abundant in the silts and silty-sands. They often occur in layers (as well as scattered), both cross-cutting and parallel to the silt laminae.

The diatomaceous silts are often fissile and commonly consist of alternating light and dark laminae (ca. 1 cm). These bands might relate to seasonal floods. Such events occur today.

Two distinct horizons of white silt occur in the west of the sector. These close together westwards, although they remain separate, before dying out between sections 3 and 4 (fig. 4.11).

The silty, lacustrine units are succeeded by sandier deposits throughout the sector. These resemble littoral sands forming on the modern shores of Lake Turkana. The deposits consist of loose, moderately to well-sorted, subarkoses and sublitharenites and less common arkosic arenites. Several minor unconformities occur. Heavy minerals pick out cross beds. These sediments may be time-transgressive, becoming younger to the west. They are dated at ca. 5,000 yr. B.P. in the eastern sector, and Barthelme (pers. comm.) has obtained dates of ca. 4,000 yr. B.P. to the north-west, in Area 102.

4(iii)c <u>The lacustrine deposits of eastern 103</u>

The sediments of the eastern sector are shown in figure 4.12. At the base of section 4a occur subangular pebbles of Koobi Fora sandstone (up to 10 cm), in a very poorly sorted litharenitic, fine to coarse sand of up to 1 m thickness. Several centimetres of poorly-sorted, silty lithic sand follows, and in turn is succeeded by a coquina. This consists of well-preserved Corbicula and less common Melanoides tuberculata. Raynolds dated this unit at 9880 ± 670 yr. B.P.. The coquina is succeeded by diatomaceous silts, which in the upper half of section 4a alternate with well-sorted, fine sublitharenites. These alternations may reflect changes in the level of the ancient lake. At the top of section 4a occur fine to coarse, subarkosic and sublitharenitic sands, similar to those in the upper parts of the deposits of central 103. These sands are rich in molluscs, and Raynolds (1972) has obtained a date of 5060 ± 245 yr. B.P..

The coquina at the base of section 4a continues into the base of section 12 (fig. 4.12). The overlying silty units have thinned and occasional small, gritty, channel scours can be seen at the top. Above these are Corbicula and Melanoides rich sands. The molluscs occur in thin (4 to 5 cm) mollusc-rich beds that alternate with mollusc-poor units.

Throughout the central and eastern sectors a recurrent pattern of sedimentation is apparent. This is as follows.

C. Upper, littoral, well-sorted sublitharenites and subarkoses.

B. Middle, lacustrine diatomaceous silts

C. Lower, alluvial, colluvial and occasional littoral, poorly-sorted, litharenites.

This pattern is also repeated in the isolated section 29

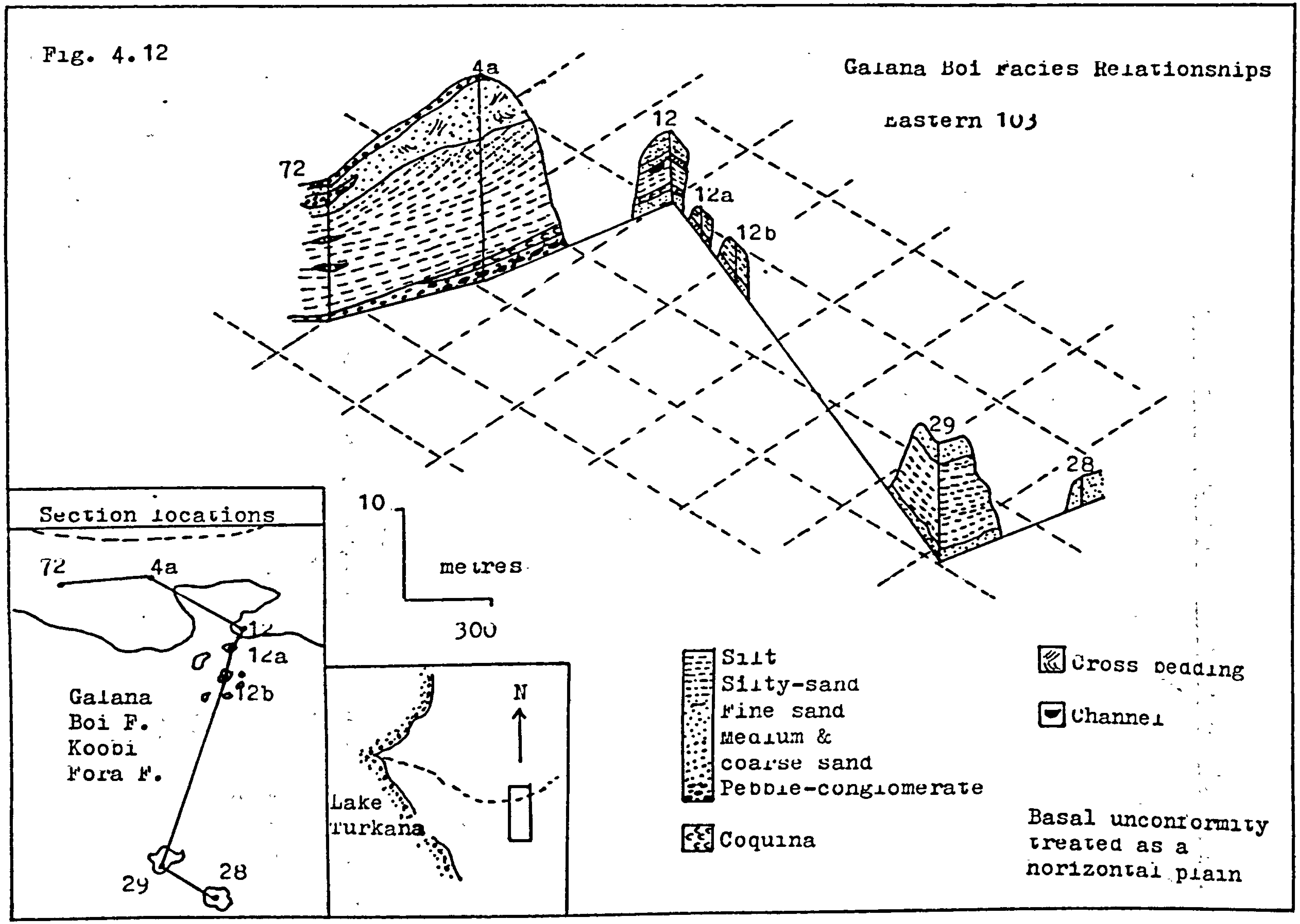


Fig. 4.12
Galana Boi Facies Relationships
Eastern 103
72
4a
12
12a
12b
29
28
10
metres
300
Section locations
72
4a
12
12a
12b
29
28
Galana
Boi F.
Koobi
Fora F.
N
Lake
Turkana
Silt
Silty-sand
Fine sand
Medium &
coarse sand
Pebble-conglomerate
Coquina
Cross bedding
Channel
Basal unconformity
treated as a
horizontal plain

(fig. 4.12). The pattern does not indicate that the units are contemporary. In fact they are probably diachronous and follow major transgression-regression cycles.

4(iii)d The sediments in the western sector of Area 103

Figure 4.13 shows the sediment distribution in the western sector of Area 103. Alternating poorly-sorted arkosic arenites, litharenites and better sorted sublitharenites and subarkoses are common. Diatomaceous silts and impure diatomites also occur, together with a tuff unit. Individual units range up to two or three metres thick, and are laterally variable and difficult to trace. Erosion surfaces, palaeosols and reworked sediments are common.

At sections 6 and 7 (fig. 4.13, plate 4.7) a 2 m thick, massive impure diatomite sits unconformably on moderately indurated silty sands. The impure diatomite is calcareous, and is succeeded by a 6 to 7 cm thick, flaggy tuff. This is the only tuff yet observed in the Galana Boi Formation. The nearest potential source is North Island, some 15 km to the north-west. Here, trachytic lavas overstep probable Holocene high lake level erosional benches. If these are associated, then a young age is implied for these deposits (middle to late Holocene ?). The tuff is succeeded by a well-laminated, slightly calcareous, impure diatomite. It has been strongly eroded, and the maximum thickness that remains is about 3 m. The erosion suggests a regression, after a period of quiet water diatomite sedimentation. Blocks of eroded diatomite (ca. 6 cm) occur in a channel in the middle of section 9. Above the impure diatomites is an arkosic silty-sand rich in molluscs. This deposit suggests a transgression and the development of a littoral environment.

In section 9 (fig. 4.13), below the eroded diatomite blocks, occur well-sorted, cross-bedded, litharenitic sands

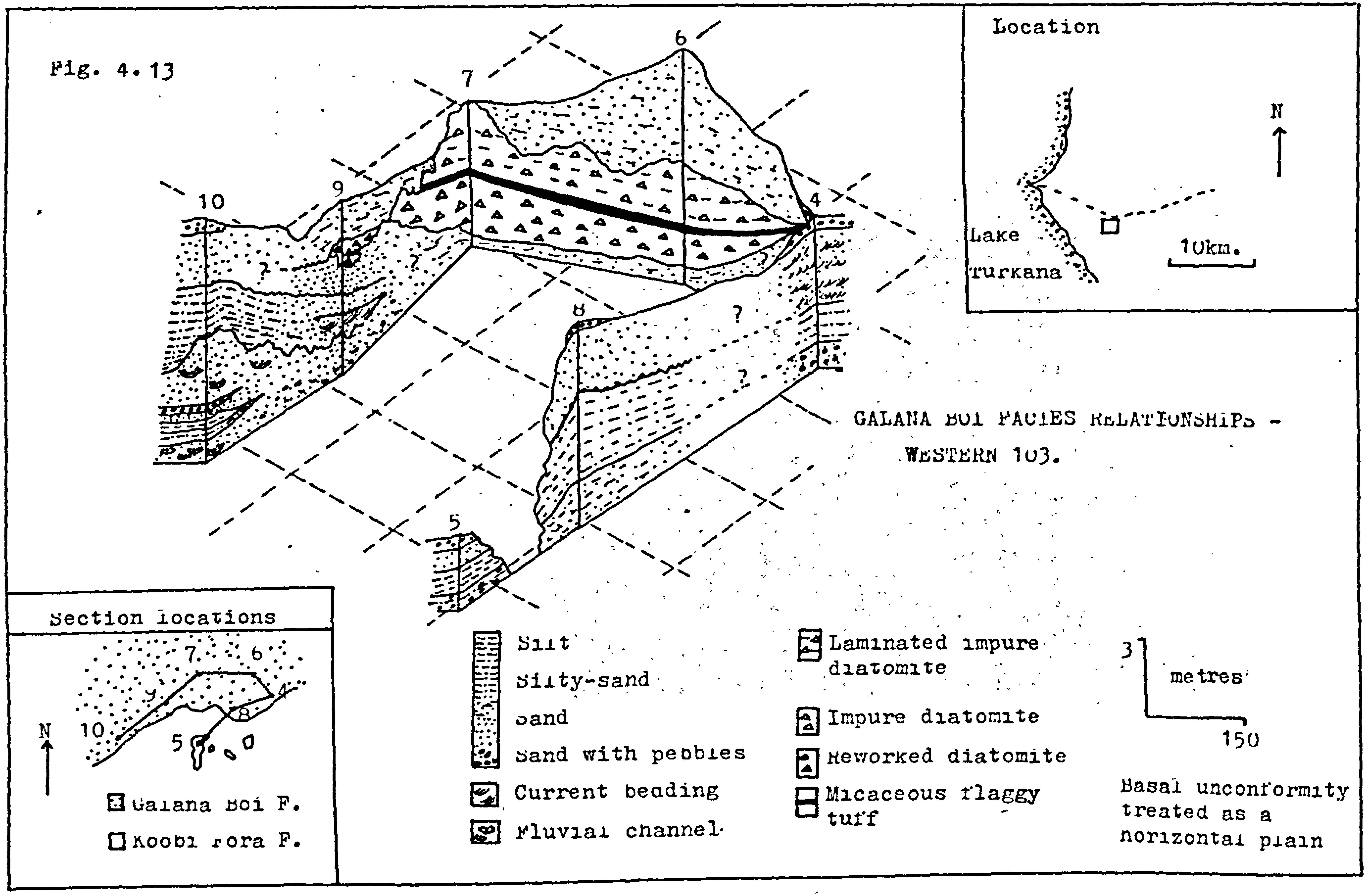


Fig. 4.13

GALANA BOI FACIES RELATIONSHIPS - WESTERN 103.

Plate 4.7

Middle to late Holocene impure diatomites. Calcareous impure diatomites occur at the base of the outcrop. A thin tuff (the only clearly defined deposit of this type, of Holocene age, that occurs at East Turkana) forms the ledge at 'Robins' shoulder. Above this, a well laminated impure diatomite continues the succession. These are some of the youngest lacustrine (other than beach deposits) sediments in the area.

with gastropods. Their orientation suggests a south-westerly palaeocurrent. At a height of 1.5 m in the section, and below the gastropod sands, is a calcareous litharenite, which contains a 2 to 3 cm thick fish bed. Ostracods are common in parts of this unit. At the base of this section occur subangular, poorly-sorted litharenites, with occasional fish fragments.

Beach deposits dominate in the east of the sector. At section 4 (fig. 4.13), planar cross beds and ripple drift laminae are present at the top of the sequence. These sands are well-sorted, contain heavy mineral bands, and are of subarkosic to sublitharenitic character. They overlie silty sands that contain fish vertebrae. Pebbly, poorly-sorted, coarse litharenites occur at the base of these Holocene deposits. Correlation of these sediments with those of the central sector is difficult due to poor exposure. They may be equivalent to the upper sands of the central sector, or rest unconformably on them. Their stratigraphic position, as far as can be assessed, and lithology are similar to the sands of section 19 (p.134). These two outcrops may form part of the same palaeoshoreline.

This sector was subject to several, probably middle to late Holocene, transgressions and regressions, with several periods of emergence from the palaeolake.

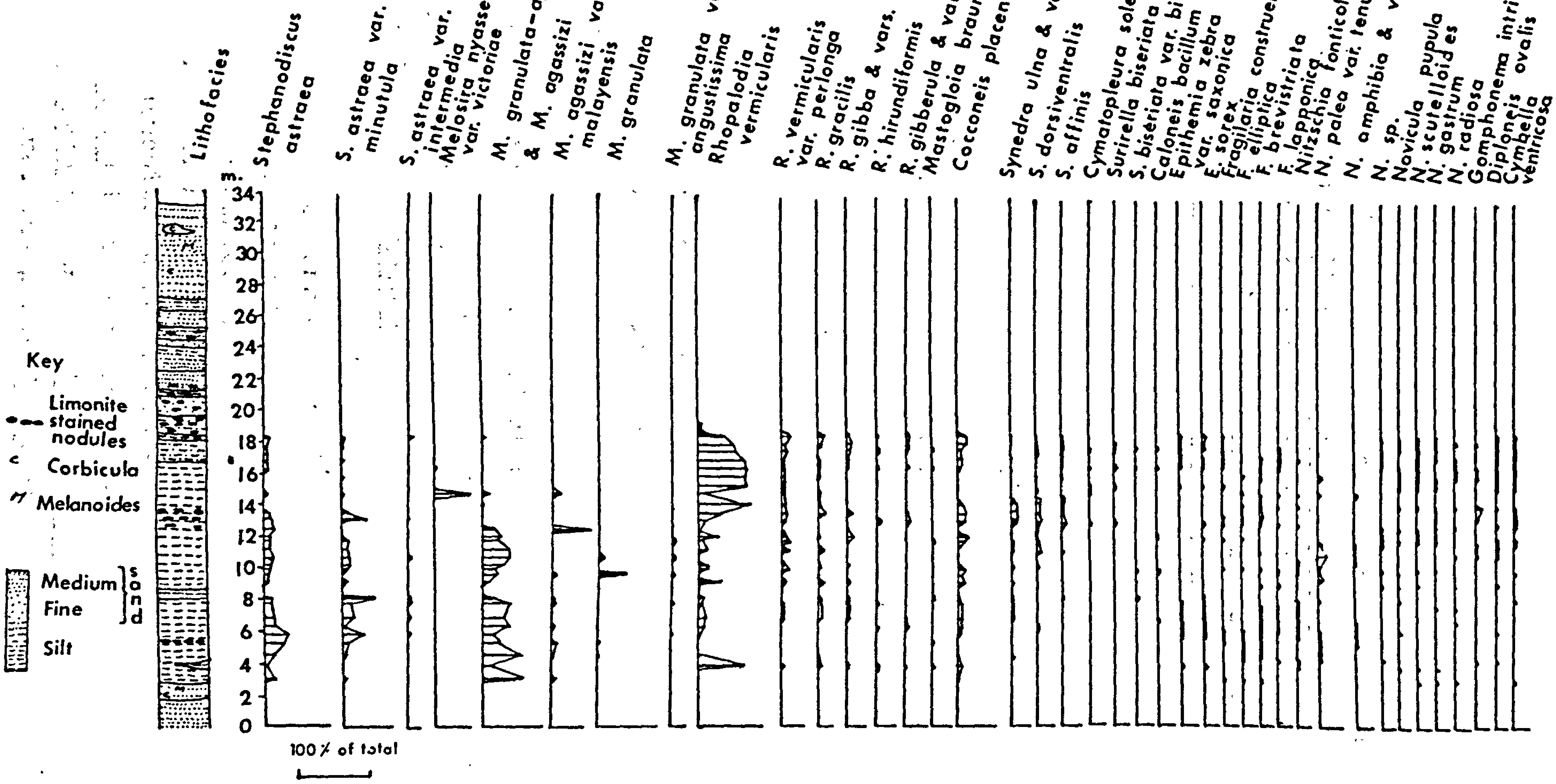
4(iii)d <u>The diatoms of Area 103</u>

The diatom stratigraphy of section 72, which lies in Area 103, has already been described. Several other sections were examined for their diatoms, and these are described in the following paragraphs.

Section 45 lies about 300 m to the south of section 72 (fig. 4.14). Here the deposits are 33 m thick, of which 15 m are diatomaceous. This section lies at a slightly lower altitude than section 72, which is reflected in a higher proportion of planktonic floras. The Zone A flora

Fig. 4.14

Diatom stratigraphy of section 45; Area 103

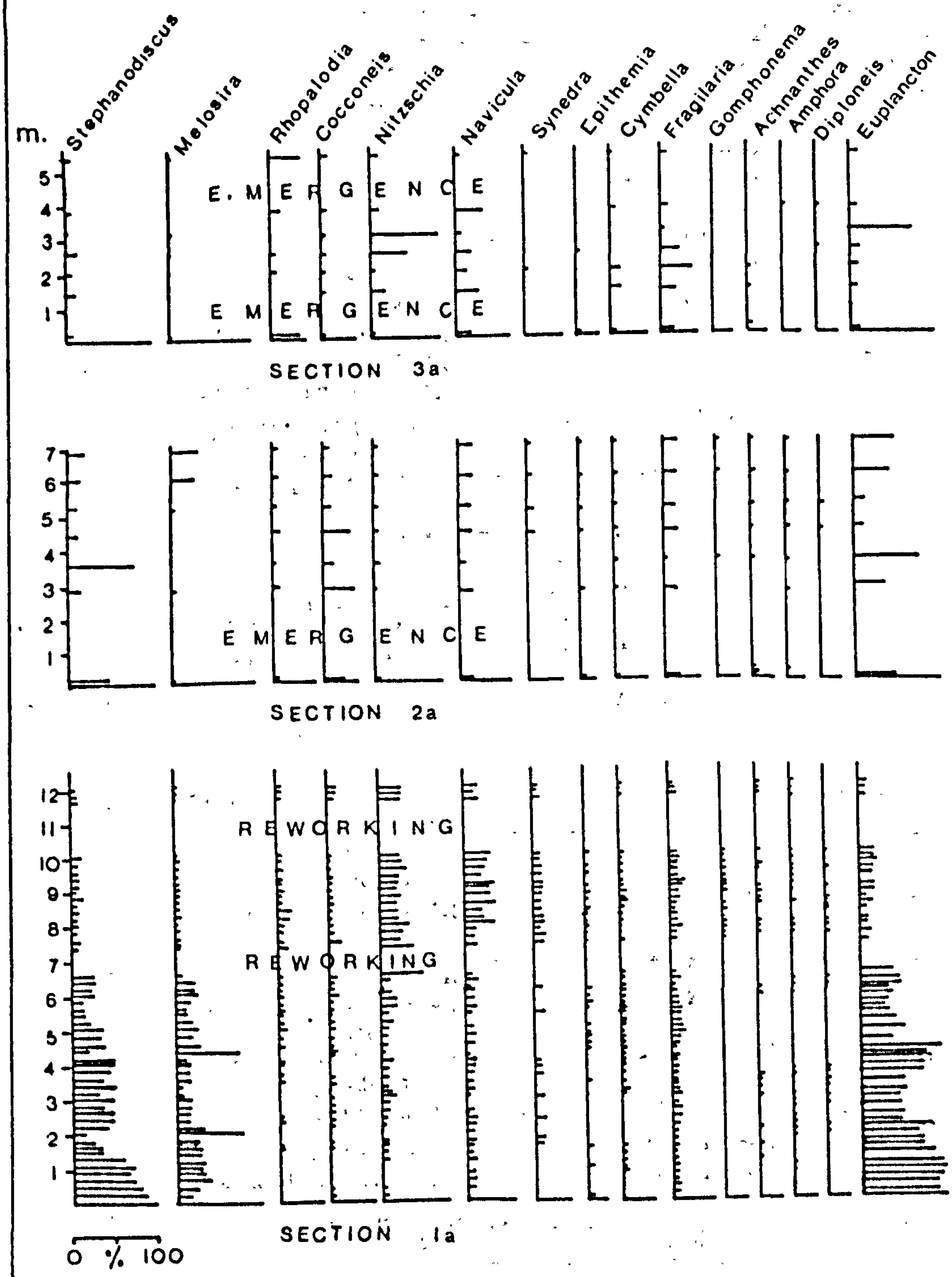


(see chapter 3), with its dominance of Melosira and Stephanodiscus, appears to be well developed between 3 and 8 m. A regression is probable between 8 and 9 m, where diatoms disappear apart for some fragments. The planktonic flora between 9 and 12 m suggests renewed high lake levels. Above this, the diatom Rhopalodia vermicularis becomes dominant, except for one or two levels, suggesting a shallowing of the lake. Stephanodiscus astraea var. minutula and Melosira nyassensis var. victoriae are dominant at 12.5 and 14.5 m respectively. Richardson (1968) comments that the latter is favoured by slightly alkaline water. It is common in oligohalobian lakes, and is endemic to Africa. Today, it occurs in Lakes Kyoga and Victoria in open water, and is favoured by low silica concentrations. S. astraea var. minutula is also an alkaliphile diatom, found in oligohalobian lakes of low silica concentration. It is common in nutrient-rich environments, and is favoured by transparent waters (allowing light penetration). Above 18 m, diatoms disappear and sandy sediments suggestive of littoral conditions prevail.

The generic counts shown in section 1a (200 m west of section 72) of figure 4.15 are dominated by planktonic diatoms.Two transgressions are probable, with shallow water phases being represented by reworked diatoms. Sections 2a and 3a, in the same figure, reflect shallow waters with occasional periods of emergence. Transgressions in these latter sections are indicated by increases in the percentage of Stephanodiscus and Melosira.

The diatoms of sections 6 and 7 (western 103) contrast with those recovered from the sediments of central 103. The diatom stratigraphies of these sections are shown in figure 4.16. Sections 6 and 7 contain the most highly diatomaceous deposits found in either Area 103 or Area 102. Melosira granulata is more common here than elsewhere, Thalassiosira rudolfii and Cyclotella meneghiniana appear for the first time. The genus Stephanodiscus, common in other localities, is absent, while Fragilaria species are

Fig. 4.15 Generic diatom stratigraphy of sections 1a, 2a, and 3a; Area 103 (Central sector).



For section locations see figure 4.11

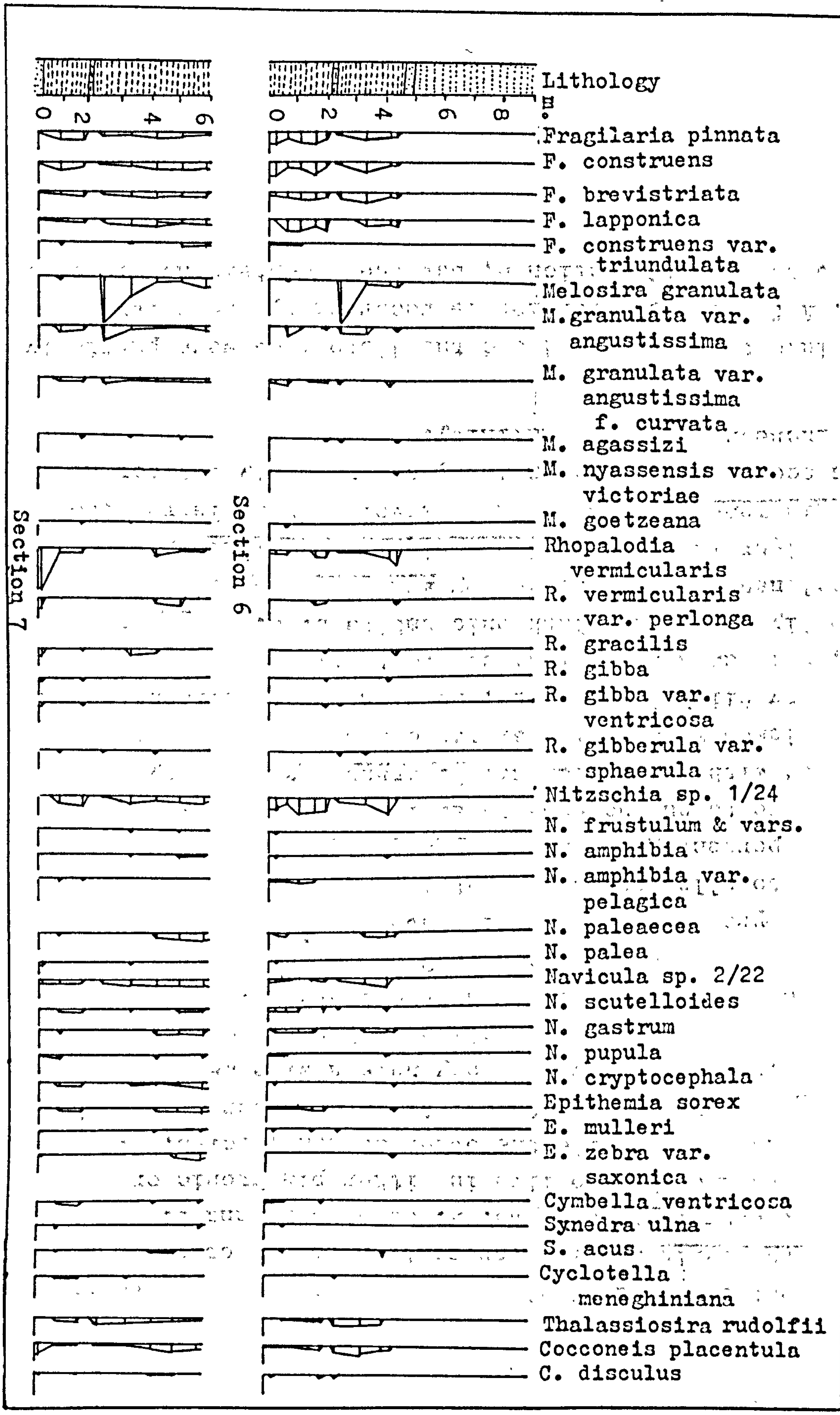


Fig 4.16 The diatom stratigraphy of sections 6 and 7, Area 103

more common.

Rhopalodia vermicularis occurs in a silty sand at the base of section 7, but declines rapidly to be replaced by several Fragilaria species (present in both sections 6 and 7). Today, Fragilaria pinnata, F. construens and F. brevistriata are able to live in either planktonic or benthonic habitats, while the other common species, F. lapponica is a benthonic diatom. All are favoured by a pH of about 7.5 to 8, and while they have a wide salinity tolerance are most common in oligohalobian water. They also tend to occur in lakes of low nutrient status. All diatoms disappear at the tuff horizon (210 cm in section 7). This probably represents an ash fall into the lake, sufficiently rapid not to allow the accumulation of diatoms. Above the tuff, the percentage of Melosira granulata increases. This might be due to an increase in silica availability, associated with the volcanism. M. granulata is today found in lakes with a high silica concentration. It is favoured by slightly alkaline, nutrient-rich, oligohalobian waters, and has a pH optimum of 7.8 to 8.2 (Cholnoky, 1968). It normally occurs in planktonic habitats. M. granulata soon declines and is replaced by Fragilaria spp.. There is also a slight increase in Thalassiosira rudolfii and Cyclotella meneghiniana at these levels. These latter two diatoms occur in the modern lake, and probably reflect a slight increase in the alkalinity.

The lake then regressed and the diatomites were partially eroded. A final transgression is recorded by the silty sands at the top of section 6, but these contain no diatoms.

4(iv) The geological history of the area to the east of Koobi Fora

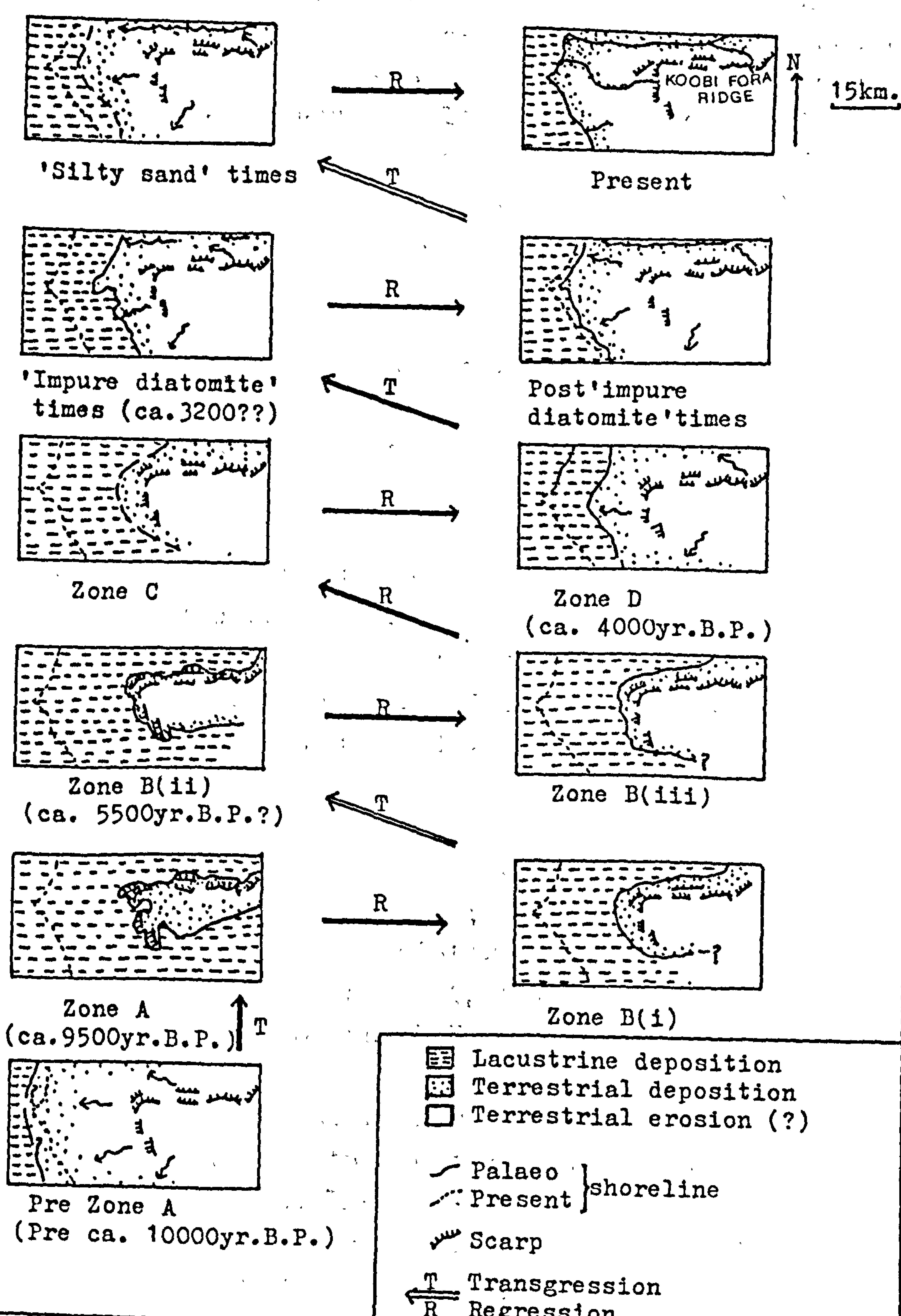
Figure 4.17 shows a series of simplified palaeogeographical maps for the region to the east of Koobi Fora. These indicate the approximate position of shorelines, as indicated by mapping in conjunction with diatom and sedimentological studies. The reliability of the dating varies from good to poor, but the stratigraphical order is essentially correct. The 'Zone' terminology is based on the study of section 72, and is discussed in chapter 3.

During pre-Zone A times the area was dominated by erosion. Channel conglomerates suggest a well-ordered stream network. This latest Pleistocene erosive phase has also been recognised in the Omo region, to the north of Lake Turkana, by Butzer (1972). He dated it at between 37,000 and 10,000 yr. B.P.. The shoreline position is unknown, but probably lay to the west of Areas 102 and 103.

A major transgression during Zone A times led to the deposition of silts throughout Areas 102 and 103. At this time the Koobi Fora Ridge may have been periodically inundated, but more probably was emergent as a linear, north-east to south-west trending land mass (for further data see chapter 5). The diatom evidence suggests that the lake level was not stable. Altimeter readings on beach sediments suggest a maximum height of about 80 m above the modern lake. The palaeolake contained a rich biota which included fish, crocodile, hippo, molluscs, ostracods, diatoms and macrophytes. The shorelines were frequented by early fishermen. Sediments dated from here and other parts of East Turkana suggest that this phase took place between about 9,800 and 7,700 yr. B.P..

A regression of limited extent took place during Zone B(i) times. The shoreline shifted away from the Koobi Fora Ridge, but still remained closely parallel to it. Silt deposition was maintained through most of Areas 102

Fig. 4.17 Inferred shoreline changes at Koobi Fora during the Holocene



The diagrams are based on field evidence, diatom data and radiocarbon dates. The shoreline positions are approximate. For full explanation see text.

and 103. The lake remained fresh and of essentially unchanged character.

A second major transgression occurred during Zone 'B(ii)' times, although the lake may not have attained the heights it did during Zone A. A second high-level phase has been recorded elsewhere along the Koobi Fora Ridge. This conforms to a pattern noted by Butzer in the Omo region, where he dated the second transgression at between about 5,000 and 6,000 yr. B.P.. However, such a correlation must be treated with caution.

A regression occurred during Zone B(iii) times. Small streams advanced, particularly on the northern side of the Koobi Fora Ridge. The shoreline still lay close to the Ridge.

By Zone C times the shoreline was located over areas of earlier silt deposition. Alternating lacustrine silts and beach sands suggest that the lake was still subject to fluctuations of height. Fluvial sediments were prograding into what was still a freshwater lake with an extensive biota.

Lacustrine silt sedimentation had receded from most of Areas 102 and 103 by Zone D times. Sediments belonging to this phase in the lake's history have been dated by Raynolds (1972) and Barthelme (pers. comm., 1978) at between 4,000 and 5,000 yr. B.P..

A third, more limited transgression, during 'impure diatomite' times, lead to the deposition of impure, calcareous diatomites. The lake had become slightly more alkaline, but remained much fresher than it is today. Contemporary volcanism took place, probably centred on North Island. Fluvial and deltaic environments were more widespread across Areas 102 and 103.

Regression lead to erosion of former lake deposits during 'post impure diatomite' times. The shoreline may have stood close to its modern location. A minor transgression followed in 'silty sand' times, during which the shoreline probably passed through the western sector of Area 103 and through southern 102.

The lake continued to recede, probably with several minor transgressions, until the modern shoreline was attained. Butzer (1971) has demonstrated that during historical times the lake has risen and fallen between heights of -5 m and +15 m (fig. 4.4).

CHAPTER 5

THE VARIETY OF QUATERNARY LACUSTRINE SEDIMENTS ACROSS THE EAST TURKANA BASIN

5(i) Introduction to the range of lithofacies present at East Turkana

This chapter describes several distinct areas, that together complete the story of Holocene sedimentation at East Turkana. These areas include:

(i) Areas 120 and 127. The deposits present include *Etheria* shell banks, coquinas, diatomaceous silt and impure diatomite, littoral and aeolian sands.

(ii) Area 119. The deposits present include coquinas, beach ridge sands, lagoonal silts and regressive sand sheets.

(iii) Areas 100 and 104. The deposits include micaceous littoral sands and silts, coquinas, calcretes and alluvial sediments.

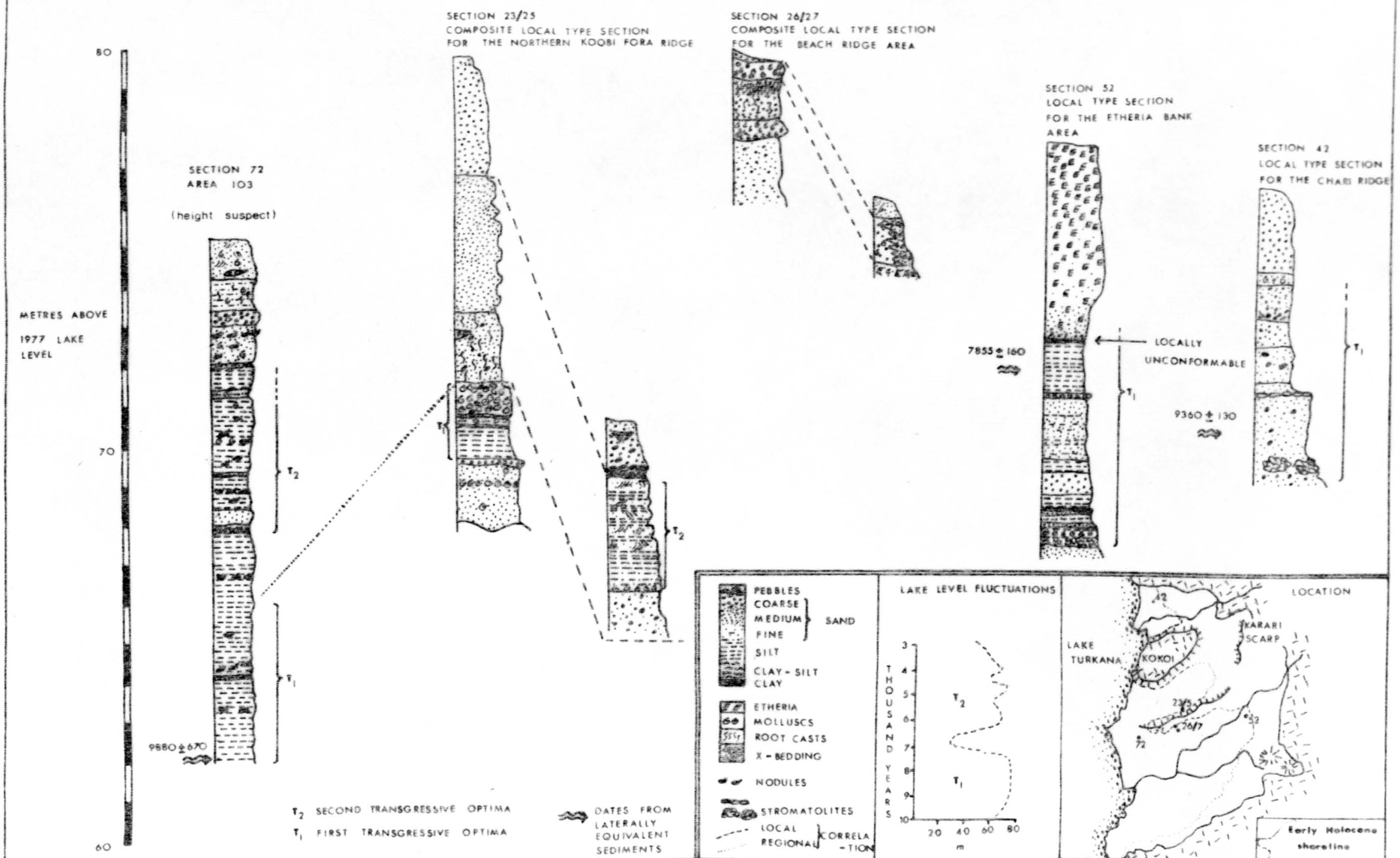
(iv) The Chari Ridge area, in the extreme north of East Turkana. Both Pleistocene and Holocene sediments are described. These include littoral sands, stromatolites, coquinas, claystones and siltstones.

(v) Areas of the modern lake from which cores have been obtained. The sediments are dominated by light and dark banded, calcareous clays.

Figure 5.1 shows a series of Holocene 'local type sections' for each of the areas to be discussed (except for the core material), and also shows the section 72 sediments (discussed in chapter 3). The diagram includes data on heights, lithologies, dates and major transgressions.

Fig. 5.1

ALTITUDE AND CORRELATION OF LOCAL TYPE SECTIONS IN THE GALANA BOI FORMATION



5(ii) The lacustrine sediments and '*Etheria elliptica*' shell concentrations of Areas 120 and 127

5(ii)a Introduction to the sediments of Areas 120 and 127

Holocene lacustrine sediments crop out to the east of the Bura Hasuma River, 25 km east of Koobi Fora, within Areas 120 and 127. There are no direct roads into these Areas, but they can be approached from the north without too much difficulty. A geological map, based on aerial photographs and field observations, is shown in figure 5.2a, while the facies variations are given in the block diagram of figure 5.2b. The local type section (numbered 52) is presented in figure 5.1.

This area is informally referred to as the '*Etheria* Reef' locality, because of local concentrations of the mollusc, *Etheria elliptica*. Although found elsewhere in the East Turkana region, it is most abundant here.

The sediments can be informally divided into two units, an upper and a lower unit (fig. 5.2b). The upper unit consists of aeolian and littoral, litharenitic and sublitharenitic sands, with local *Etheria* concentrations. The upper unit often rests unconformably on the lower unit. The lower unit is less extensive than the upper, and is dominated by lacustrine feldspathic silts, coquinas and impure diatomites. The various lithofacies present in both units will be described in the remainder of this section.

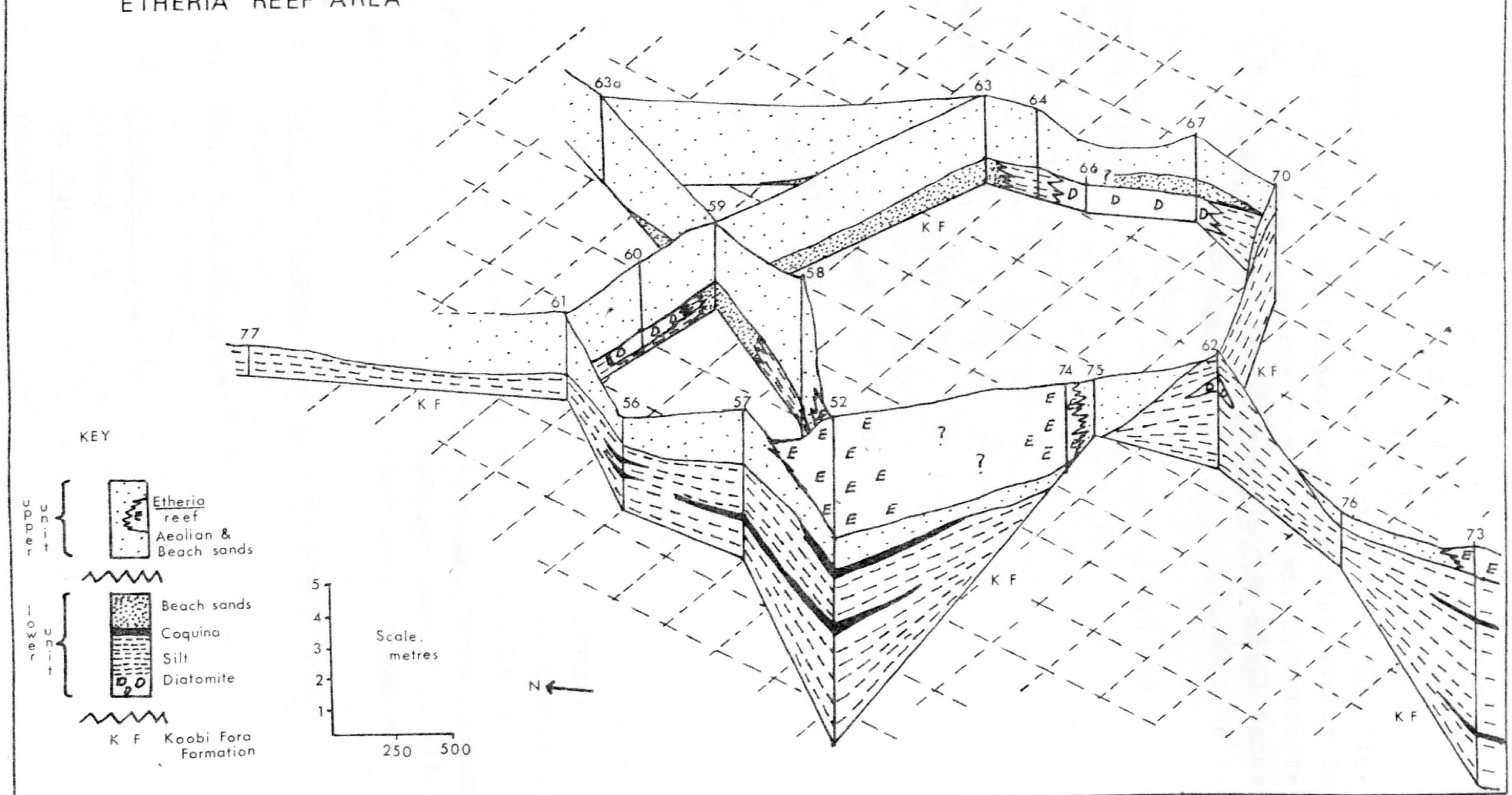
5(ii)b The distribution, lithology and palaeontology of the '*Etheria* shell banks' and coquinas

The '*Etheria* facies' consists of tightly cemented shells of *Etheria elliptica*. Where it is best developed, such as in sections 52 and 74 (fig. 5.2b, plate 5.1), there

Fig. 5.2a

GEOLOGICAL MAP OF THE "ETHERIA REEF AREA" - EAST TURKANA

Fig. 5.2b
FACIES VARIATION IN THE "ETHERIA REEF AREA"



is little or no detrital contribution of silt or sand. This biogenic deposit is confined to the upper unit, where it often forms a cap-rock. The *Etheria* facies reaches a maximum thickness of 4.5 m at section 52 (fig. 5.1). In this section the facies passes gradationally into underlying and lateral, poorly consolidated, litharenites. At section 73 (fig. 5.2a), *Etheria elliptica* shell banks sit on a planar erosion surface cut into lacustrine silt.

Etheria elliptica thrives under high energy conditions (Williamson, pers. comm.). Today, it occurs along the interdistributary channels of the Omo River delta (Butzer, 1971). Satellite photos show that a possible overflow from Lake Chew Bahir (see discussion in chapter 7, p.223) may have entered the palaeolake in this area. A high energy shoreline, with a freshwater input, would seem to be a suitable environment for this mollusc. In other parts of East Turkana, *Etheria* occur scattered through sandy deposits, but never attain the concentrations found here. No diatoms were recorded in this facies.

Other molluscs occur in coquinas that are usually lensoid bodies of less than 1 m lateral extent and 4 to 5 cm vertical thickness. However, the most extensive coquina (in the vicinity of section 52) can be traced for about 400 m. The molluscs mostly occur in a silt or poorly-sorted, fine to medium sand matrix. Three common types of coquina occur (based on mollusc content), all of which are best developed in the lower unit. These are:

a) *Melanoides tuberculata* dominated. Usually found in low numbers.
b) *Corbicula africana* dominated. Usually found in high numbers.
c) *Corbicula africana* and *Melanoides tuberculata* jointly dominant. A wider variety of species, eg. *Mutela sp.* and *Cleopatra spp.*. Usually found in high numbers

Plate 5.1

Section 52. Early Holocene deposits up to 80 m above the modern lake. Note the 'panga' and hat, for scale (about 30 cm). Lacustrine diatomaceous silts and clays are overlain by shell banks, composed of well-cemented Etheria elliptica.

Among the more common molluscs present are: Melanoides tuberculata, Pila ovata, Bellamya unicolor, Cleopatra spp., Mutela emini, Etheria elliptica, Caelatura sp. and Corbicula africana. A large proportion of the shells are disarticulated or worn, especially in the upper unit. This probably indicates transportation prior to deposition. Diatoms occur, but are mostly fragmentary. The most common species belong to the genera Rhopalodia, Epithemia and Cocconeis, and are all littoral forms.

5(ii)c The fine grained lithofacies of the 'Etheria Reef' locality

Three groups of fine grained lithofacies occur. These are:

a) The black shales
b) The diatomaceous silts
c) The impure diatomites

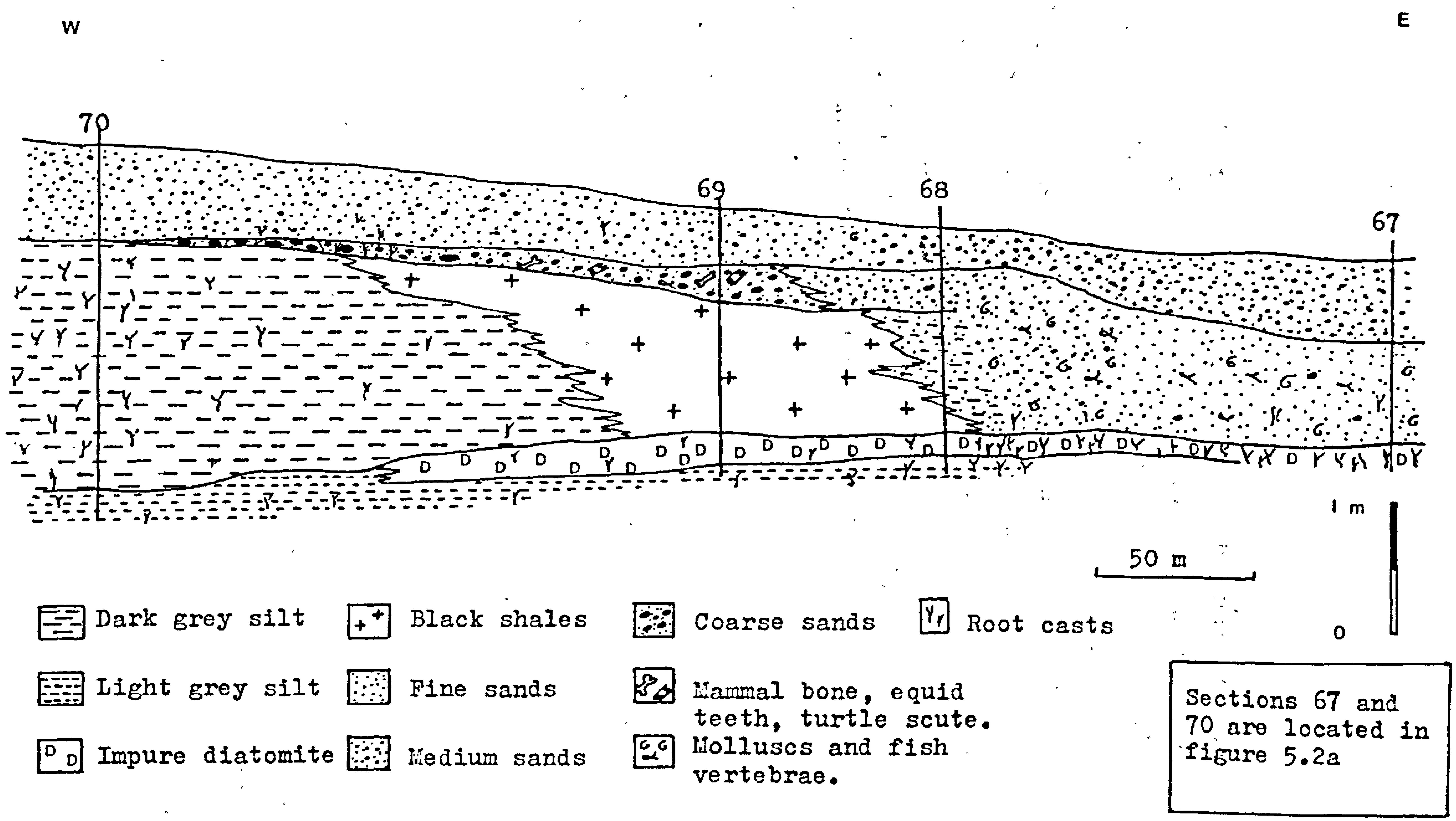
Each of these lithofacies will be discussed in turn.

a) The black shales

X-ray diffraction and grain size analyses of these shales show that montmorillonite clay (8.5+ phi) forms up to 85 wt. % of the black shale lithofacies. The remainder consists of fine to medium silts (5.0 to 8.5 phi). This is the only part of East Turkana where clays attained such concentrations. The black shales are confined to the lower unit. They crop out in section 52 (fig. 5.1) as two thin horizons, both less than 4 cm thick. The two horizons are well consolidated and devoid of any biota.

Black shales are best developed at section 69 (fig. 5.3). Here, hard black shales form a deposit about 1 m thick. The upper and lower boundaries of this deposit are sharp, while laterally it grades into dark grey silts, with abundant root casts. No fossils were observed in the

Fig. 5.3 The lithofacies relationships of sections 67 to 70, Area 127.



shales. They probably represent quiet-water sedimentation, and possibly anaerobic conditions (in view of the lack of fossils). Possibly they are lagoonal.

b) The diatomaceous silts

Lacustrine diatomaceous silts form the bulk of the lower unit. They are poorly consolidated and occasionally weakly laminated. Diatoms are often fragmentary and consist mainly of littoral types. These are dominated by Rhopalodia vermicularis and Cocconeis placentula. Their fragmentation suggests a turbulent environment, perhaps as a result of wave action. The silts attain a maximum thickness of about 5 m in sections 52 and 73 (fig. 5.2b). X-ray diffraction shows feldspars to be dominant (up to about 80 %), while minor quantities of montmorillonite are present.

c) The impure diatomites

Impure diatomites occur only in the lower unit. They often contain root casts (eg. in section 67, fig. 5.3), and are powdery to the touch. Laterally they grade into less diatomaceous silts. The flora of these deposits is as follows.

DOMINANT	:	Rhopalodia vermicularis
SUBDOMINANT	:	Cocconeis placentula
OCCASIONAL	:	Synedra ulna & varieties, S. rumpens, Rhopalodia gracilis, R. hirundiformis

Today, these diatoms occur in littoral environments, often rich in reeds. In order to allow these diatoms to accumulate, the areas may have been sheltered or lagoonal.

5(ii)d The sandy lithofacies of the 'Etheria Reef' locality

Sandy sediments are mainly confined to the upper unit, and the north-eastern parts of the lower unit. Both littoral and aeolian sands can be recognised.

The littoral deposits consist of unconsolidated, structureless, fine to medium, arkosic and lithic arenites. In thin section the sands can be seen to be dominated by orthoclase, albite, quartz and lithic fragments. The latter include basic volcanics and less common reworked sandstones. Other minerals are the same as those found in the sands of Areas 102 and 103 (p. 120). Heavy minerals are common, but do not form distinct bands. The grains in most sands are subangular to angular (lithics are often better rounded), and moderately to poorly sorted. The poor sorting, angularity and mineralogy of the sands suggests the proximity of an area of sediment input. Molluscs, in various states of preservation, are common.

Better sorted, fine sands also occur in the area. These occasionally show trough cross-bedding and are devoid of lacustrine fossils, other than comminuted shell debris. Although these deposits were not examined in detail, they are probably of aeolian origin.

The deposits of the '<u>Etheria</u> Reef' locality are mostly of littoral or lake marginal character. The sediments lie between 75 and 80 m above the 1977 lake level. Barthelme (pers. comm.) has obtained a date of 7855 ± 160 yr. B.P., from molluscs in the lower unit. This suggests that the early Holocene shoreline passed through this area.

5(iii) The beach ridges and sandy lithofacies to the south of the Koobi Fora Ridge

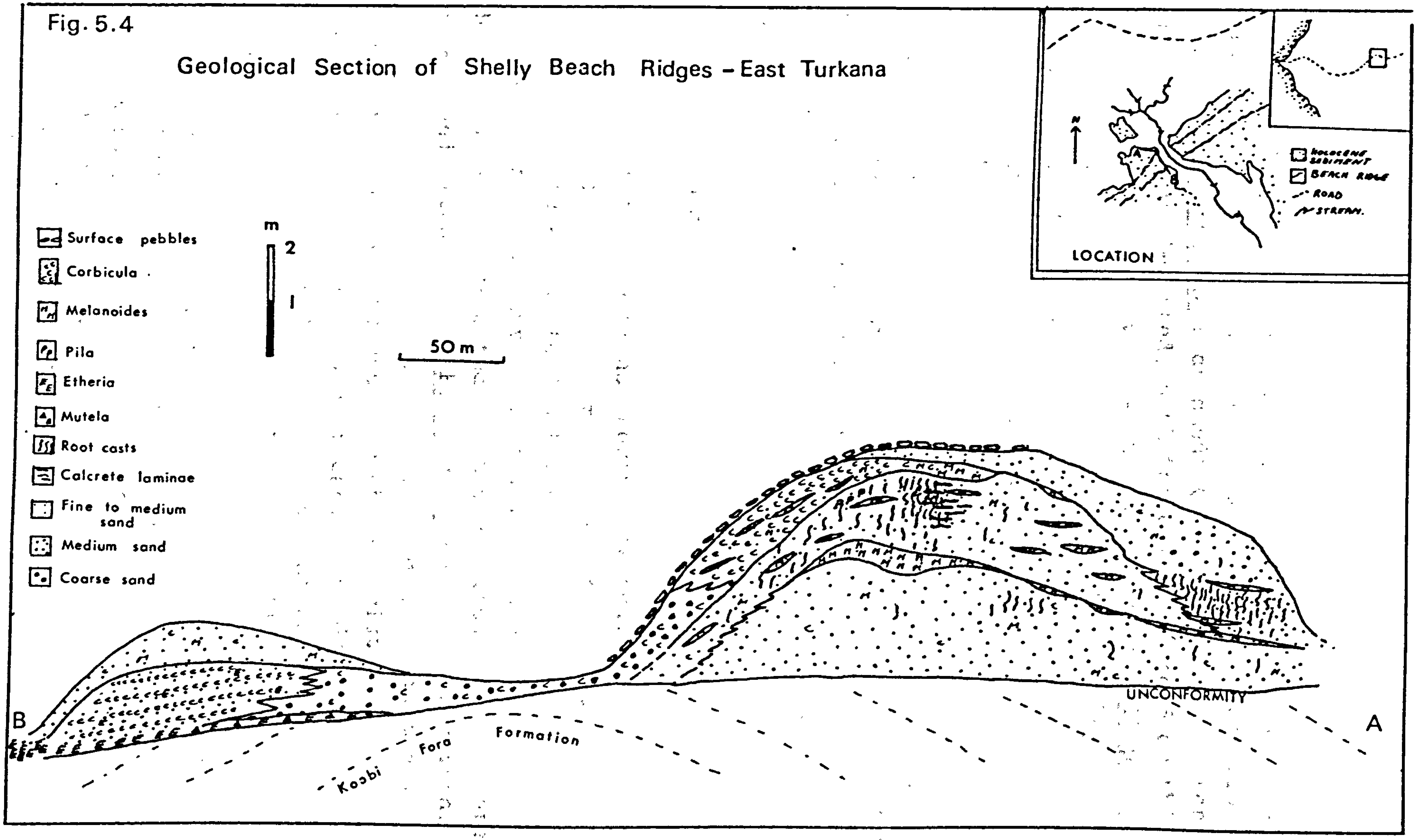
The sediments to be discussed here lie some 10 to 15 km to the east of Koobi Fora, mainly in Area 119. They crop out on the gentle southern slopes of the Koobi Fora Ridge. Several lithofacies occur; these include beach ridge sands and coquinas, regressive sand sheets, pebble-conglomerates and aeolian sands. No diatoms were found in these sediments, which will be described under two headings: the beach ridges, and the sandy lithofacies.

a) The beach ridges

Two beach ridges are visible on aerial photographs of this area. They run parallel to the Koobi Fora Ridge on a north-east to south-west trend for about 6 km (see map of the area to the east of Koobi Fora, at the back of the thesis). Both ridges are well exposed due to river incision at their south-western ends (fig. 5.4). To the north-east they become topographically less distinct, particularly the lower ridge. Eventually they diverge due to a change in angle and orientation of the slope on which they sit.

Figure 5.4 shows the lithologies and lateral relationships of these ridges. The higher ridge (on the right of the diagram) consists of well-sorted, medium litharenites and sublitharenites, which contain two distinct shell beds. The lower is dominated by Melanoides tuberculata (90%). To the palaeoland side (north-west) and above this shell bed, calcareous sandy root casts are found in growth positiom. These probably developed in linear lagoons parallel to the palaeoshorelines, and protected from the lake by the beach ridge. Similar environments exist along the modern shoreline (except that molluscs are absent due to the high alkalinity). The upper shell bed is dominated by Corbicula africana, although Melanoides tuberculata is

Fig. 5.4 Geological Section of Shelly Beach Ridges - East Turkana



increasingly common towards the palaeoland. Pila ovata occurs in lenses below the latter shell bed.

The Corbicula coquina passes, downslope, into a coarse sublitharenite. In turn, this grades into the lower beach ridge where Corbicula rich sands (1 to 2 cm thick) alternate with medium, well-sorted, sublitharenites (2 to 3 cm thick). At the base of this lower beach ridge, Etheria elliptica dominates in a medium sand (up to 10 cm thick). Melanoides, Corbicula and Mutela are also common. Fine sands with scattered Melanoides and Corbicula occur in the upper 80 cm of the ridge.

While the ridges are not dated, their height of ca. 75 m above modern Lake Turkana, indicates that they developed during a high lake phase, possibly the early Holocene. The continuity of sediments between the two ridges suggests that the two ridges are not widely separated in time.

b) The sandy lithofacies

A series of sections showing the sediments to the north-east of the beach ridges are shown in figure 5.5. These deposits are up to 4 m thick and represent a complex series of shoreline environments. The sediments are dominated by poorly-sorted, lithic arenites. Molluscs are common and often broken. Pila ovata was found in several sections, but was particularly abundant in section 47. Today, this amphibious snail is characteristic of temporary swamps. It occurs at Sandersons Gulf (to the north of Lake Turkana), which is subject to periodic submergence by Lake Turkana (Butzer, 1971).

At section 48, and in the upper part of section 51, coarse lithic sands alternate with rounded gritty pebble-conglomerates. This may reflect the influence of an oscillating shoreline. However, the ancestral river Bura Hasuma would have entered the lake about 200 m to the east, and the alternating sediments possibly reflect changes

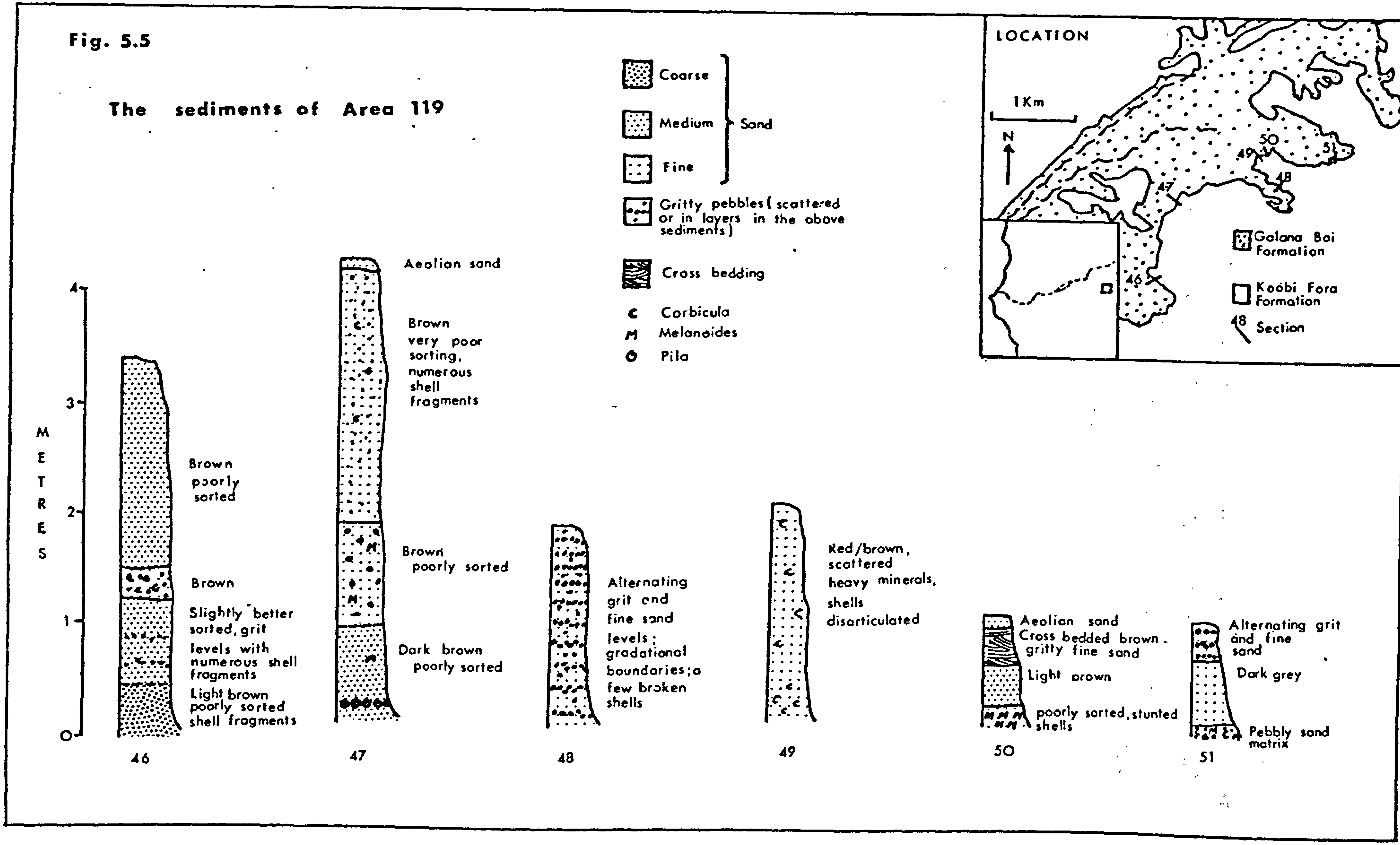


Fig. 5.5

The sediments of Area 119

in sediment supply.

Large spreads of mainly structureless sands occur to the south-east of the beach ridges. Shoreline sediments usually form linear bodies, but upon a regression a series of such deposits may coalesce to form broad sheets of sand. This is considered the probable origin of the structureless sands. The lack of structure may be due to reworking and/or bioturbation.

In general, the deposits to the south of the Koobi Fora Ridge can be considered to have formed along the shores of a high-level lake, with an area of sediment-input to the north-east.

5(iv) The sediments to the north of the Koobi Fora Ridge

Extensive deposits of modern and late Holocene alluvium occur about 5 km to the north of the Koobi Fora Ridge (fig. 3.1, p. 87). Older, Holocene alluvium and colluvium underlie these sediments and fringe along the lower flanks of the Ridge. At higher altitudes are a further series of sediments, which contain evidence of former higher lake levels. It is these latter deposits that form the subject of this section.

In contrast to the southern gentle slopes of the Koobi Fora Ridge, the northern side consists of steep scarps and deeply incised valleys. These valleys often contain remnants of Holocene sediment. The largest Holocene outcrop is shown in plate 5.2 and in the inset of figure 5.6, which also illustrates several sections from this area. These sections will be described in the following paragraphs. The local, composite, type section (numbered 23/25) is given in figure 5.1.

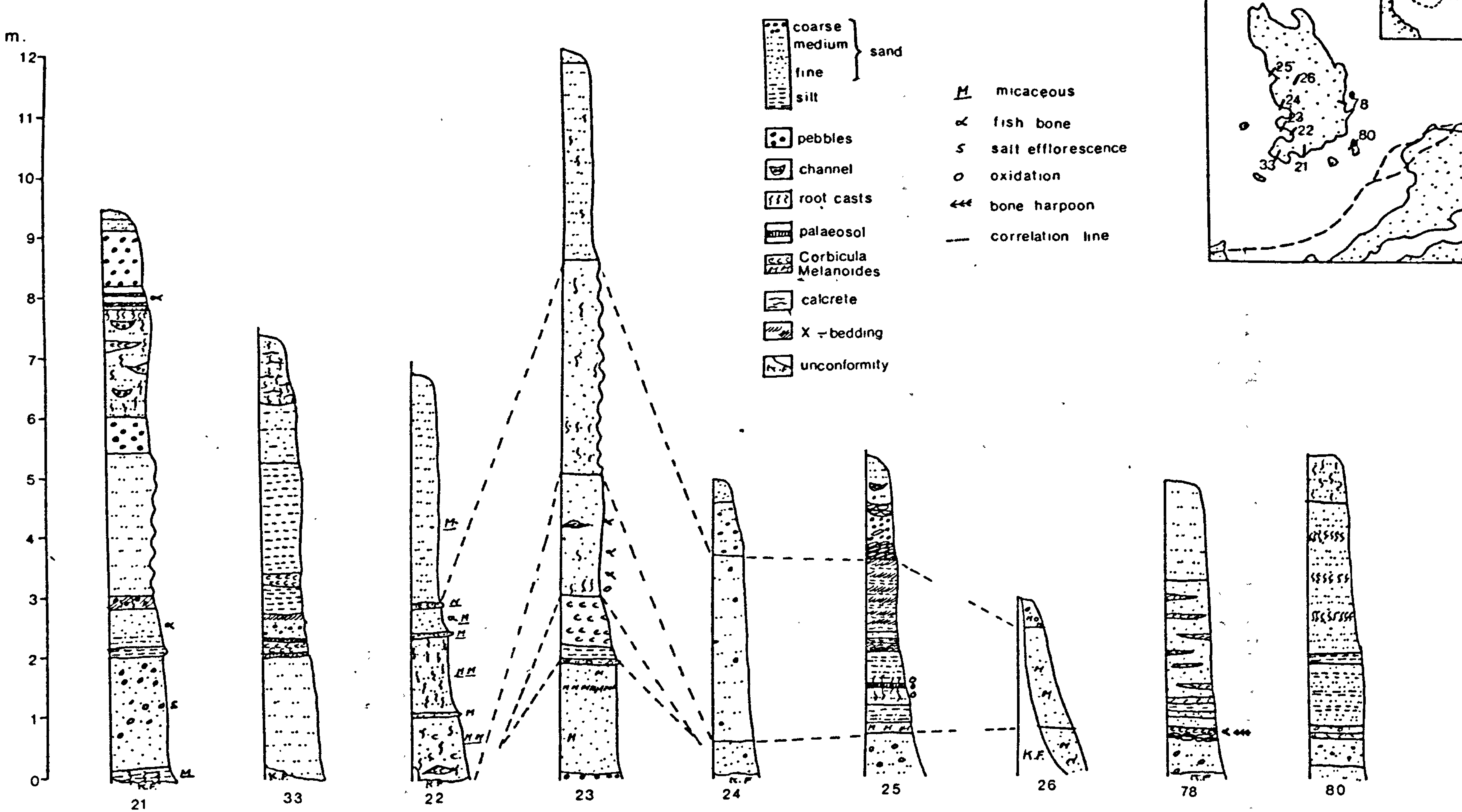
A high lake level incursion is indicated by 20 cm of laminated silts, 2 m from the base of section 23. Several diatoms occur, including Rhopalodia vermicularis, Cocconeis placentula, Epithemia zebra and Synedra spp.. In modern lakes such floras are common in the littoral, reed-rich areas. Root casts are in fact common, especially in the sandier units. Above the silts in section 23 is a coquina up to 50 cm thick (plate 5.2). This is laterally extensive, and can also be seen in section 33. Well preserved Corbicula spp. dominate. Two thin (0.5 cm) horizons of white, diatomaceous silt, dominated by Rhopalodia spp., occur within the coquina.

A lake regression is indicated by a coarsening upwards into fine, micaceous litharenites above the coquina of section 23. A second sandy unit, rich in mica, above this, contains abundant root casts. This unit can be traced downhill, where it experiences a facies change. By section

Plate 5.2

View looking north from the Koobi Fora Ridge. Holocene, diatomaceous, lacustrine silts, sands and coquinas (white beds) can be seen in the middle distance. These are 'banked up' against high ground, and were laid down under an expanded Lake Turkana, that formerly covered the plain beyond.

Fig. 5.6 The Holocene sediments to the North of the Koobi Fora Ridge.



25, the root cast sandy unit has passed into a sequence of diatomaceous silts and silty sands, cross-bedded, fine sands, and a coquina. These deposits suggest a second, lower lake level. A former river channel, containing imbricated conglomerates, is eroded into the top of the latter deposits. This fluvial unit grades laterally into medium grained, micaceous sands, with root casts and occasional tabular calcrete. The calcrete may reflect an arid environment.

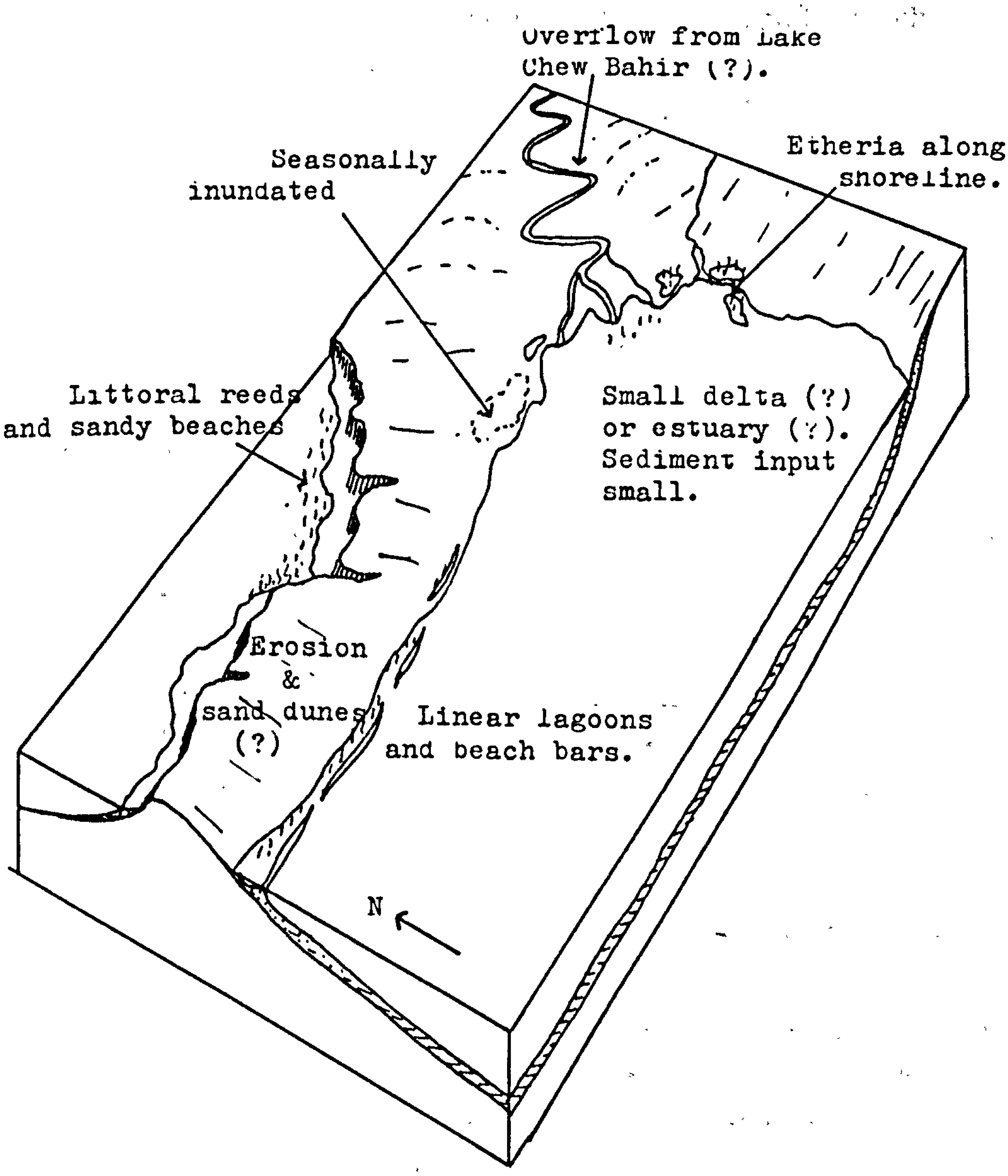
The thickest unit of diatomaceous silt occurs in section 33, where they attain 2.5 m. These silts are laterally equivalent to those of section 23 (described above). At the top of section 33 is a root cast sand that contains abundant tabular calcrete.

A number of sections could not be directly correlated with those previously discussed. These indicate a wide range of environments from fluvial to littoral lacustrine and swamps. In section 78, scattered fish bone and bone harpoon heads occur in a sandy coquina, which rests on a pebble conglomerate. This probably represents a shoreline occupied by people practising a fishing economy.

The contrasting nature of the sediments so far discussed in this chapter,allow a generalised reconstruction of the palaeogeography of the Koobi Fora Ridge to be attempted (fig. 5.7). The reconstruction shown in figure 5.7 represents the early Holocene lake maximum, and pulls together data that may not be strictly contemporary. However, the broad relationships are probably correct, and the diagram brings out the central role played by the Koobi Fora Ridge.

Fig. 5.7

Generalised palaeogeography of the Koobi Fora Ridge and 'Etheria Bank' areas during the early Holocene lake maximum.



The representation is schematic. It is based on evidence that may not be exactly time equivalent. Rather it represents a broad situation during the early Holocene.

5(v) The Quaternary sediments of the Chari Ridge, northern East Turkana

5(v)a The Pleistocene sediments of the Chari Ridge

The Chari Ridge is an area of high ground in the extreme north of the study area, that lies between Ileret village and the Kokoi volcanics (fig. 1.3, p. 31). It is formed by folded and faulted sediments of the Koobi Fora and Guomde Formations, of Plio-Pleistocene and Pleistocene ages respectively. These are overlain unconformably by the Holocene sands of the Galana Boi Formation. Figure 5.8 shows the distribution of these Formations.

Although no diatoms were observed in the Koobi Fora Formation of this area, diatoms have been recovered from equivalent sediments, about 10 km to the east of Koobi Fora. Here, diatoms occurred in low numbers in two of twenty samples from lacustrine units. The diatoms found were: Melosira granulata, Synedra ulna and Rhopalodia vermicularis. Findlater (pers. comm.) notes the presence of diatomites, although these were not examined.

Diatoms are more common in the Guomde Formation. This Formation was defined by Bowen and Vondra (1973) as being, " the strata overlying the Chari tuff and underlying the Holocene diatomaceous siltstones". Both upper and lower boundaries are unconformable. The name of the Formation was taken from the Kolum Guomde, a tributary of the Lage Tula Borr. These shallow lacustrine and alluvial deposits (plate 5.3) are of middle Pleistocene age. The same time span to the south of the Kokoi volcanics is represented by an unconformity.

Guomde Formation diatoms attain a maximum concentration of about 1000 valves/g of sediment. Figure 5.9 summarises the floral distribution in the two main sections studied. The following species occur: Melosira granulata,

Fig. 5.8

The Geology of the Chari Ridge Area

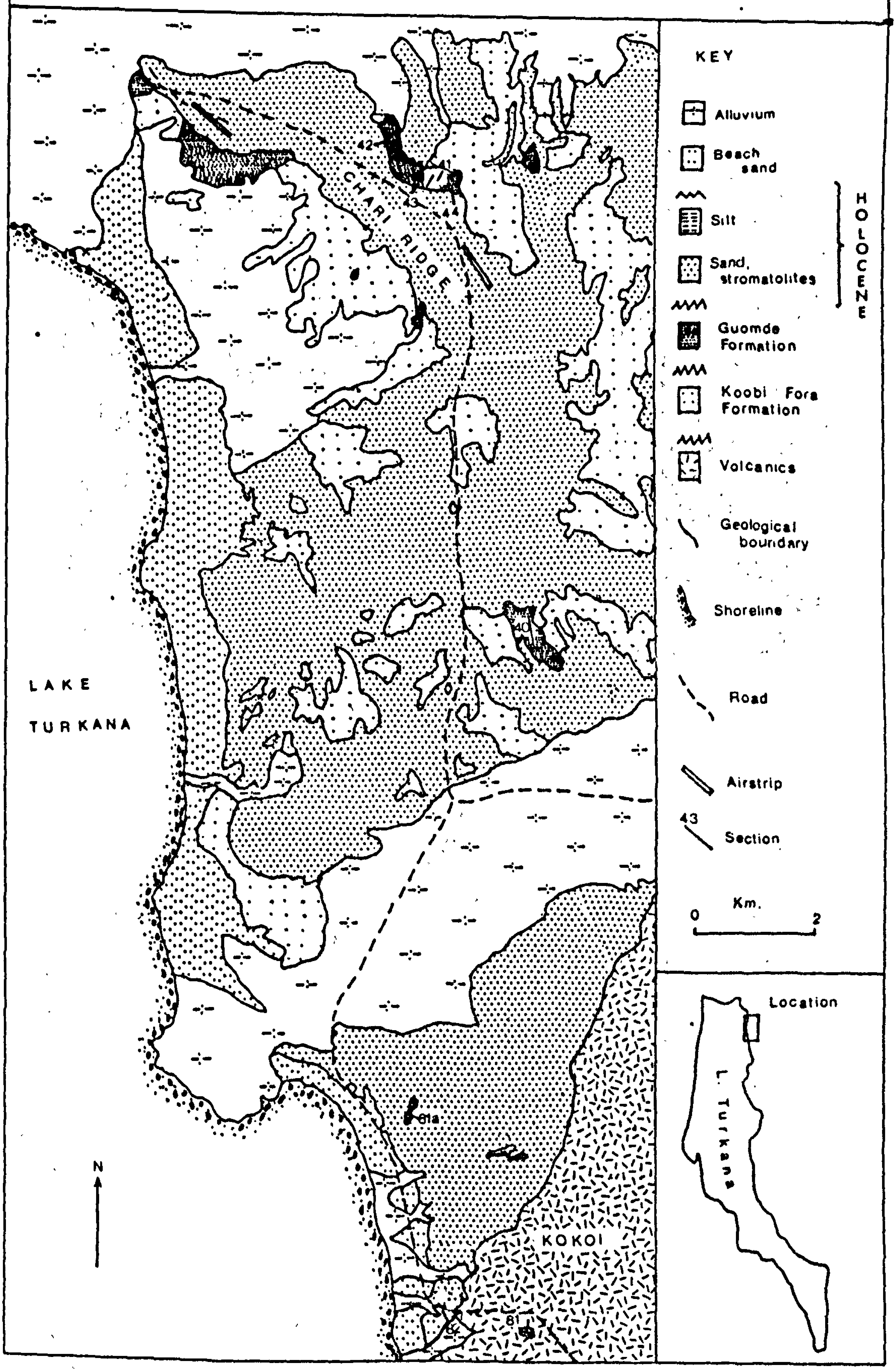
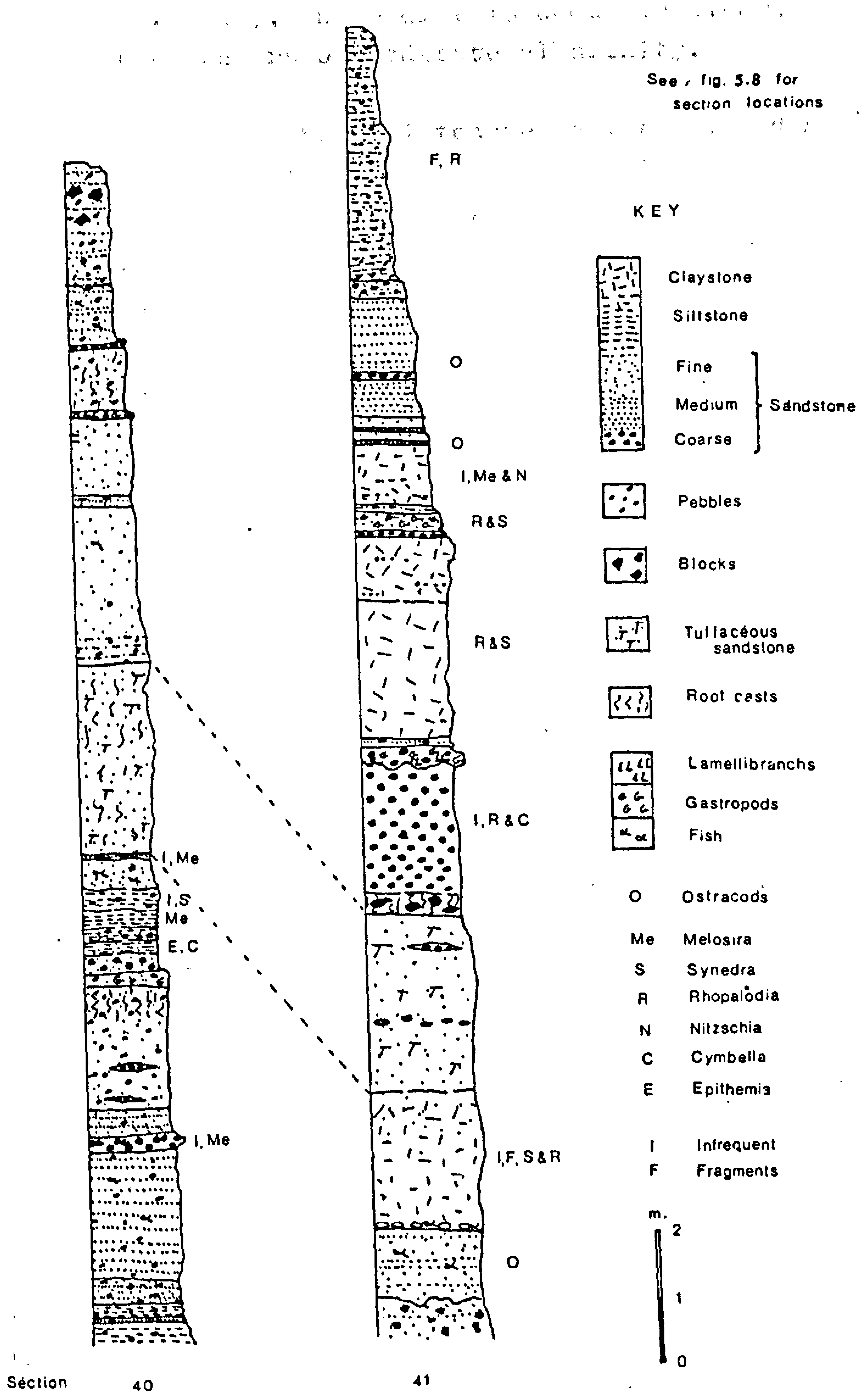


Plate 5.3

Holocene sands (Galana Boi Formation) can be seen resting unconformably on the middle Pleistocene Guomde Formation. These latter deposits consist of a mixture of lacustrine clays, silts, sands and bioclastic units, alluvial silts and sands, and tuffaceous sediments.

Fig. 5.9

The Lithology and Diatoms of the Guomde Formation



Cyclotella kutzinginiana, *Rhopalodia vermicularis*, *R. gracilis*, *Synedra ulna*, *S. acus*, *Epithemia argus* and *Cocconeis placentula*. *M. granulata* is most common, while the other species are scattered through the sections in low numbers. Today, these diatoms occur in clear, oligohalobian waters of moderate alkalinity.

Grid faults cut the Pleistocene sediments, and may be partly responsible for the cessation of lacustrine sedimentation in this area. However, climatic aridity may have contributed, and certainly had an impact during the latest Pleistocene, when most East African lakes were low. The latest Pleistocene at East Turkana was predominantly a period of erosion, although lacustrine sediments may have been laid down only to be subsequently stripped off (the Galana Boi deposits are being rapidly eroded today). By the early Holocene an irregular, deeply incised, topography had formed, and it was upon this that the Galana Boi Formation was laid down.

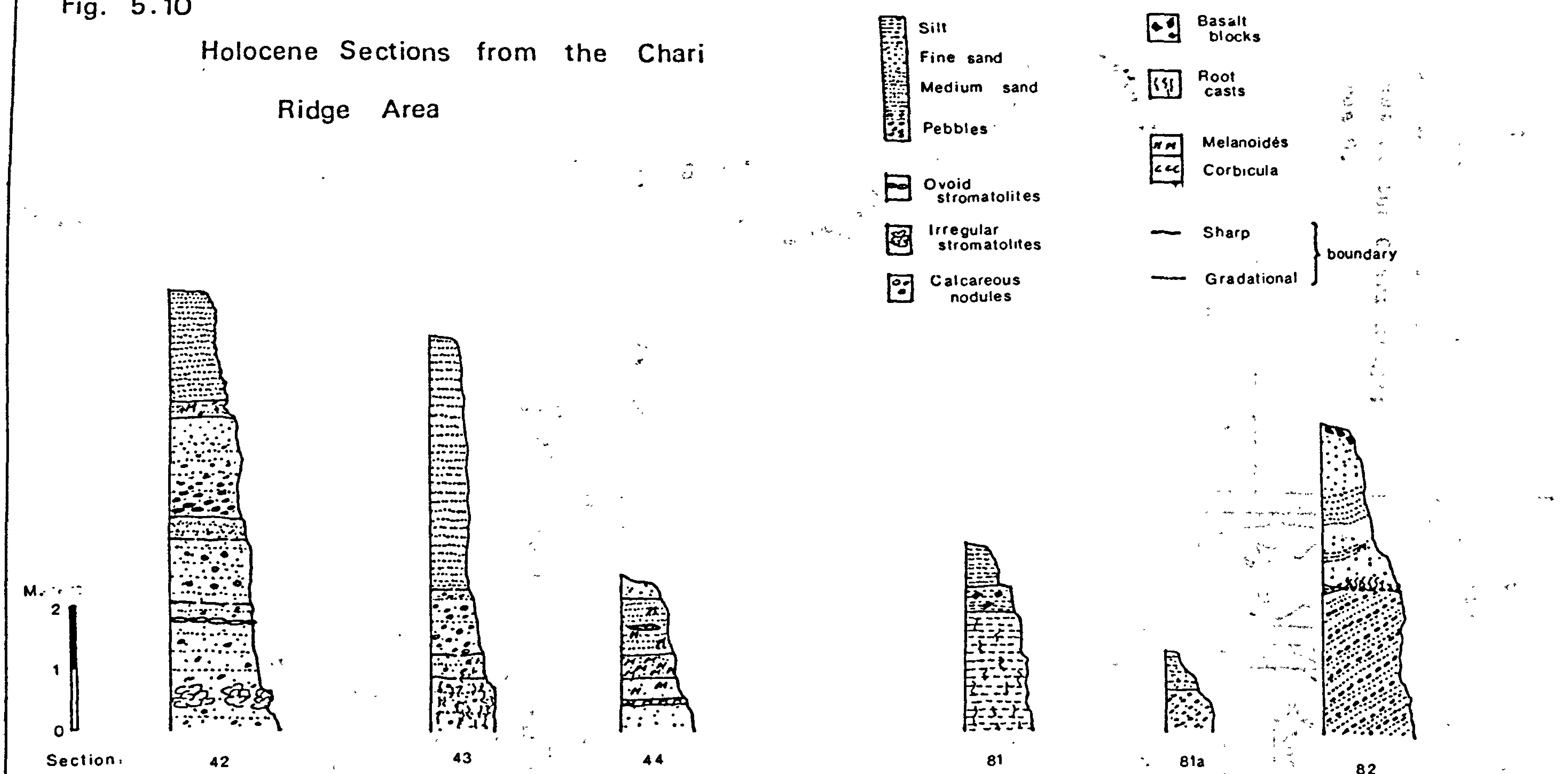
5(v)b The Holocene sediments of the Chari Ridge

Holocene sediments, up to 80 m above the modern lake, occur at the Chari Ridge. Vondra et. al. (1971) dated these deposits at 9,360 ± 135 yr. B.P.. Figure 5.10 shows a series of sections in these sediments.

Stromatolites distinguish these deposits from other Holocene units at East Turkana, although they have been reported from Allia Bay, in the extreme south (Barthelme, pers. comm.). The distribution of stromatolites at the north-eastern end of the Chari Ridge is shown in figure 5.11. Here, the Galana Boi Formation sits unconformably on the Koobi Fora and Guomde Formations. Section 42 (fig. 5.10) shows the sediment succession at this locality. The deposits are *ca.* 7 m thick, and consist of poorly-sorted, medium to coarse, arkosic and lithic arenites. Two contrasting stromatolite horizons occur.

Fig. 5.10

Holocene Sections from the Chari Ridge Area



See fig. 5.8 for section locations

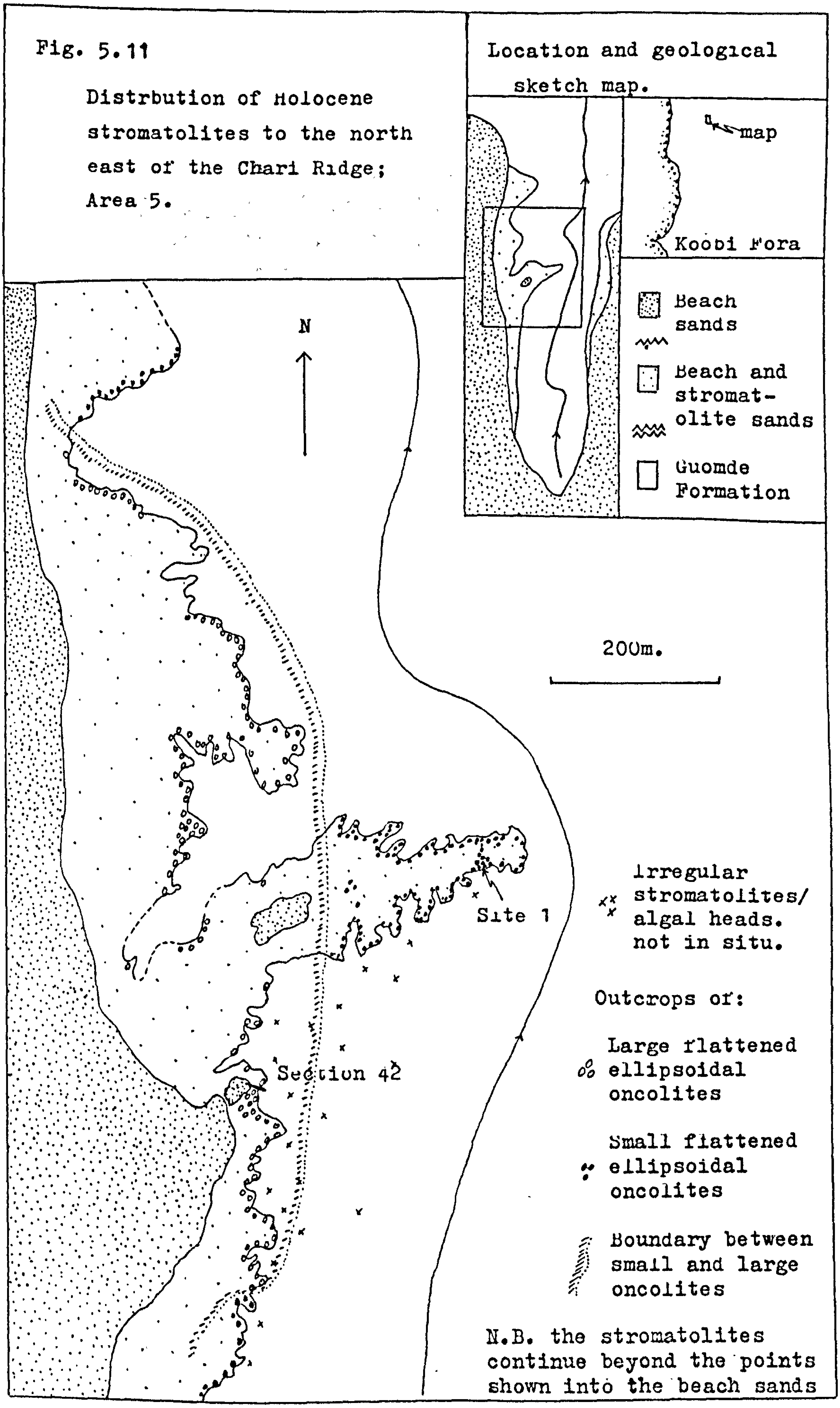


Fig. 5.11 Distrbution of Holocene stromatolites to the north east of the Chari Ridge; Area 5.

The lower horizon, at the base of section 42, consists of well spaced, dark grey stromatolites (algal heads), resting in a medium to fine, poorly-sorted sand (plate 5.4). These algal heads are up to 70 cm in diameter, and have formed around several molluscan centres (usually Etheria elliptica). Recrystallisation has obscured the stromatolitic laminae, and replaced it with radial (cf. travertine) patterns. These commonly rest on eroded Guomdẹ Formation, and are restricted to the south of the area shown in figure 5.11.

The second stromatolite horizon occurs 2 m from the base of section 42. These are light creamish grey stromatolites, whose shape is a smooth, flattened ellipsoid (oncolite; plate 5.5). They are centred on Etheria, Melanoides, and less often on pebbles and bone fragments. Alternating light and dark, concentric laminae (composed of low magnesian calcite) may reflect seasonal or longer term lake level changes, and hence climatic fluctuations. The oncolites sit on a flat erosional surface, and their distribution is shown in figure 5.11. Two sizes are common, although these grade into one another. The larger may be up to 25 cm in the long axis (although 50 cm is recorded elsewhere), and tend to occur on higher ground. At slightly lower elevations the oncolites are smaller and more spaced out.

The smaller types were examined in some detail at site 1 (marked in figure 5.11), where in situ beds are well exposed. The oncolites rest on a poorly-sorted, calcareous litharenite. Their shapes range from tubular to ellipsoid. Indentations occur where oncolites are in contact. The long axes of the oncolites are usually parallel to the erosion surface on which they sit, although they occasionally dip at up to 5 or 6^{o}. The mean lengths of the a, b and c axes were as follows.

a	=	8.3 cm	
b	=	6.5 cm	(sample of 50 specimens)
c	=	4.1 cm	

Plate 5.4

Irregular stromatolites centred around several <u>Etheria</u> shells. These are found in the base of early Holocene sandy units, at heights of up to <u>ca</u>. 75 m above the modern lake.

Plate 5.5

Ovoid stromatolites (oncolites) in early Holocene sands, near Ileret (northern East Turkana). These lie on a widespread 'flat surface', and probably formed under shallow water.

Where double layers are present, the upper part usually consists of larger, smooth oncolites, while the lower is composed of smaller, slightly pitted, and more irregular types.

The size variations may reflect proximity to ancient shorelines. Johnson (1974) has used stromatolites in the older East Turkana units to indicate near shore and distal zones. Open growth forms, such as occur in the upper horizon are more common in distal environments. Coalesced, compound types, such as in the lower horizon, are found in proximal environments. Stromatolites are mostly found in well aerated water with little detrital input.

Above the upper stromatolite horizon of section 42 are well consolidated, medium to coarse, poorly-sorted litherenites. Molluscs are common and often fragmentary. Medium grained, brown litharenites sit unconformably on top. These sands lack any molluscs.

Some 0.5 km to the south-east of section 42 are thinner sandy sequences, with no stromatolites. At the base of section 43 (fig. 5.10) are abundant root casts, which suggest aquatic macrophytes along the palaeoshoreline. At section 44 the sands are less pebbly and contain fewer root casts. The sediments are dominated by poorly-sorted, medium-grained sands, with thin (1 to 2 cm) levels rich in Melanoides. Oncolites again become common at the southern end of the Chari Ridge.

Holocene sediments also occur on the northern slopes of the Kokoi uplands. These range from diatomaceous silts, with abundant root casts at ca. 50 m in palaeovalleys (section 81, fig. 5.10) to beach type sands (with high initial dips and heavy mineral bands) in section 82. These latter deposits are devoid of stromatolites, lie at ca. + 15 m, and probably reflect an historically high lake level

5(vi) Late Holocene sedimentation in Lake Turkana

A large number of short cores (1 to 3 m long) were obtained from Lake Turkana by Yuretich (1979). Using removal rates of calcium carbonate from the lake water, he estimated a mean sedimentation rate of 50 to 100 cm/ 1000 years. His cores were dominated by fine muds. Detrital sedimentation was found to be dominant in the northern of the two basins of Lake Turkana, while biogenic (diatoms and ostracods) deposition prevailed in the southern one. This pattern reflects the dominant water and sediment input from the River Omo, at the northern end of Lake Turkana.

Dr. C. Barton kindly made core material available to this study. Data from here contradict the estimated sedimentation rate of Yuretich. Counting laminae (from a core near Central Island), and assuming an annual periodicity, a rate of 1000 cm / 1000 years is obtained. However, strong rainfall periodicities of 3 to 5 years (Rodhe and Virji, 1976) may have influenced the development of these laminae. If so, a lower sedimentation rate is implied. Barton has suggested a rate of 450 cm/ 1000 years, based on data from palaeomagnetic declinations. These would suggest that his 6 m long cores represent the last 1200 years.

The cores examined (from the north basin), consist of soft, very fine-grained, greenish brown-grey, calcareous banded muds. Barton has determined water contents of 79 to 86 wt. %. Diatoms were infrequent in the core taken near Central Island. *Melosira granulata* is the most common species. Much less common are *Rhopalodia vermicularis* (often broken) and *Stephanodiscus astraea var. minutula*. Generally, the state of preservation is good. *M. granulata* is usually found in fresh water and its presence in even the youngest parts of the core, which ought to reflect the modern saline, alkaline conditions, suggests that it may be derived.

Banded muds were also present in a core from Allia Bay, just offshore East Turkana. These muds are probably derived from the River Omo. Since the Omo delta was up to 100 km further north during the earlier Holocene, sediments from this source ought to have been finer and/or less common, at this time. The question arises as to the source of the Holocene silts at East Turkana. Three possibilities can be recognised.

a) Local reworking of sediments and lavas
b) A contribution from longshore drift
c) Sediments carried in from the Chew Bahir overflow (see chapter 7, p.223), and active minor streams

A large source of silt would seem unlikely from any one source, and a combination of these provenances may have operated. Beach sands, on the other hand, probably owe their existence mainly to longshore drift, after the initial sediment input.

CHAPTER 6

MODERN SEDIMENTATION AND THE ENVIRONMENTAL IMPLICATIONS OF THE LITHOFACIES AT EAST TURKANA

6(i) Present day sedimentation and processes operating at East Turkana

6(i)a Contemporary shoreline development at East Turkana

Deposits forming today were briefly studied as an aid to palaeoenvironmental interpretation. Figure 6.1 shows the distribution of major depositional and erosional environments near Koobi Fora. The environments shown will be referred to in the following text.

The modern shoreline has developed in response to a mainly regressing lake. Beach deposits are predominantly of sand grade, probably redistributed by wind-generated waves and long-shore drift processes. Well developed ridge and swale patterns have been left behind the active shore. Each ridge records a former, higher lake level (with increasing antiquity inland). These fossil beach ridges are subparallel to the present lake margins, are usually less than one metre in relief, are up to several hundred metres long and are spaced up to 100 m apart.

Contemporary beach ridges consist of moderately to well-sorted, fine to coarse-grained, subarkoses and sublitharenites, with derived shell debris. The percentage of quartz tends to decline towards the ephemeral deltas of East Turkana, where it is replaced by an increase in lithic fragments. This implies a process of differential sorting and/or erosion of the mineral grains. Heavy minerals are abundant and are often sorted into distinct bands.

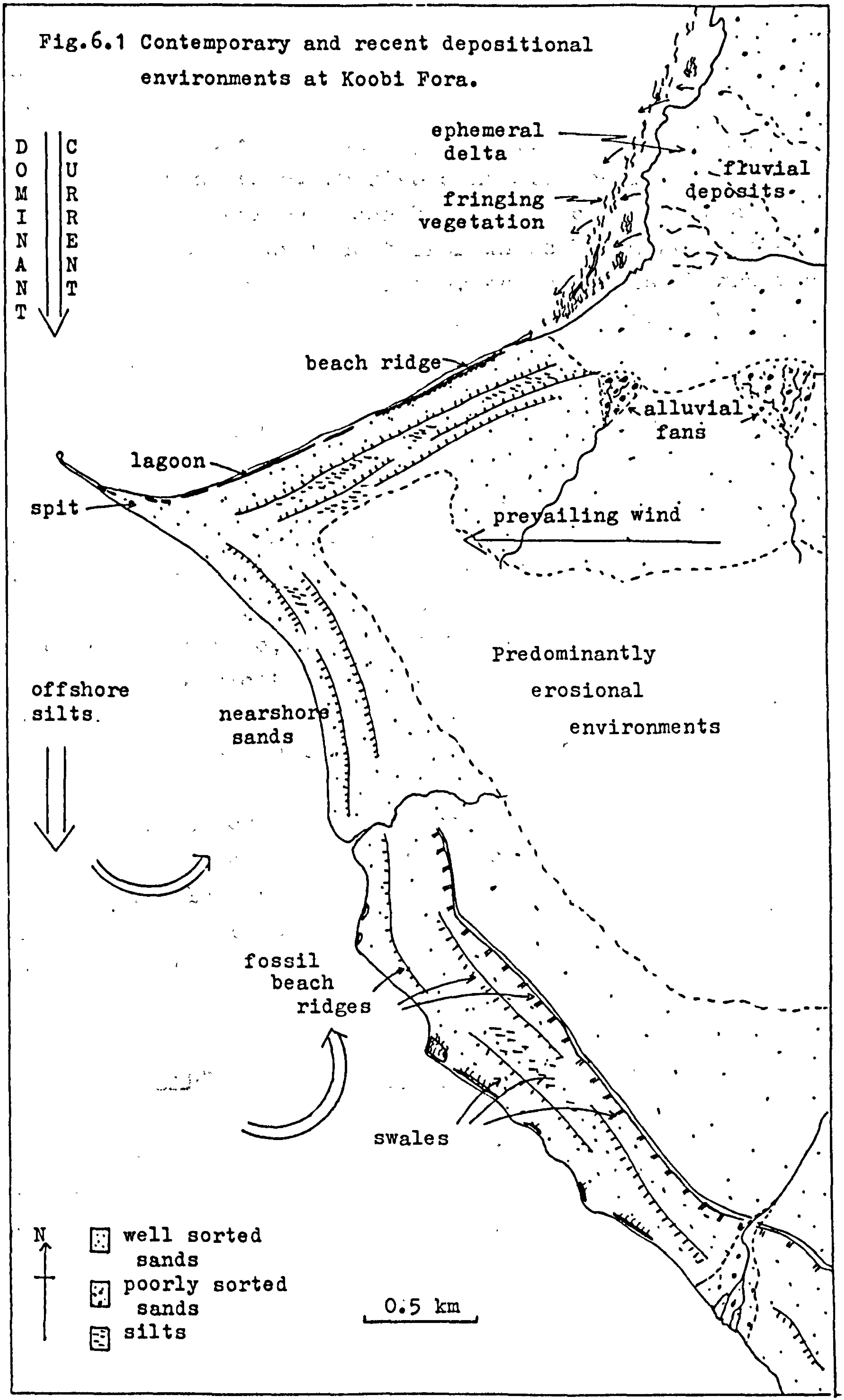


Fig.6.1 Contemporary and recent depositional environments at Koobi Fora.

Lakewards, beach bars consist of small scale ripple laminae, interbedded with low angle, planar cross-strata. Landwards, higher angle, landward-dipping laminae are common. The slopes of contemporary ridges rise sharply from a sandy surface. Erosive contacts occur at their bases, and several bars can be seen to cut into older ones. These bars may result from waves breaking on the shoreline and dumping their coarser sediments. Migration of bars occurs due to the seasonal and longer term shifts in lake level.

Lagoons often develop behind the beach bars. Today, these often contain blue-green algae and diatoms (p. 80). Silts and silty sands commonly form the substrate. Fine laminae may be present, but normally such features are disrupted by littoral reeds. Evaporative concentration of lagoonal water, supplied by washover events, seepage and capillary rise, takes place (fig. 6.2). During periods of dessication layers of salt (trona) often forms on the surface of the sediments. These mostly form 'blister crusts'. Mudcracks also develop at such times.

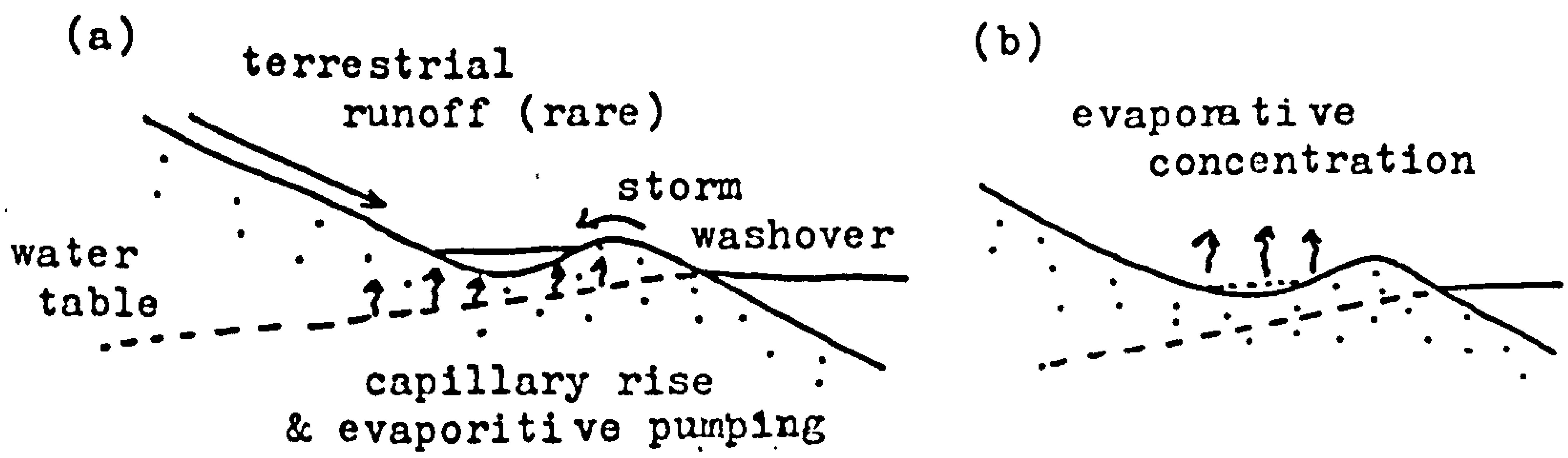
Recently exposed beach shorefaces show low angle, lakeward-dipping cross-strata, occasionally associated with ripple laminae, in mainly fine and medium sands. However, such structures have often been disturbed by the roots of littoral plants.

6(i)b The ephemeral deltas and floodplains

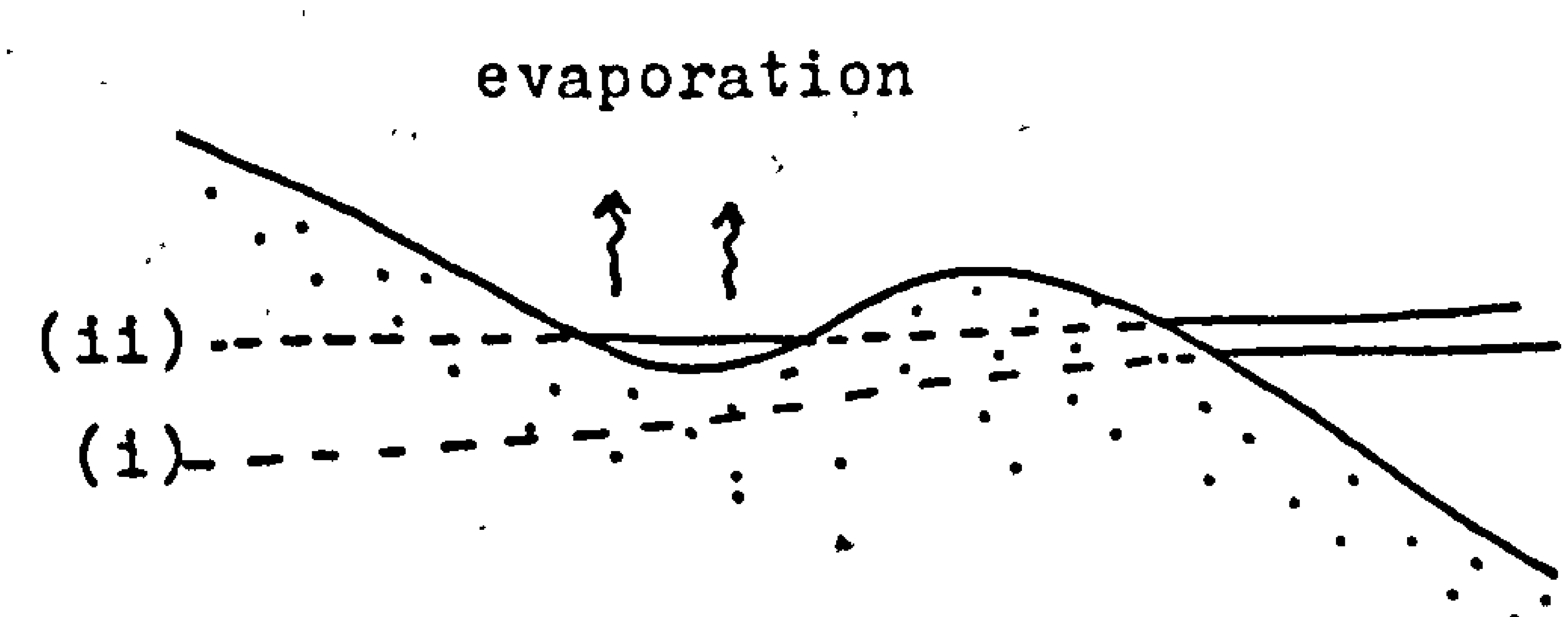
Many deltas along the shores of East Turkana are only occupied by flowing water during flood periods. These ephemeral deltas consist of poorly to moderately-sorted, fine to coarse, subangular litharenites. These deltas mostly form irregularly indented shorelines. Sediment input is presumably equalled or exceeded by processes of sediment removal (long shore drift, currents). As a result delta shorelines rarely extend into the lake.

Fig. 6.2 Salinity controls in the lagoonal environment

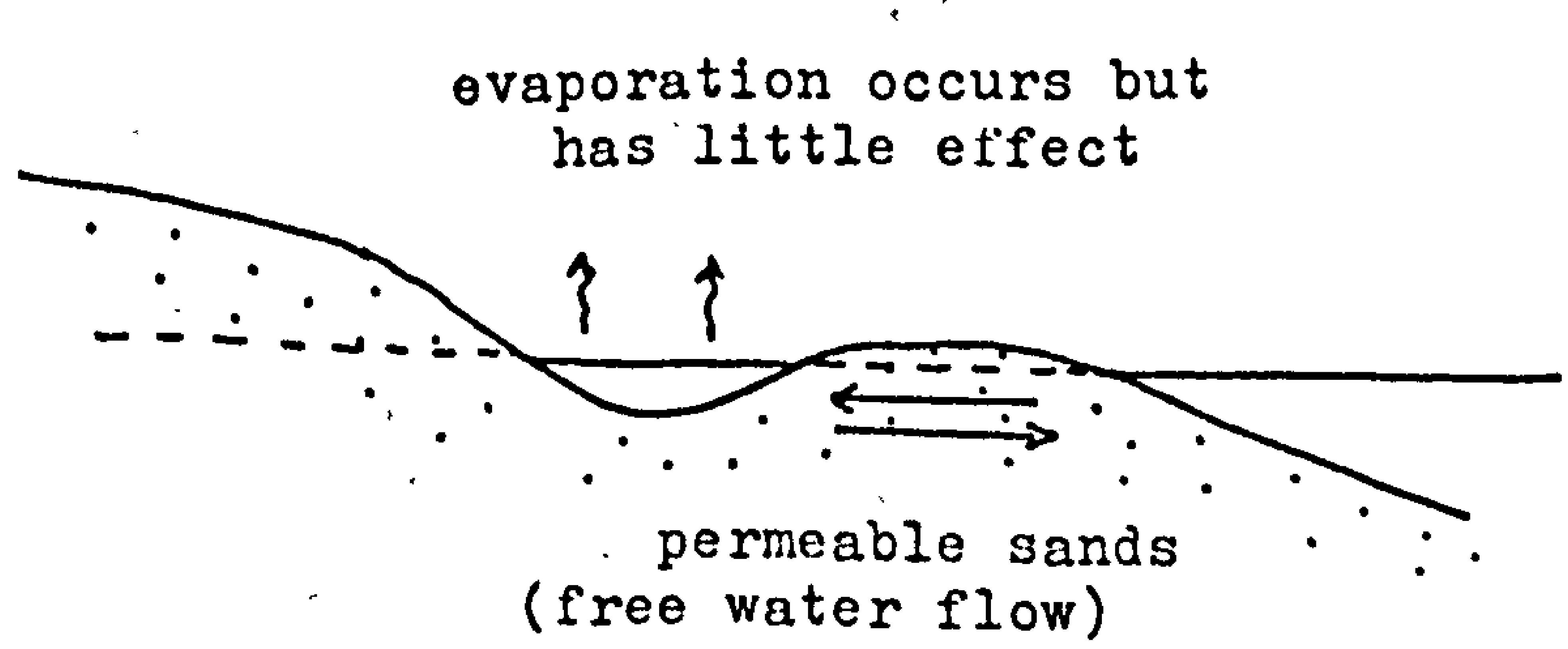
1. Water may be supplied periodically from a variety of sources (a). Subsequent evaporation then concentrates the water in salts. Where evaporation exceeds water input dessication results with the possible formation of trona crystals, blister crusts etc (b)



2. A temporary rise in the water table from position (i) to (ii) will bring water to the surface directly or by capillary rise. A fall followed by evaporation will then increase the salt concentration.



3. Permanently high water tables may result in the establishment of an hydrographic window. Free exchange of water through permeable sands may result in lagoonal waters of similar ionic content to the adjacent lake.



Fringing, littoral vegetation is common on the sublacustrine portions of the deltas. These plants may act as sediment traps, partly offsetting removal processes.

Although not examined in detail, deposits were studied at various localities along the courses of several rivers. The largest rivers at East Turkana have floodplains that extend up to 30 km away from the lake.

These ephemeral floodplains rarely contain flowing water, except during brief flash floods. Complex networks of braid bars occur, together with a few non-braided, well-defined channels. Numerous tributaries join a central river complex. The floodplains are usually covered with wind blown sand, derived from the dry river beds. Calcrete is locally present.

Near upland source regions, such as the Koobi Fora Ridge, of the smaller floodplains, the deposits consist of channel-fill conglomerates, with inclined bedding and grits with horizontal or subhorizontal laminae. Trough cross-bedding and planar laminated sands with occasional ripple laminae predominate in the middle stretches. Towards the lake, fine sand with less common medium sands predominate. In these areas horizontal and ripple laminae are the most common structures.

6(i)c <u>Aeolian processes operating at East Turkana</u>

Large tracts of Holocene alluvial sands and lacustrine silts are being eroded by winds. This process is enhanced by the sparse vegetation and the unlithified nature of the Holocene sediments.

Two types of wind are common at East Turkana. Dust devils blow between 11.00 a.m. and 3.00 p.m.. These were subjectively estimated to reach heights of up to 75 m. They tend to move in a westerly direction. The second wind type is a strong and continual wind. This blows from early evening until the following noon, towards the lake.

A thin cover of aeolian sand is present over much of the area. In some places it has formed small hillocks (less than 2 m high), stabilised by xerophytes and/or carbonate cements. These were not examined in detail, but they do show occasional trough cross-bedding in well-sorted fine sands.

During the earlier Holocene these processes may not have been as important, since the region was wetter and there was probably more stabilising vegetation. In addition, much of the area now being eroded by winds was then under water.

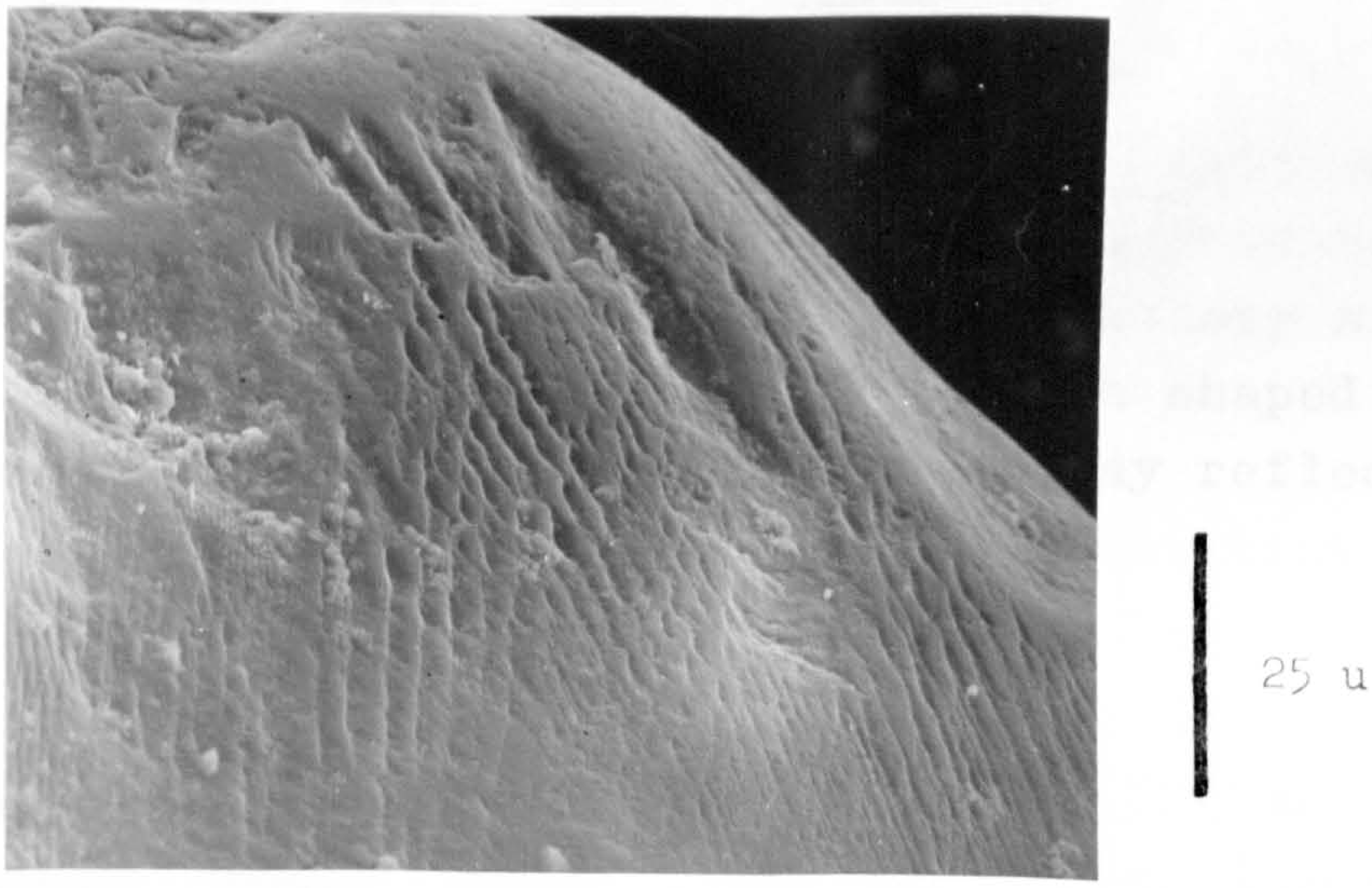
6(i)d The significance of quartz grain surface textures

Quartz grains were collected from a variety of modern environments (beach, fluvial and aeolian) and examined with a scanning electron microscope for surface textures. It was hoped that environmentally significant characters might be observed. However, solution and redeposition of silica have smoothed the surface relief of most grains (plate 6.1). This is apparently a common process in tropical desert regions (Krinsley and Doornkamp, 1973). Solution and redeposition may be localised on quartz grains or may be transported from one part to another. The undulating smooth surface of many grains suggests rapid silica precipitation . Kuenen and Perdok (1962) attribute smoothness of this type to a rising pH,due to the presence of dissolved salts, during the evening (and consequent silica removal), followed by daytime evaporation, which leads to silica redeposition.

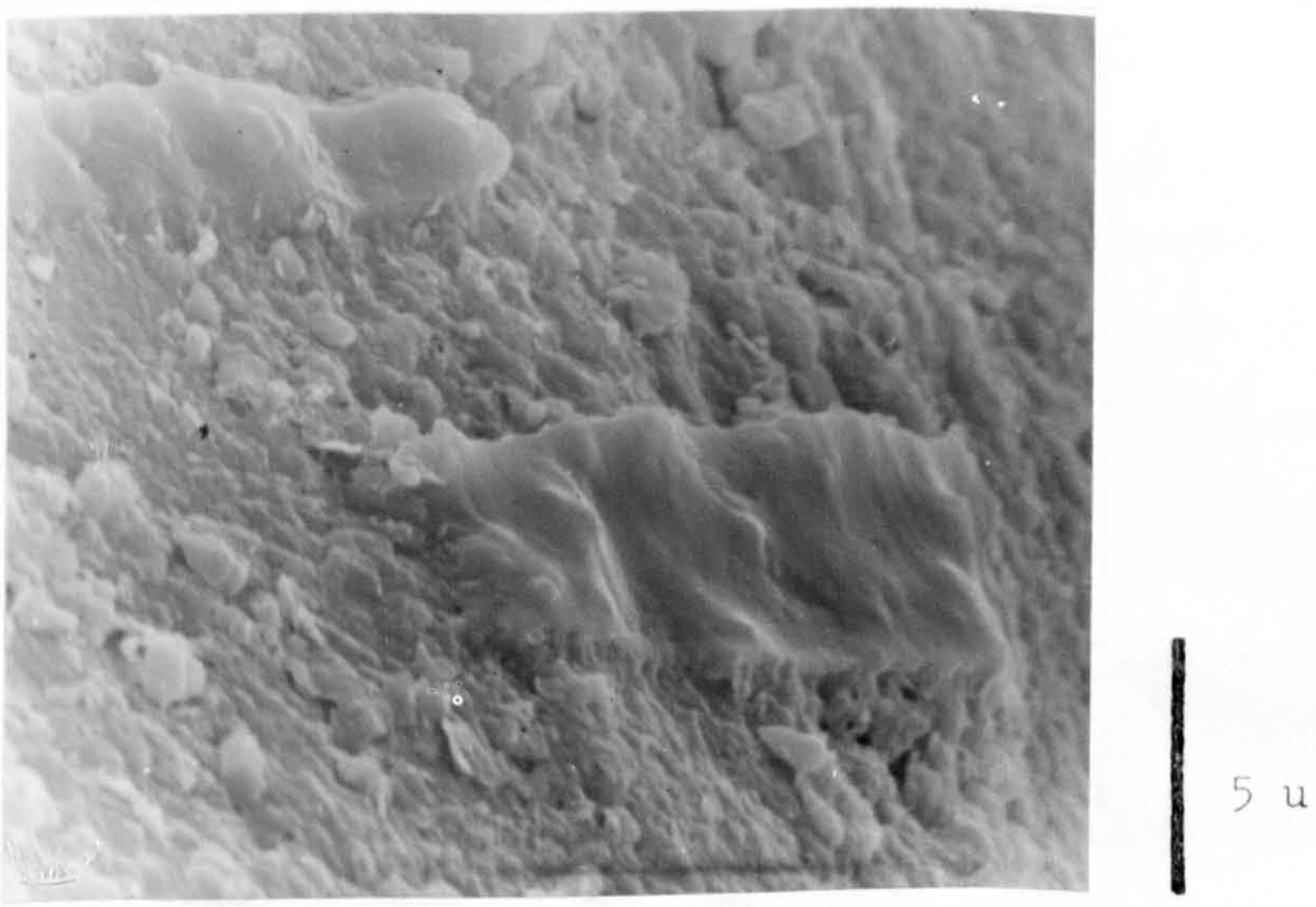
Chemical etching, deep surface solution, precipitated upturned plates and smooth precipitation surfaces obscure mechanical features that may be environmentally important.

Plate 6.1

Quartz grain surface textures



This S.E.M. photo shows preferential solution along intersecting cleavage lines. The quartz grain was obtained from an aeolian sand dune.



The irregular surface of many quartz grains has been obscured by the secondary precipitation of silica. Two small patches of redeposited silica can be seen on this grain, which was recovered from an aeolian sand dune.

Mechanical 'V' forms were observed in modern high energy beach deposits, but these were less common than straight or curved grooves.

A sample from sands of probable aeolian origin again possessed extensive silica precipitation. Many grains were rounded, probably due to abrasion (with secondary silica overgrowths enhancing this appearance). Dish shaped concavities were occasionally present and may reflect impacts during transportation.

6(i)c <u>Soil formation at East Turkana</u>

Soils are very poorly developed on the Holocene sediments. When present they are of lithosolic type, forming on highly permeable sands. A weakly developed organic horizon may be present in the upper one or two centimetres of soil profiles. Roots penetrate below these dark grey humified layers.

Calcretes occur, but for the most part are spatially restricted. Calcareous horizons develop in areas such as East Turkana because leaching is only slight, and soluable constituents are not removed. Calcium carbonate is also responsible for the stabalising of a number of sandy units.

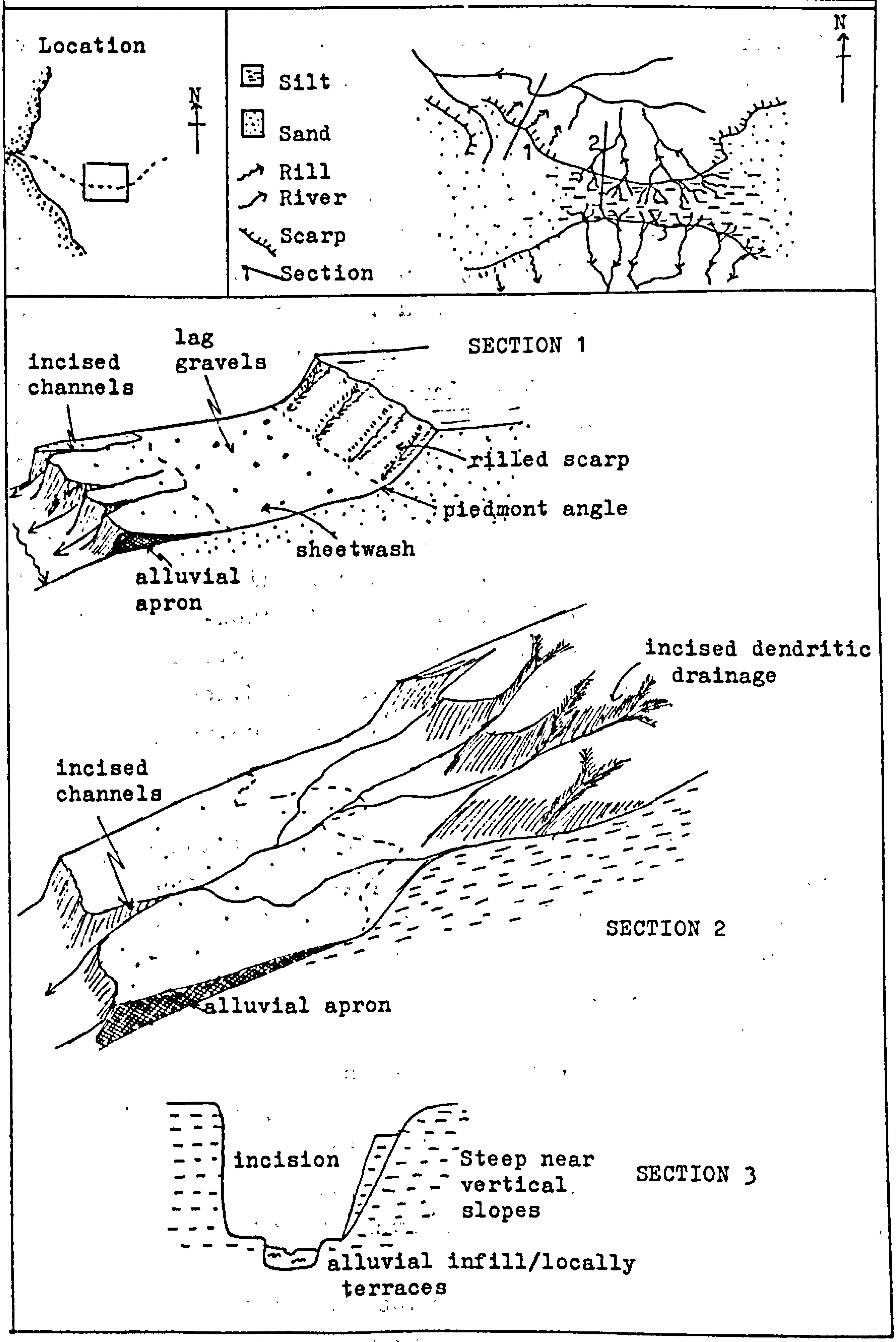
6(i)f <u>The contrasting patterns of drainage and erosion on Holocene sediments</u>

Modern drainage and slope evolution varies dramatically on Holocene sediments of differing lithology. Silt-dominated deposits tend to develop dense dendritic drainage patterns with intensive rilling on the interfluvial slopes. A less dense pattern is developed on sandier facies.

Silts have higher threshold angles than sands and hence steep-angled (often vertical) slopes are found at incised channels cutting through them. More gentle slopes typify the sands.

These differences are well exemplified in the boundary region between Areas 102 and 103 (fig. 6.3). The central area is predominantly silty, but becomes sandier to the west and east. In the central area dendritic channels carry silt onto a thin alluvial apron, and then into the main channel system (section 2, fig. 6.3). In contrast, in the sandier west, slope retreat by pedimentation is taking place, while rills have developed on the scarp slopes. Below the piedmont angle (section 1, fig. 6.3), sediment is carried across a pediment by sheet wash and is redeposited on an alluvial apron downslope. In both cases the alluvial apron is incised on its lower margins, and ultimately feeds the main channel system.

Fig.6.3 Slope development in areas 102 and 103; East Turkana.



6(ii) Major influences on sedimentation at East Turkana

While the detailed distribution of lithofacies relates to local conditions, major aspects of sediment type and location can be related to a few important factors. These include tectonic, volcanic, source rock lithology and climatic influences.

Tectonic influences, such as uplift and subsidence, have played only a minor role in influencing Holocene lithologies at East Turkana. This is mainly due to the tectonic quiescence of the period. However, the orientation of Holocene sedimentary units, such as beach bars, have been influenced by fault scarps existing from the Pleistocene. The modern shoreline still reflects these fault lines (fig. 6.4). The shorelines of the northern half of Lake Turkana follow a broad north to south trend, although this simplification breaks down when examined in detail. To the east of the lake, north-west to south-east and north-east to south-west structural trends dominate, with the eastern shoreline following this pattern (interfering to produce the north to south alignment). Similar, though differently orientated relationships exist to the west of the lake.

On a longer time scale, tectonics have probably affected sedimentation, potentially through subsidence of the Turkana trough, by changing outlet heights of the lake, or by changing the heights of source areas (and hence accelerating or retarding erosion rates).

Volcanism seems to have had little impact on late Quaternary sedimentation at East Turkana, although eruptions have occurred at North Island. The role of volcanism in controlling sedimentation is discussed further when describing the Baringo district (chapter 8, p. 267).

The lithology of the surrounding areas has resulted in the mineralogy of Lake Turkana sediments differing from

Fig. 6.4 The relationship between modern shoreline orientation and major structural trends, N. Lake Turkana

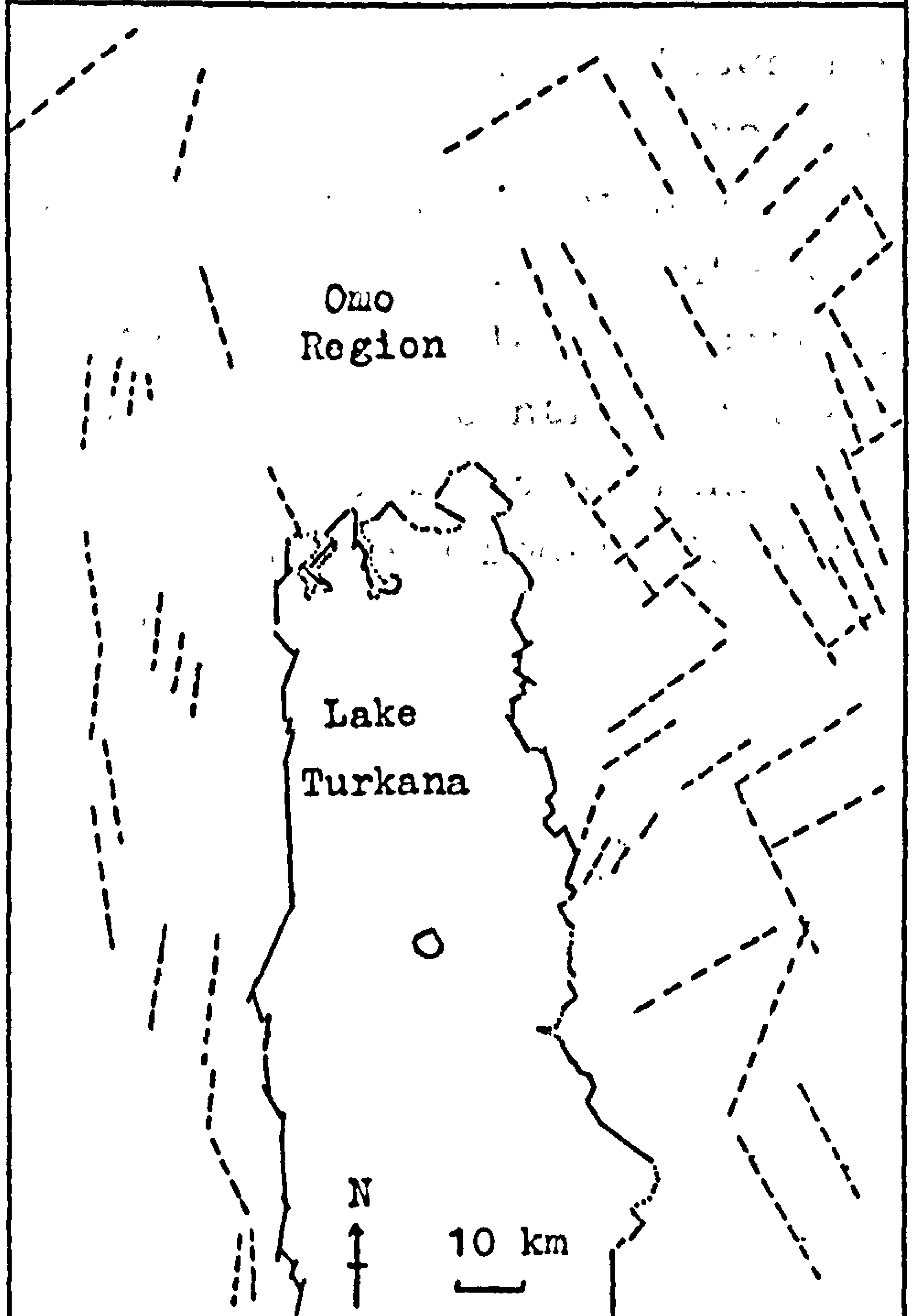
Key:

Simplified shoreline; approximated to a straight line trend.

Complex shoreline; unsimplified

Major structural trends; mainly faults but also prominant ridge alignments.

Based on satellite photos.



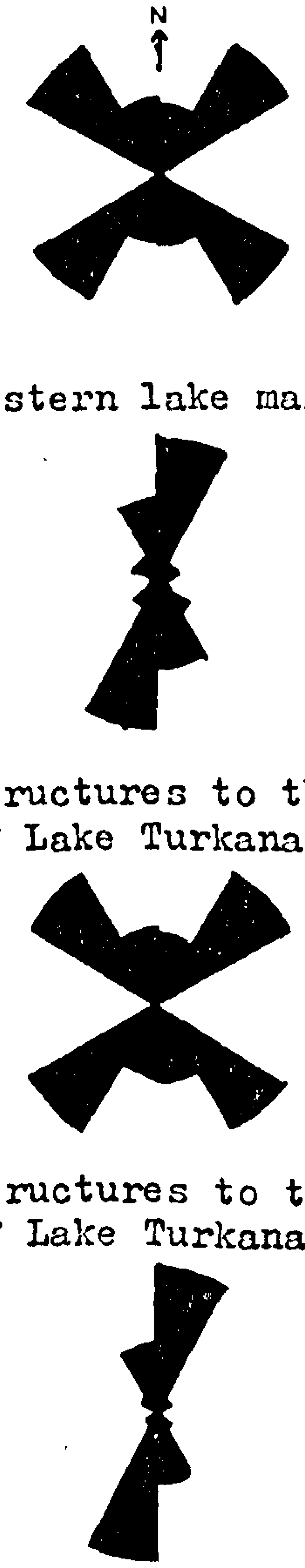
Shoreline and structural orientations around Lake Turkana

A. eastern lake margin

B. western lake margin

C. structures to the east of Lake Turkana

D. structures to the west of Lake Turkana



Shorelines are simplified to approximate straight lines (see map) and are shown together with major structural elements. The orientations of these trends are plotted on the rose diagrams. Note the similarity of the western shoreline and western structural alignments and how these differ from areas to the east.

most other Kenya Rift lakes. Here, the deposits contain an abundance of quartz, which mainly reflects the outcrop of metamorphic rocks in the basin. Such outcrops are rare in other parts of the Kenya Rift. However the dominance of alkali volcanics, as in other basins of the Kenya Rift, has resulted in the modern and ancestral Lake Turkana being predominantly fresh to saline and alkaline. This water chemistry has in turn played a major role in controlling biogenic contributions to the sediments.

Climatic influences have dominated the late Quaternary history of Lake Turkana. Sediment supply has varied in relation to changing rainfall. This process has mainly operated by changing erosion rates, and by producing and losing rivers and overflows from other basins. Rainfall periodicities have and are resulting in seasonal and longer term pulses of sediment input, causing 'varve like' deposits to form. The interaction of climatically controlled lake level fluctuations and an irregular topography has controlled the detailed facies distribution, and resulted in lacustrine sediments that are presently left well above modern lake levels.

6(iii) Environmental recognition in the Galana Boi Formation

6(iii)a Environmental classification of the Holocene sediments of East Turkana

Several attempts have been made to classify the Pliocene and Pleistocene sediments of East Turkana, according to their environment of formation (Findlater, 1978; Vondra & Bowen, 1979). These attempts were based on wide environments and as such are not suitable in studies of the Galana Boi Formation.

A complex and varied range of environments are recorded by the Galana Boi Formation. Certain lithofacies appear to characterise different environments (as confirmed by diatom and modern shoreline studies). The classification suggested here summarises the range of environments present in the Holocene deposits of East Turkana. This classification follows, and the various environments are shown in figure 6.5.

A. THE LACUSTRINE ENVIRONMENT

(i) Littoral and shallow water subenvironments

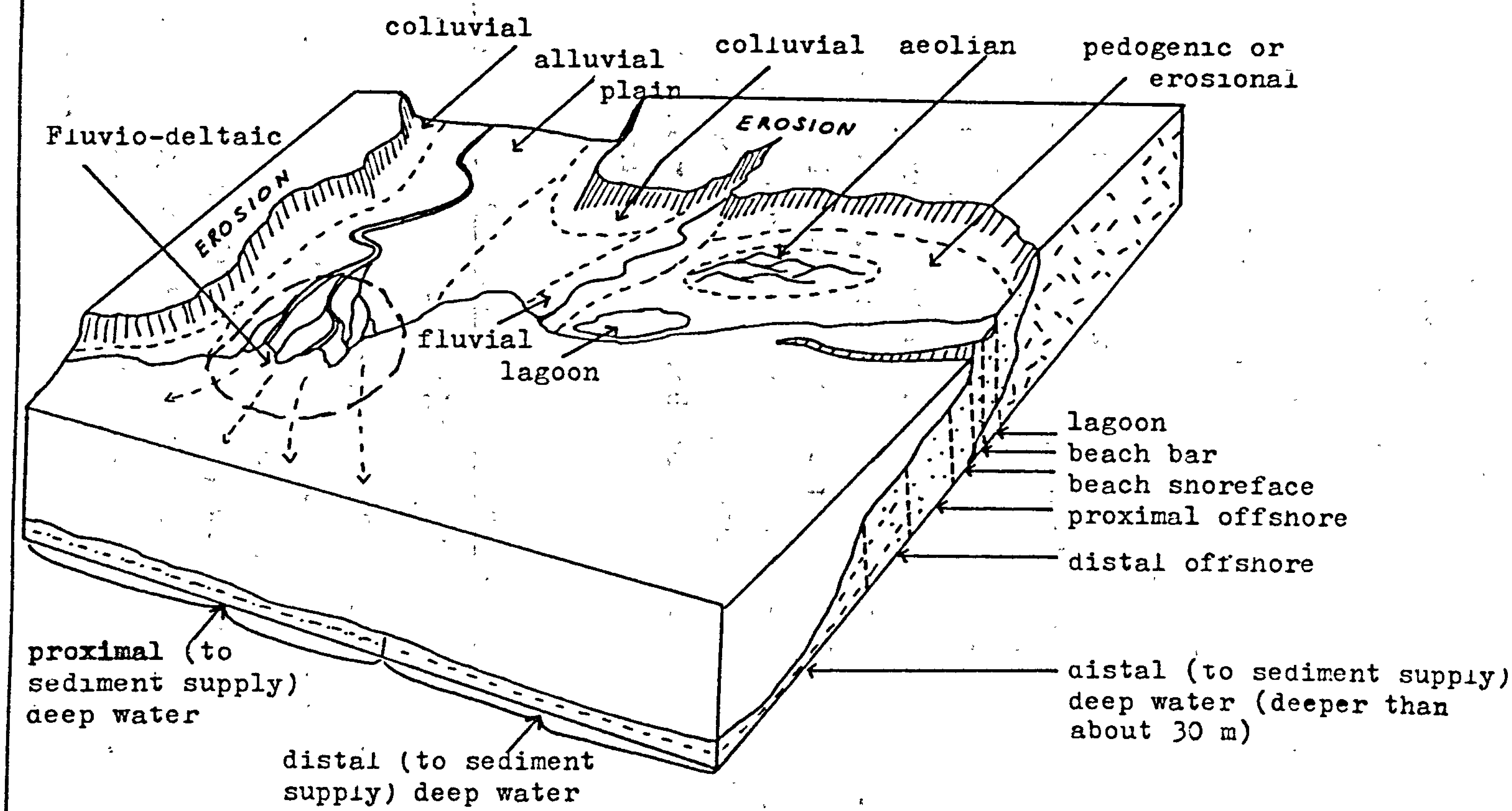
a) The beach bar zone
b) The lagoonal zone
c) The beach shoreface zone
d) The proximal offshore zone
e) The distal offshore zone

(ii) Deep water subenvironments

a) The proximal (to sediment supply) zone
b) The distal (to sediment supply) zone

B. THE FLUVIO-DELTAIC ENVIRONMENT

Fig. 6 . 5 Diagrammatic representation of the sedimentary environments recorded in the Holocene deposits of Lake Turkana



C. THE TERRESTRIAL ENVIRONMENT

(i) Fluvial subenvironments
(ii) Colluvial subenvironments
(iii) Aeolian subenvironments
(iv) Pedogenic subenvironments
(v) Erosional subenvironments

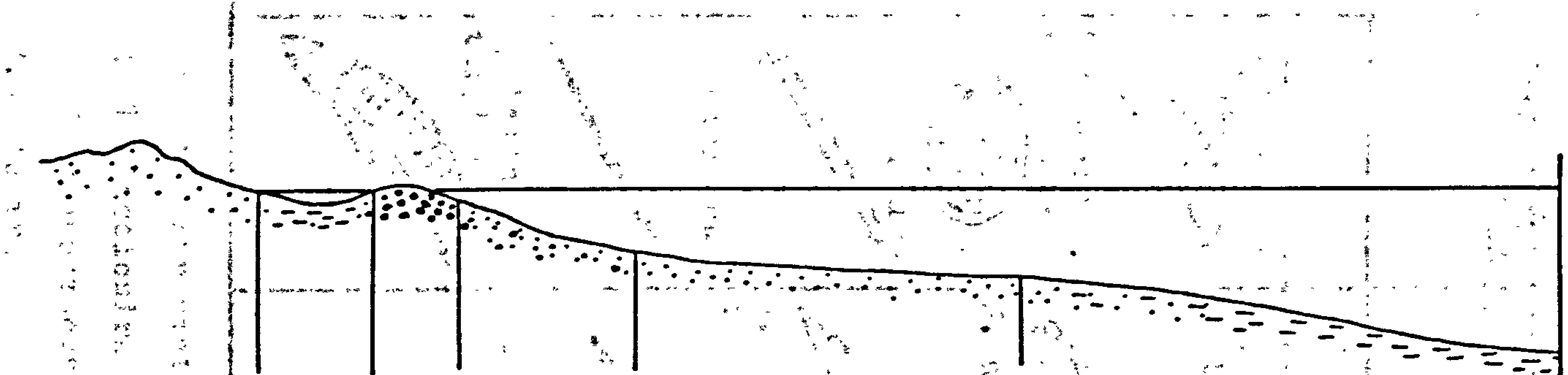
The major characteristics of the lacustrine environment are summarised in figure 6.6. The Galana Boi Formation is essentially lacustrine in character. Fluvio-deltaic environments are less common. Where present they are mostly represented by subangular arkosic and lithic arenites, which have a sheet-like form, and which are often cut by channel sands and conglomerates. Terrestrial environments are rare in the Formation. However, late Holocene fluvial situations were common across much of East Turkana, having advanced westwards in response to a regressing lake. Colluvial and aeolian deposits are present locally and soils have been observed in only a few restricted Galana Boi units. Erosional breaks are common and of varying scale. They relate to climatically induced lake level changes rather than tectonic events.

6(iii)b Summary of the main criteria used in environmental interpretation

Diatoms have proved extremely useful in characterising depositional environments. Figure 6.7 shows how some of the major diatoms present in the Galana Boi Formation relate to the habitat in which they were laid down. The diagram also incorporates the effects of alkalinity changes, which is a major factor in determining the particular species present.

Diatoms are far from being the only diagnostic fossils. Molluscs are also useful indicators of environment. Etheria elliptica occurs along rivers and on high energy

Fig. 6.6 Simplified classification of littoral and shallow water environments typically found in the Galana Boi Formation.



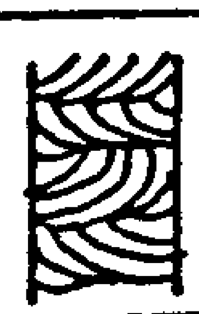
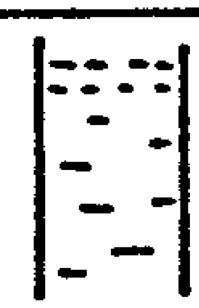
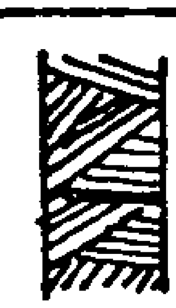
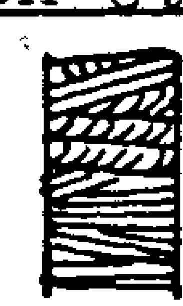
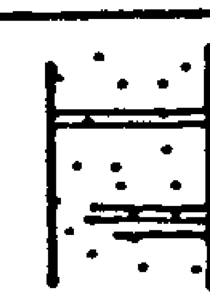
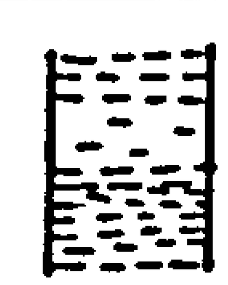
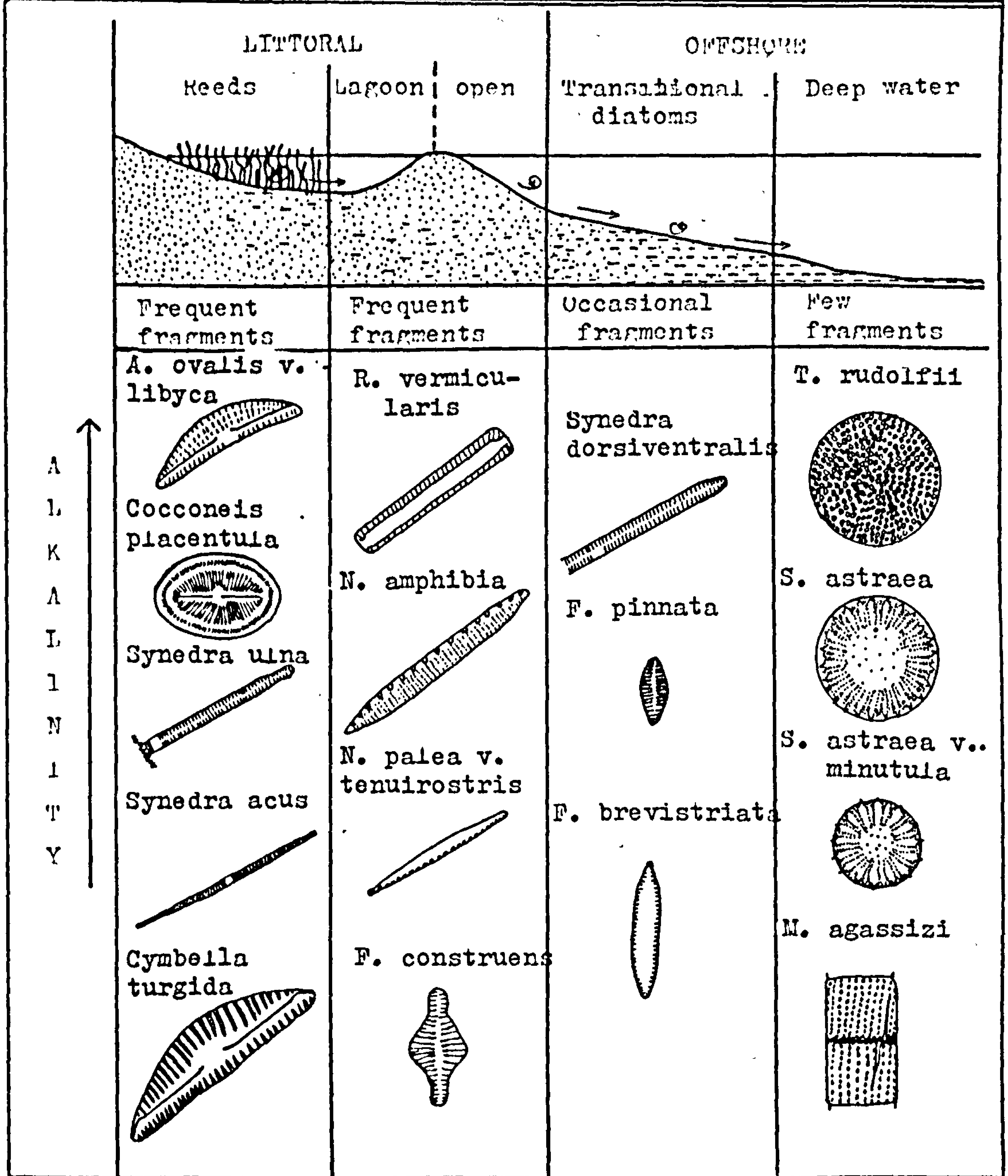
Aeolian	Lagoon	Beach bar	Beach shoreface	Proximal offshore	Distal offshore	
Aeolian trough X-beds or struct-ureless	Laminat-ed or more commonly structure-less	Low & high angle X-beds.	Low angle planar X-beds. Ripple laminae.	Structureless (bioturbated) or rarely laminated (parallel and ripple).	Parallel laminae or more rarely structureless.	Sedimentary structures
Fine to medium sand	Silt & clay	Medium to coarse sand	Fine to medium sand	Fine sand	Silty sands, silts and clayey silts.	Texture
Root casts	Diatoms Molluscs Root casts	Diatoms rare Molluscs rare	Diatoms rare Ostracods, Molluscs Fish etc.	Diatoms, mollusc ostracods, fish aquatic mammals & root casts	Diatoms abundant Molluscs rare ostracods and fish present	Dominant fossils (only fish are common today)
						Typical section

Fig. 6.7

Major lacustrine environments as typified by dominant diatoms in the Galana Boi Beds.



Generic abbreviations:

T -Thalassiosira
S.-Stephanodiscus
M.-Melosira
F.-Fragilaria
N.-Nitzschia
A.-Amphora
R?

Key:
Probable currents
Sand
Silt

shorelines (Williamson, pers. comm.; Butzer, 1971), while Pila ovata often occurs in seasonally inundated swamps (Butzer, 1971). However, late Holocene sediments at East Turkana lack molluscs due to the higher alkalinities of this period (molluscs disappear above about 16 meq/l; Cerling, 1979). The size and spacing of stromatolites can indicate shoreline proximity (Johnson, 1974), while root casts commonly reflect littoral zones. Figure 6.8 summarises the presence or absence of different fossil groups in various environments. The data in figure 6.8 are based on this work and information presented by Behrensmeyer (1975) and Findlater (1976).

Figure 6.8 also shows a number of environmentally significant sedimentary criteria, that commonly occur in the Galana Boi Formation. While the fauna and flora have varied with chemical changes through the Holocene, features such as cross-bedding and lithology have remained constant. These can be used to compare earlier Holocene and modern conditions. The most useful sedimentary characteristics have proved to be the lithology, bed shape, sorting, grain size and lamination.

The value of the Holocene sediments of East Turkana is that they allow both modern and recently deposited sediments to be studied in three dimensions, rather than as the two dimensional sections more commonly available in older, better lithified Formations. They therefore provide a bridge between ancient and modern Rift Valley sediments, and should aid in recognition of the former.

6(iii)c Summary of the distribution and significance of the Holocene sediments at East Turkana

The Holocene Galana Boi Formation consists of sediments laid down under a series of former, higher lake levels. Numerous transgressions and regressions resulted in the build up of a complex body of mainly lacustrine deposits,

Fig. 6.8 Criteria for Depositional Environments at East Turkana

Environ. / Criteria	Lacustrine	Beach-Shoreface	Lagoon	Beach bar	Delta margin	Distributary channel	Delta mudflat	Channel	Flood-plain
Major Lithology	Silt & clayey silt	Sand	Silt	Sand	Silty sand	Gravelly sand	Silt	Gravel & sand	Silt
Shape of bed	Sheetlike extensive	Sheetlike extensive	Elongate local	Linear local	Sheet-like	Linear local	Sheet-like	Linear local	Sheet-like
Sorting	Good	Good	Good	Good	Moderate	Moderate-poor	Good	Poor	Poor
Mud clasts	-	-	-	-	+	+	+	++	-
Limonite	-/+	-	-	-	+	-	+	Grain coating	-
Primary $CaCO_3$ nodules	?	-	-	-	trace	+	-	-	-
Root casts	-	++	++	+	+	+	+	+	++
Bioturbation	-/+	+	+	+	+	+	+	+	+
Cross-stratification	-	-	-	Planar	Small scale trough & planar	Small-large scale trough	poor small troughs	small to large troghs & planar	trough in sand lenses
Ripple marks	+	+	-	-	+	+	-	+	-
Horizontal beds	+	+	+	-	+	-	+	-	+
Massive bedding	+	+	-	+	+	+	+	+	-/+
Laminae	+	-	+	-	+	-	+	-	+
Mudcracks	-	-	+	-	+	-	+	-	Trace
Palaeosol	-	-	-	-	-	+?	+	-	+
Calcrete	-	-	-	-	-	-	-	-	+?
Ostracods	+	+	-	-	+?	-	+?	-	-
Diatoms	++	+	+	+	++	-	-	-	-
Algal nodules	-	+	-	-	-	-	-	-	-
Plant phytoliths	-	+	+?	-	+?	-	+?	-	+
Fish bones	++	++	+	+	++	-	-	-	-
Invertebrates	Trace	++	+	++	+	-	+	-	-

- Absent + Present ++ Abundant

which show rapid lateral and vertical facies variation.

Figure 6.9 shows a series of representative sections in the Holocene sediments at East Turkana. Although simplified, they demonstrate the main lithological types present. The diagram also shows the environments under which these deposits formed, and the probable correlations between sections. The most complete record of the Holocene is provided by considering sections 72, 20 and 6 together. These provide a record of events from ca. 10,000 yr. B.P. up to between 4,000 and 3,000 yr. B.P.. These three sections are combined, in a highly idealised manner, to produce figure 6.10. Two major lithofacies are recognised in this latter diagram, which are lacustrine silts and littoral sands. Their distribution reflects the changes in level of Lake Turkana through the Holocene. Four main transgressive periods can be recognised (labelled T_1 to T_4 in the diagram), although many, less significant, fluctuations can also be suggested.

Figure 6.11 summarises the distribution of Holocene sediments to the east of Koobi Fora. This area contains the best record of Holocene lake-level fluctuations and environmental diversity at East Turkana. The early Holocene palaeoshoreline is also shown in this figure.

Fig. 6.9 Major lithologies in the Galana Boi Formation and their environmental implications.

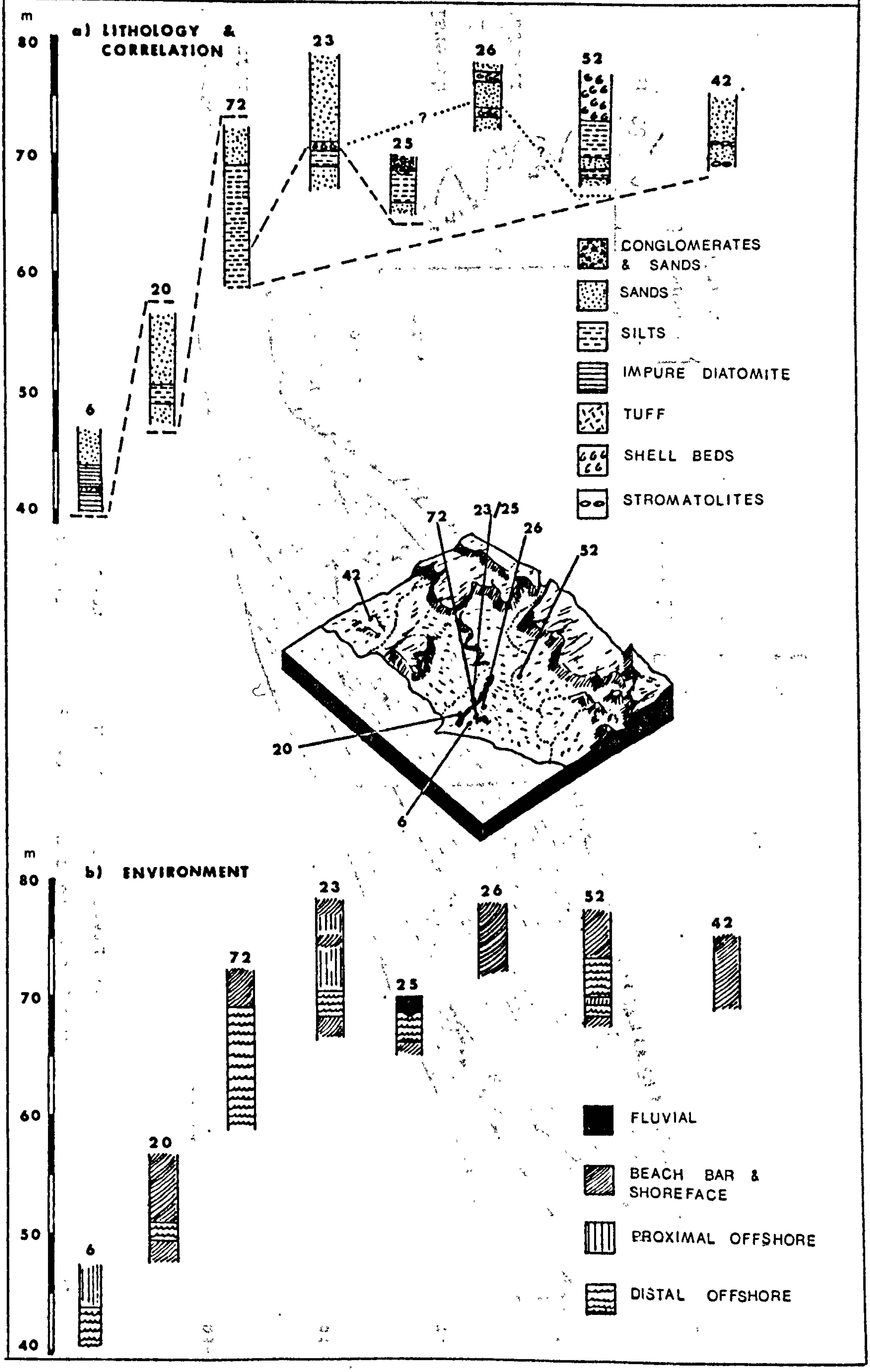


Fig. 6.10 Highly idealised cross section showing the transgressive and regressive sediments of the Galana Boi Formation

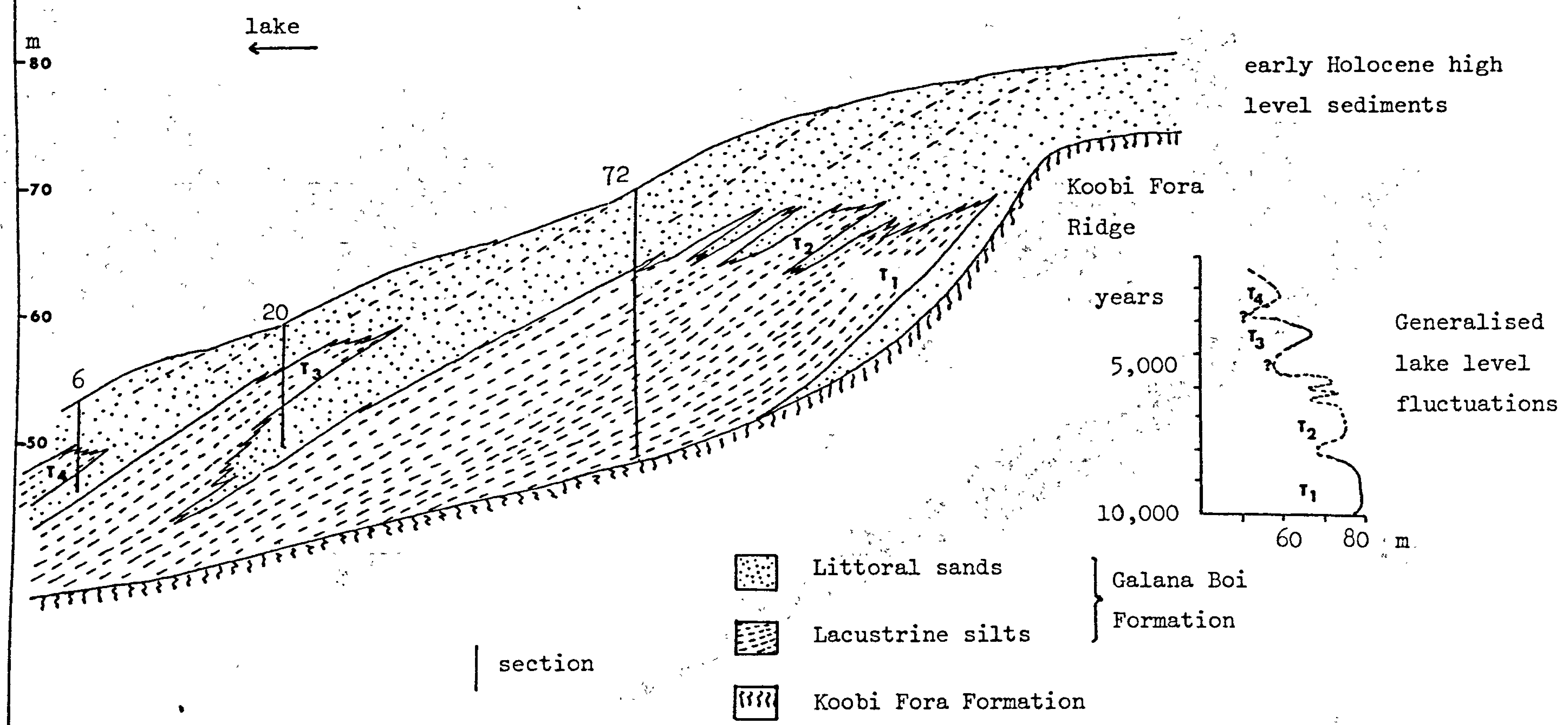
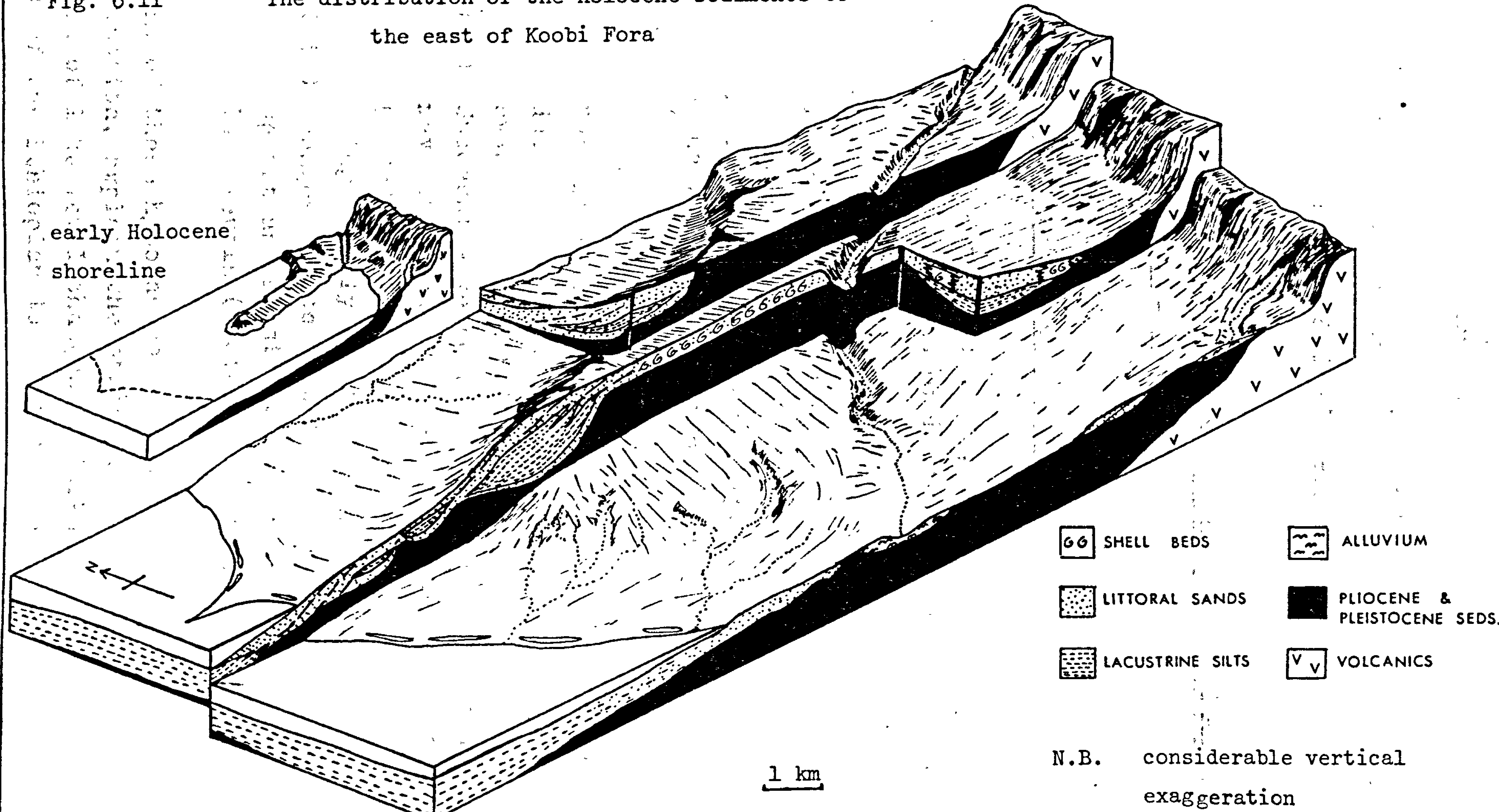


Fig. 6.11 The distribution of the Holocene sediments to the east of Koobi Fora



CHAPTER 7

THE HISTORY OF LAKE TURKANA AND OTHER EAST AFRICAN LAKES DURING THE LATE QUATERNARY

7(i) The late Quaternary history and palaeohydrology of Lake Turkana

7(i)a The late Pleistocene history of Lake Turkana

During the latest Pleistocene, extensive erosion occurred around the present margins of Lake Turkana. This erosive phase is reflected in major unconformities at the base of the Galana Boi Formation, and between Members III and IVa of the Kibish Formation (Butzer & Thurber, 1969). In the latter case the erosive period has been dated between 37,000 and 9,500 yr. B.P.. Three hypotheses can be suggested to explain the lack of high level lacustrine sediments of this age.

(i) Prolonged internal drainage and low lake levels due to lower precipitation and/or higher evaporation (climatic control).
(ii) Successive veneers of high level lacustrine units may have been stripped off during later arid phases, just as the Galana Boi Formation is being rapidly removed today (climatic control).
(iii) Changes in the outlet height of the lake by uplift and subsidence may have resulted in lower lake levels (tectonic control).

Any of these hypotheses can independently, or in combination, explain the observed facts. The Holocene record of lake level changes at Turkana is similar to that of the Ethiopian lakes, yet it apparently differs during the late Pleistocene. The latter group of lakes expanded prior to 70,000 yr. B.P., again from prior to 40,000 yr. B.P. to about 30,000 yr. B.P., and finally between about 30,000 and 17,000 yr. B.P. (Gasse & Street, 1978). The question arises; did the third lake expansion take place at Lake Turkana? No high level sediments of this age have yet been recognised. However, in view of the close relationships with the Ethiopian lakes shown during the Holocene, it cannot be discounted.

7(i)b The early Holocene palaeohydrology of Lake Turkana

Lake Turkana reached its outlet height during the early Holocene, at which point it stood about 80 m (*ca*. 450 m O.D.) above its modern elevation.

Estimates of palaeohydrological parameters such as rainfall, evaporation and runoff can be made from a knowledge of the modern water balance for any lake, if its former extent is known. The annual water balance for a closed lake such as Turkana is given by the following equation (from Street, 1979).

$$A_b P_b K + A_l P_l = A_l E$$

where A_b = catchment area (km^2)
A_l = lake surface area (km^2)
P_b = mean ppt. over the catchment (mm)
P_l = mean ppt. over the lake (mm)
K = runoff coefficient (the proportion of rain falling on the catchment that reaches the lake)
E = evaporation from the lake surface

When this equation is applied to the modern lake (data shown in table 7.1), a budget only 6 % in error results. The error may be due to inaccuracies in estimating the runoff coefficient.

Table 7.1

Data used to compile hydrological budgets.

Turkana:

Item	Data Source
Catchment area (A_b): 140,000 km^2	Butzer, 1971
Modern lake surface area (A_1): 7500 km^2	Butzer, 1971
Surface area of +80m. lake: 18,000 km^2	Sheet SK 41, Kenya (north).
Mean annual precipitation (P_b): 798 mm.	Average over whole basin; from maps in Griffiths 1972
Mean precipitation on lake surface (P_1): 250mm.	As above
Evaporation from the lake surface (E): 3607 mm.	Base on Lodwar climatic data in Griffiths 1972 & Morgan, 1971.
Runoff coefficient (K): 0.24	Schumm, 1965

Suguta:

Item	Data Source
Catchment area (A_b): 13,000 km^2	Butzer, 1971
Modern lake surface area (A_1): 128 km^2	Sheet SK 41 Kenya (north) mean of max. and min. extent of ephemeral lake
Area of +330m. lake: 1216 km^2	Sheet SK 41.
Mean annual precipitation (P_b): 360mm.	Average over whole basin; from maps in Griffiths 1972
Mean precipitation on lake surface (P_1): negligible	Dodson, 1963
Evaporation from lake surface (E): 5000 mm.	Estimate based on Langbein 1961 and other rift lakes
Runoff coefficient (K): 0.14	Estimate based on total evaporative loss to total water input ratio.

Figure 7.1 shows several combinations of precipitation, evaporation and runoff that could support Lake Turkana at + 80 m. If we assume that runoff and evaporation were similar to today (diatom floras suggest that temperatures were similar), then an increase in precipitation of the order of 106 % (compared with today) would be required to maintain the lake at + 80 m. Should the runoff constant have been greater, perhaps 0.3 (due to vegetation changes?), then a 70 % increase in mean annual rainfall would be needed to maintain the highest lake levels. However, these represent minimum figures, since at its outlet height, any further increase in rainfall would be lost by overflow, and not be recorded by lake expansion.

The results of this study are somewhat high when compared with other estimates of early Holocene rainfall. Examples of these include the following (all are minimum values).

Basin	% ppt. above present	Source
Nakuru-Elmenteita	65	Butzer et. al.,1972
Naivasha	25	Butzer et. al.,1972
Manyara	33	Holdship, 1972
Ziway-Shala	47	Street, 1979

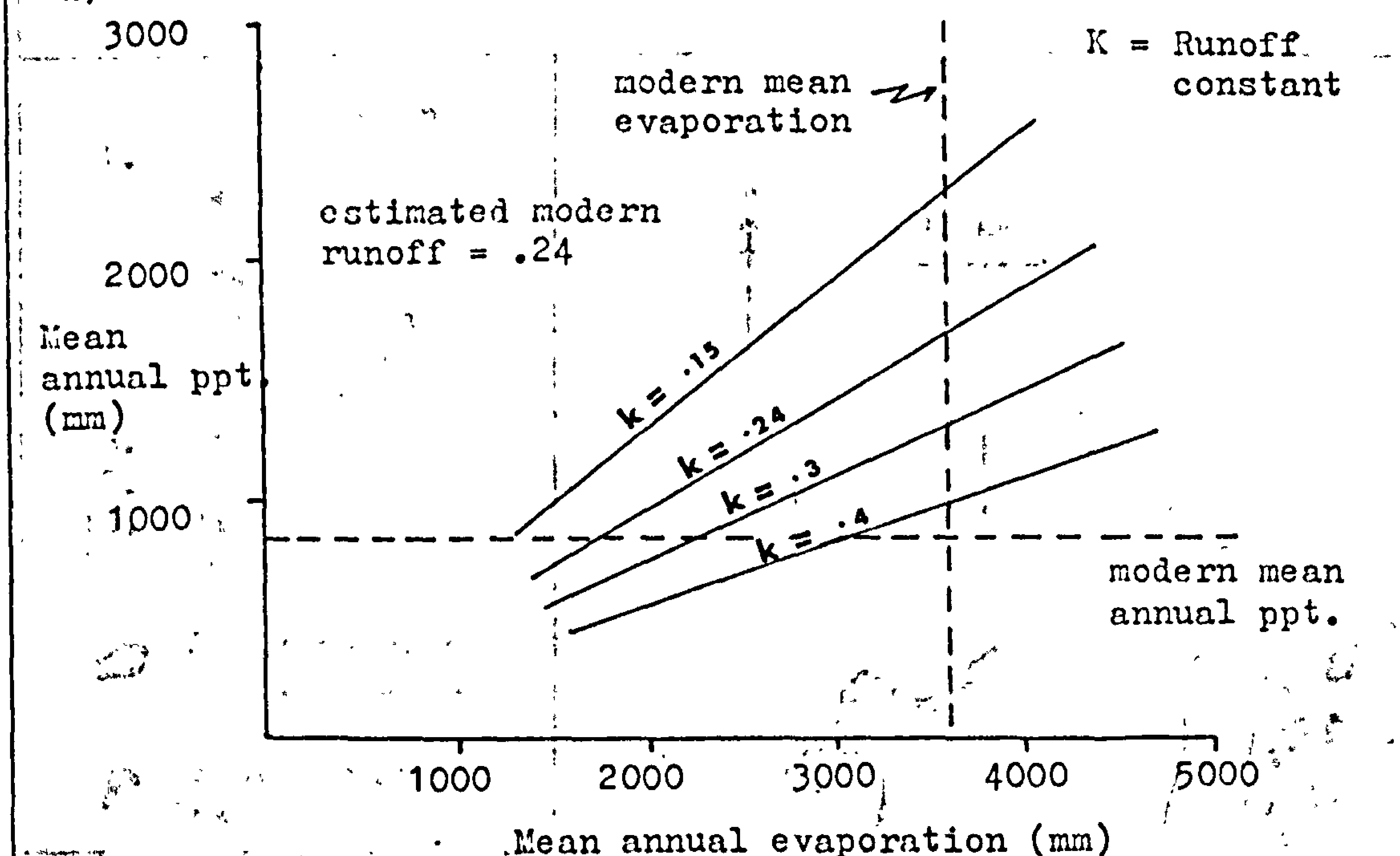
The high values at Lake Turkana probably reflect the addition of two drainage systems that are today isolated and fragmented into a series of smaller closed basins. These are the Chew Bahir-Chama-Abaya and the Suguta drainage basins (fig. 7.2). Each will be discussed separately in the following sections.

7(i)c The Chew Bahir-Chama-Abaya drainage network

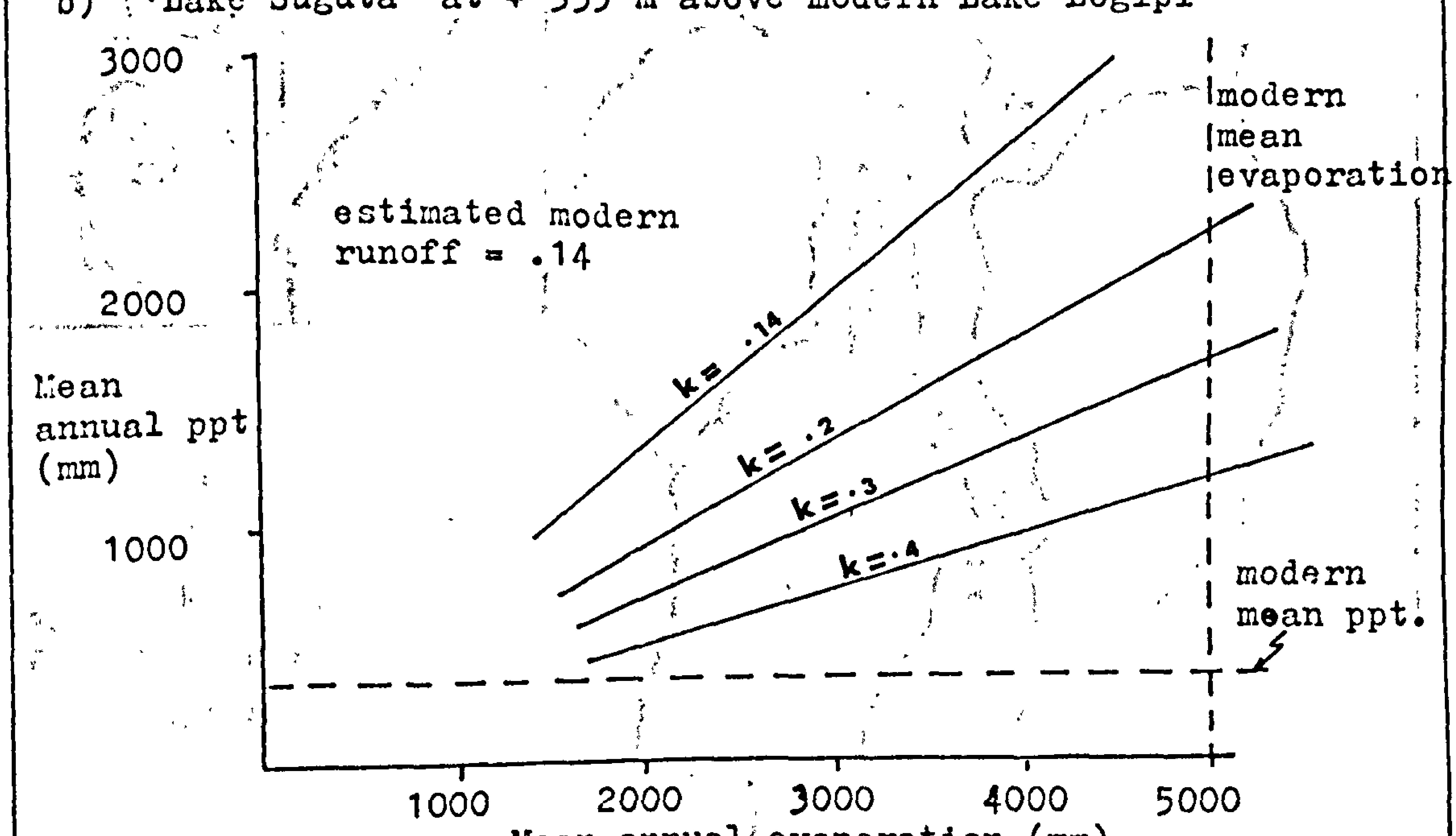
Increased rainfall during the early Holocene resulted in the expansion of the Ethiopian lakes. Lakes Shala, Ziway, Abiyata and Langano, formed a single large water-body that drained to the north via the Awash River (Street, 1979).

Fig. 7.1 Hydrological parameters adequate to maintain high lake levels

a) Lake Turkana at + 80 m

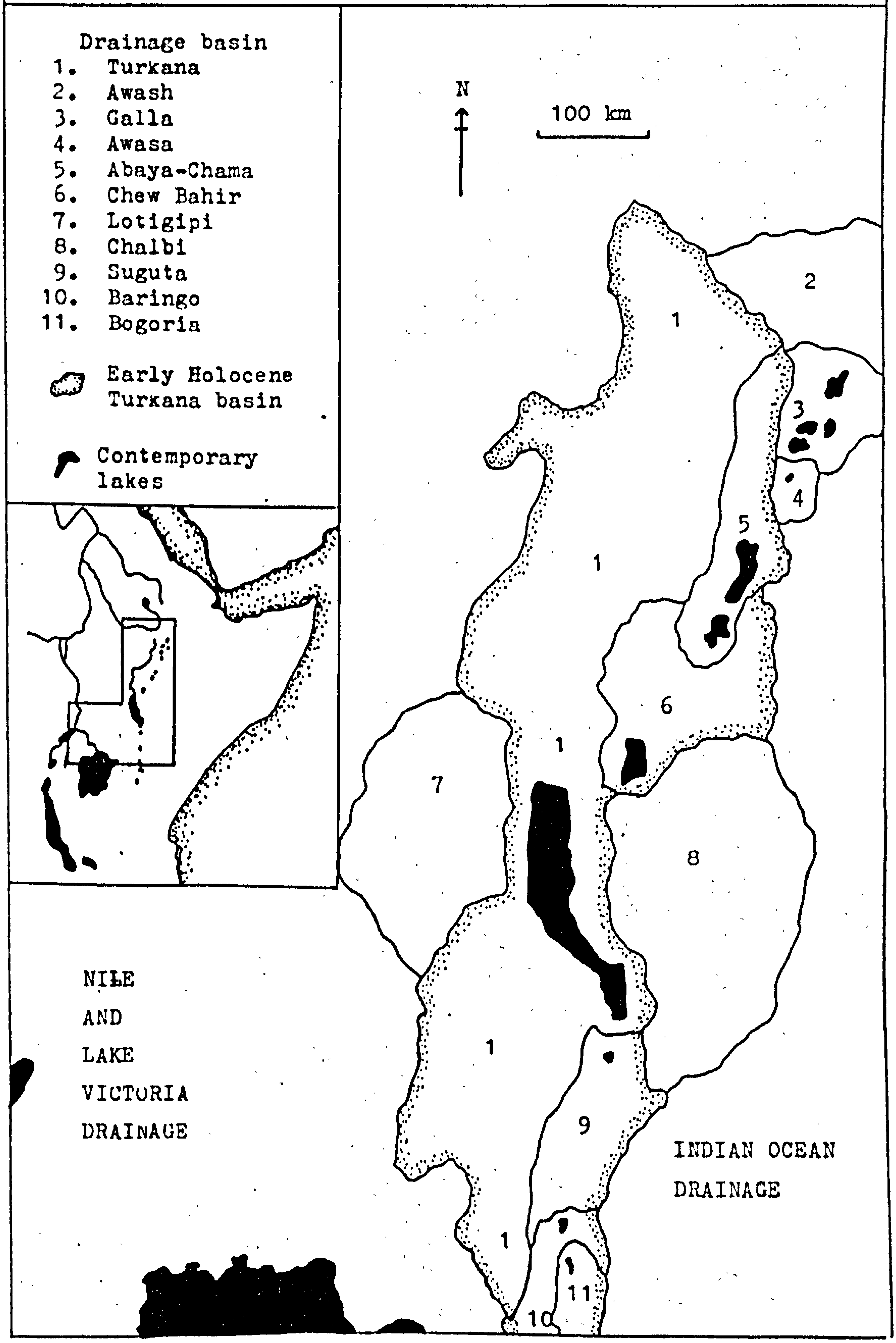


b) 'Lake Suguta' at + 335 m above modern Lake Logipi



Each line represents balancing covariations of rainfall (over the whole catchment) and evaporation (from the lake surface), with a particular runoff constant.

Fig. 7.2 Early Holocene and contemporary drainage basin network of the northern Kenya Rift



To the south-west we enter the palaeodrainage basin of Lake Turkana (fig. 7.2). Today this area is fragmented into a series of smaller drainage basins.

Modern Lakes Abaya and Chama are occasionally linked by a river that probably also operated during the early Holocene. In turn, the Sagan River would have linked these to Lake Chew Bahir (Grove et. al., 1975). Today, Lake Chew Bahir varies between marshy and fully lacustrine states. During the early Holocene it stood some 20 m higher (Grove et. al., 1975). This former drainage line is shown, together with overflow heights, in figure 7.3.

Satellite photos show the former line of drainage that linked Lake Chew Bahir with Lake Turkana. It can be seen entering the latter to the south of the Koobi Fora Ridge.

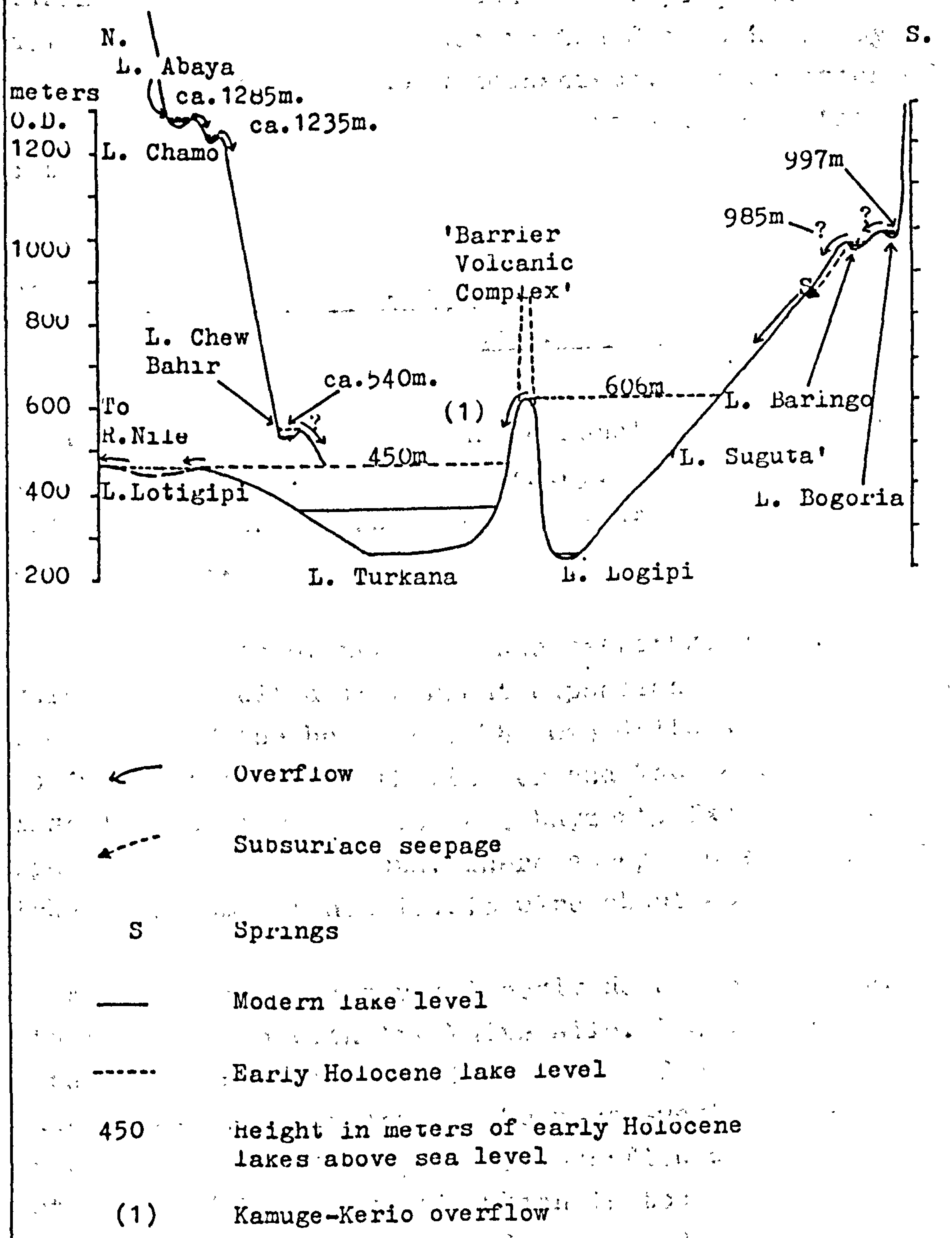
7(i)d <u>The Suguta drainage network</u>

A second major drainage network formerly entered the ancestral Lake Turkana along its south-western shore, via the Kerio River. The lower Suguta Valley was occupied by a large lake (Lake Suguta) during the early Holocene, of which Lakes Alablab and Logipi are remnants.

Lacustrine sediments are reported at heights of up to 600 m O.D. (dated at 9660 $\pm$ 210 yr. B.P.; Truckle, 1976). Truckle reports that at 606 m O.D. Lake Suguta would have overflowed into the Kerio Valley via the Kamuge River, feeding ultimately Lake Turkana.

Several possible water budgets, sufficient to maintain a lake at 606 m O.D. have been calculated (fig. 7.1b). Assuming modern runoff rates and similar temperatures to today, an 800 % increase in rainfall would be required. Clearly this bears no relation to data from other basins (p. 223). Assuming an increased runoff constant of 0.3,

Fig. 7.3 Modern and early Holocene lake heights and overflows in the northern Kenya Rift Valley



N.B. Considerable vertical exaggeration. Horizontal not to scale.

and similar evaporation rates to today, rainfall would still have to increase by 360 %.

These figures clearly argue for drainage basin enlargement. Lakes Baringo and Bogoria may have been linked during the early Holocene (chapter 9, p. 305), and both may in turn have been joined to the Suguta River by subsurface and/or overflow mechanisms. The addition of these two basins (fig. 7.2) would have doubled the catchment of Lake Suguta.

7(i)e The early Holocene palaeogeography of Lake Turkana and adjacent drainage basins

The present extent of, and connections between lakes in northern Kenya and southern Ethiopia are contrasted with their former areas and links in figures 7.4 and 7.5, respectively.

The addition of new drainage networks, and increased rainfall, resulted in a great expansion of Lake Turkana at the start of the Holocene. The Omo delta was situated 70 to 100 km further north (Butzer and Thurber, 1969), while East Turkana formed a large embayment. Expansion was less spectacular in the south, where steep slopes confined the lake. Maximum surface levels were about 80 m above present.

Figure 7.5 shows several early Holocene links with other lakes and with the White Nile. Today, high-level strandlines mark the position of the former outlet of Lake Turkana, which lay to the north-west of the expanded lake (marked 'A' in fig. 7.5). Overflow waters may have entered a 'Lake Lotigipi', which is today reduced to a swampy area. A further overflow (marked 'B' in fig. 7.5) may have provided a link to the River Kengen and ultimately the River Nile.

Fig. 7.4

Contemporary geography of the Lake Turkana and adjacent drainage basins

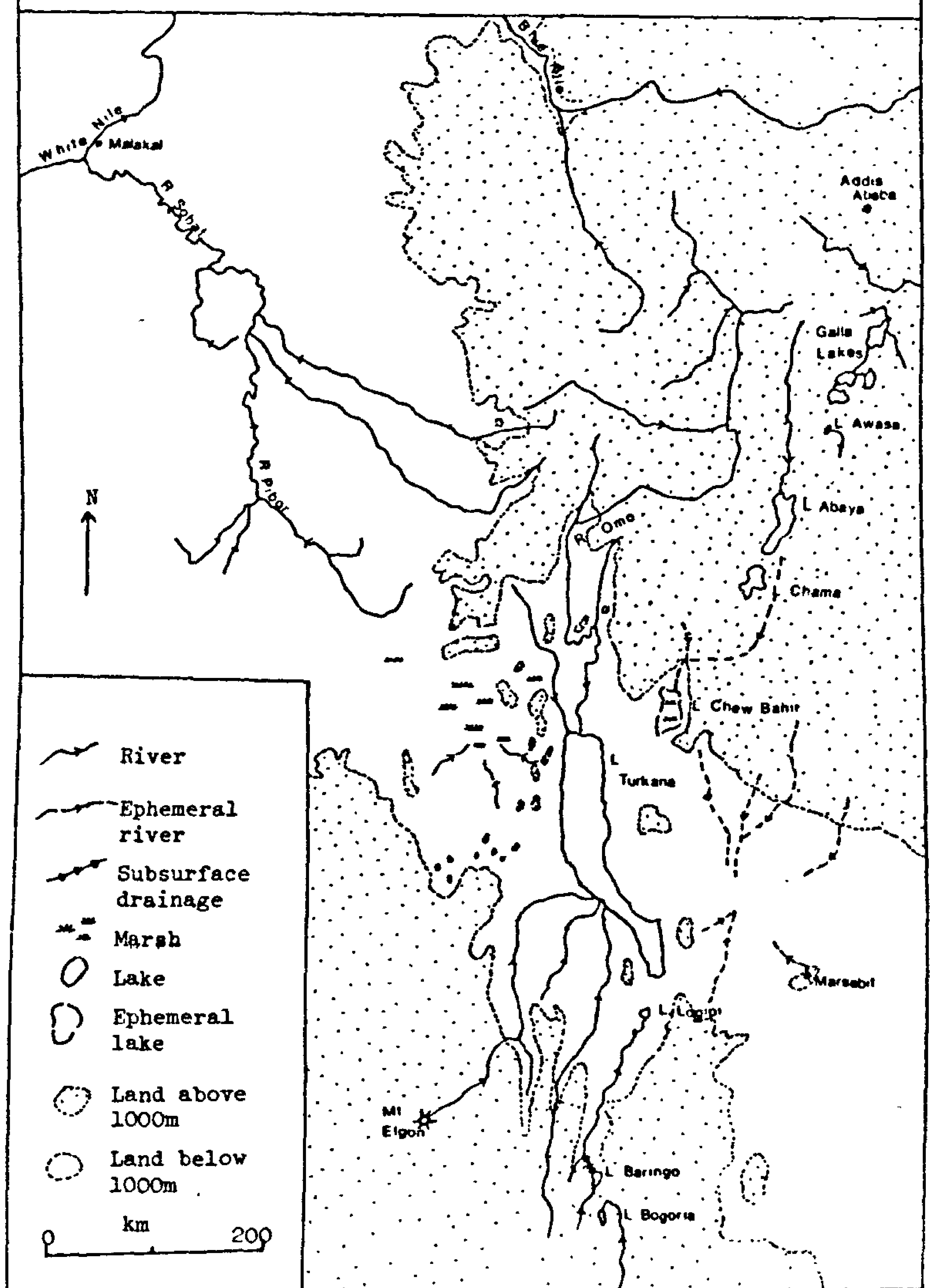
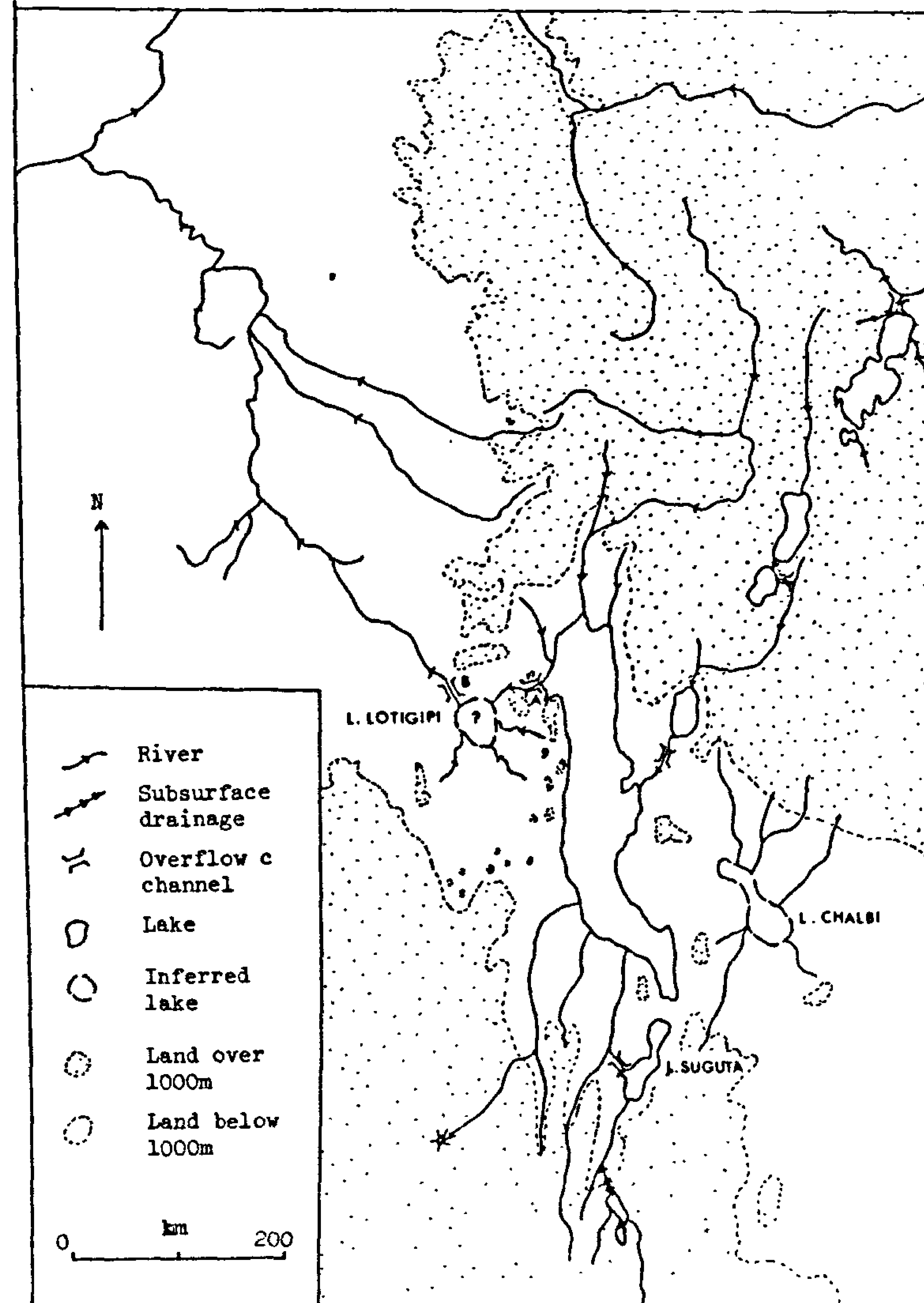


Fig. 7.5

Early Holocene palaeogeography of the Lake Turkana and adjacent drainage basins



7(i)f The middle and late Holocene development of Lake Turkana

A period of lower lake levels (though probably not less than about 55 m above modern heights) followed the maxima of the early Holocene. Dated sediments from East Turkana (Barthelme, pers. comm.) and the Omo region (Butzer and Thurber, 1969) suggest that this phase took place between about 7,500 and 6,600 yr. B.P..

This 'dry phase' was terminated by a second major rise in lake levels between ca. 6600 and 4000 yr. B.P.. At this time the lake probably fluctuated between about 45 and 80 m above its present height. The youngest diatomaceous sediments at East Turkana suggest a final transgression, after a period of very low levels, to about 50 m above the modern lake, probably during the late Holocene.

Throughout the early and middle Holocene the lake maintained a fresh character. Only in the late Holocene is their a suggestion of a change to the more alkaline and saline conditions of today. By the late Holocene links with other basins were probably severed. Butzer (1971) records a minor rise in the last millenium or two, while in historical times he notes a height range from 365 to 385 m O.D..

7(ii) The development of East African lakes during the Holocene

7(ii)a The major lake level trends in East Africa

Figure 7.6 shows the fluctuations in surface height of several East African lakes. All stood at high levels during the early Holocene. Lake Baringo appears to be an exception, but there is some question about the reliability of the dating (chapter 9, p. 285).

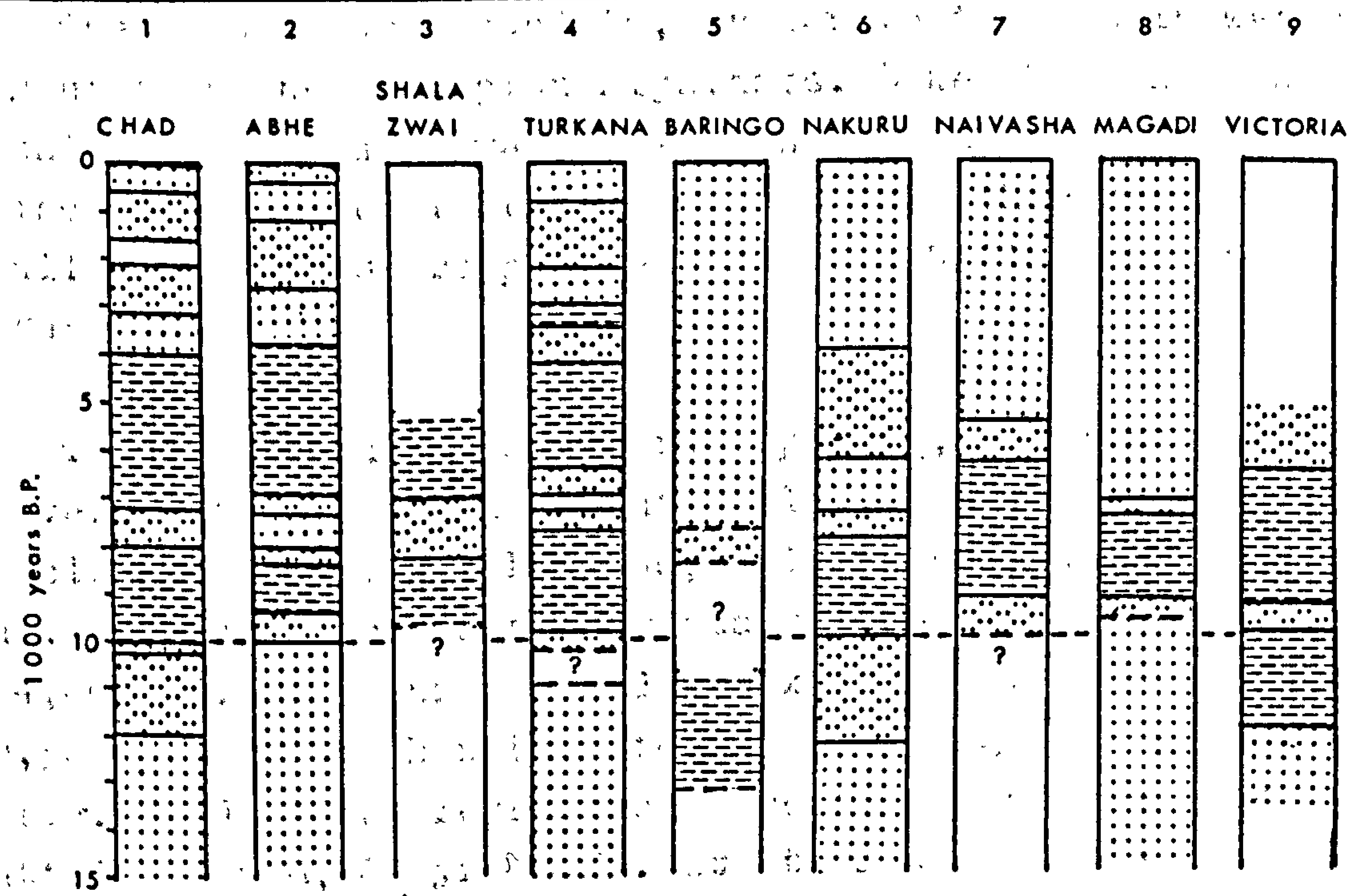
Three patterns emerge from an inspection of figure 7.6. First, Lakes Nakuru, Naivasha, Magadi and possibly Lake Baringo, all record a single major high lake level, during the early Holocene. Second, Lakes Abhe, Shala, Ziway and Turkana show at least two major periods of high lake level during the Holocene. Finally, Lake Victoria shows both an early Holocene high lake level, and another between about 10,000 and 12,000 yr. B.P..

Possible causes of these differences relate to shifts in the position of the 'inter tropical convergence zone', and are discussed more fully in section 7(iii).

Many East African lakes have been described in varying detail. The major ones will be briefly reviewed in the following discussion, in order to place the Holocene evolution of Lake Turkana in a broader context. The following lake groupings can be recognised.

(i) The Ethiopian Rift lakes
(ii) The Kenya Rift lakes
(iii) The western Rift Valley lakes
(iv) The non Rift Valley lakes

Fig. 7.6 LAKE LEVEL FLUCTUATIONS DURING THE LAST 15,000 YEARS IN EAST AFRICA



KEY

High lake level

Intermediate lake level

Low lake level

Evidence lacking

1 after SERVANT 1973

2 after GASSE 1975

3 after GROVE et al. 1975

4 after BUTZER et al. 1972

5 after BISHOP et al. 1969

6-9 after BUTZER et al. 1972

The lakes are arranged from north to south as one reads from left to right.

A series of generally high lake levels can be seen to characterise the early Holocene lakes between 8000 and 10000 years B.P.. Lake Baringo is out of phase, possibly due to C^{14} errors.

7(ii)b The Ethiopian Rift lakes

These lakes are found in, or derive their main water input from the Ethiopian Highlands. Lakes Turkana, Chew Bahir, Chama and Abaya lie within this area and have been discussed earlier in this chapter. Two other sets of lakes fall within this group, these are the Galla lakes and the Afar lakes.

Today, the Galla lakes are separate, but linked by rivers within a basin of internal drainage (fig. 7.4). They include Lakes Ziway, Langano, Abiyata and Shala. Grove et. al. (1975) report that they started to rise from about 14,400 yr. B.P. and reached a maximum elevation just after 9,500 yr. B.P., when they formed one single large lake (fig. 7.5). After regression a second high level was attained by 6,500 yr. B.P.. At its maximum this combined 'Lake Galla' overflowed into the Awash River and ultimately into the Afar region of Ethiopia. Gasse (1975) has noted that the early and middle Holocene lakes were typified by tropical diatoms such as Melosira nyassensis var. victoriae and M. agassizi.

Several highly alkaline lakes occur in the lowland, Afar region of Ethiopia. These include Lakes Abhe, Afrera and Asal. Gasse (1975) has established that the climate was arid in this area prior to 11,000 yr. B.P., but that between 11,000 and 8,400 yr. B.P. wetter conditions prevailed. Prior to 9,400 yr. B.P., Gasse notes the presence of euryhaline diatoms, which were replaced by oligohaline forms after this date. A second arid phase developed between 8,400 and 7,400 yr. B.P., with a third occurring from about 4,000 to 2,500 yr. B.P.. Today, the area is again very arid.

7(ii)c The Kenya Rift lakes

Lakes Baringo and Bogoria lie within the Kenya Rift. However, these form the subject of a detailed examination and will be discussed fully in chapter 9.

Further south, occur Lakes Nakuru, Elmenteita and Naivasha. These occupy the highest part of the Kenya Rift. During the early Holocene a major watershed passed between the enlarged Lake Naivasha and combined Lakes Nakuru and Elmenteita. Butzer et. al. (1972) note that Lake Naivasha had an overflow to the south via the Njorowa and Kedong Gorges, while Lakes Nakuru and Elmenteita had a common overflow to the north, into the Menengai caldera.

Richardson (1972) recognised three stages in the history of Lake Naivasha, based on diatom studies. Between 9,200 and 5,650 yr. B.P. the climate was warmer and more humid than today, with the lake expanded to its overflow. From 5,650 to 3,040 yr. B.P. the lake contracted. Finally, after about 3,000 yr. B.P., the lake fluctuated near to, or below modern levels.

Lakes Nakuru and Elmenteita reached their maximum height about 9,000 yr. B.P. (Butzer et. al., 1972). A second minor rise occurred between 6,000 and 4,000 yr. B.P., after which both lakes regressed to their modern positions.

Lakes Magadi and Natron lie at the southern end of the Kenya Rift. Lake Natron is highly saline and alkaline, while Lake Magadi is ephemeral and has precipitated a thick trona sequence. Butzer et. al. (1972) report a date of 9,120 ± 170 yr. B.P. for a terrace of silts and clays 12 m above Lake Magadi. Servant (in Eugster & Ming Chou, 1973) noted that the diatoms were dominated by <u>Nitzschia spp</u>..

7(ii)d The western Rift Valley lakes

A number of large lakes occur in the western branch of the East African Rift. Reports of the Holocene sediments are scarce, however detailed diatom analyses of cores have been made by Haworth (1977) and Harvey (1976), for Lakes George and Mobutu Sese Seko respectively.

Lake George lies in the Albertine Rift and is joined to the much larger Lake Edward by a narrow stretch of water known as the Kazinga Channel. Haworth recognised three diatom assemblage zones, spanning the last 3,600 years. The earliest was dominated by *Melosira* and *Fragilaria* which give way to a flora dominated by *Nitzschia* and *Fragilaria*. The final assemblage consists of *Nitzschia* and *Synedra*. She concluded that the changes were related to an increase in organic matter and nitrogen compounds.

Lake Mobutu Sese Seko lies to the north of Lake Edward. Harvey has dated his core back to about 28,000 yr. B.P., and recognised four parts to the core:

(iv) The *Stephanodiscus-Nitzschia* portion
(iii) The upper *Stephanodiscus-Melosira* portion
(ii) Diatoms rare
(i) The lower *Stephanodiscus-Melosira* portion

7(ii)e The non Rift Valley lakes

The largest of these is Lake Victoria. The lake had risen by about 12,000 yr. B.P. (Kendall, 1969), but by 10,000 yr. B.P. had again fallen to 12 m below modern levels. The lake was especially high between 9,500 and 6,500, and dominated by the freshwater diatoms *Stephanodiscus astraea* and *Melosira* spp.. The lake contracted after 6,500 yr. B.P., and pennate diatoms became more common.

Other lakes outside the rift valleys have received little attention. Strandlines are present along the margins of the Chalbi Desert in northern Kenya (fig. 7.5; Phillipson, 1978). In southern Kenya, Lake Amboselli once stood at much higher levels (Williams, 1972). In north-western Kenya, an early Holocene lake is possible in the area of the modern Lotigipi mudflats (fig. 7.5).

7(ii)f Diatom floral trends during the Holocene

A number of trends can be discerned in the centric diatom populations of many East African lakes. These mainly relate to climatically induced transgressions and regressions. Such fluctuations affect the salinity and alkalinity of the lakes and hence affect the diatoms.

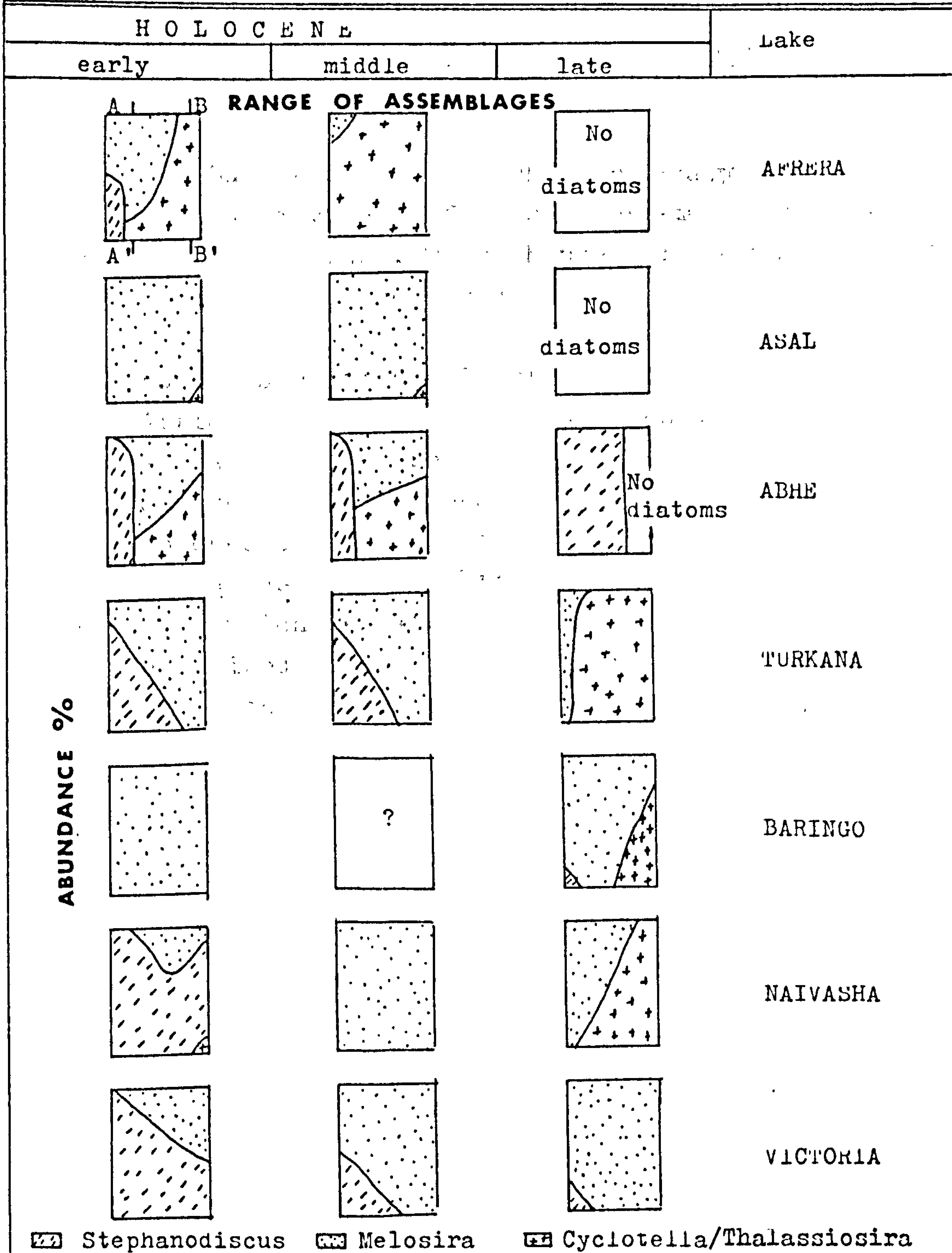
Figure 7.7 presents a series of diagrams that attempt to show diatom assemblage changes through the Holocene. The diagrams indicate the range of diatom assemblages that occurred within the early, middle and late Holocene. Only centric diatoms are included for simplicity, since these tend to reflect major environmental shifts.

Lake Afrera (fig 7.7) shows a change from an early Holocene flora dominated by *Stephanodiscus/Melosira* and *Melosira/Cyclotella*, to an assemblage consisting of *Cyclotella* spp. during the middle Holocene. By the late Holocene, the lake was much contracted, of higher alkalinity and lacked diatoms.

Lakes Abhe and Asal maintained similar floras during the early and middle Holocene, as did Lake Turkana. Diatoms disappear from the former two lakes during the late Holocene, while they decline and change to a *Cyclotella /Thalassiosira* flora in Lake Turkana.

Lake Baringo was dominated by a *Melosira/Stephanodiscus* assemblage during the early Holocene. By the late Holocene, both *Melosira* and *Cyclotella/Thalassiosira* floras were common.

Fig.7.7 Major changes of centric diatom assemblages during the Holocene in East Africa



The proportion of the vertical axis occupied by a genus represents its percentage contribution to an assemblage on that line. The horizontal axis represents the approximate range of assemblages that occur. eg. A-A' (above) represents a flora with 80% Melosira and 20% Thalassiosira and Cyclotella (T/C). B-B' represents a flora with 100% T/C. The diagrams do not indicate the frequency with which an assemblage occurs only that it is present in the lake during that time period. Based on Kendall, 1969; Richardson & Richardson, 1972; Gasse, 1975 and personal observations.

Lake Naivasha has shown a trend from Stephanodiscus-dominated (early Holocene) to Melosira-dominated floras (middle Holocene), and finally to assemblages consisting of varying percentages of Melosira and Cyclotella (late Holocene.

Finally, Lake Victoria has shown a change from Stephanodiscus-dominated floras to assemblages in which Melosira is most common. This changeover took place at the early to middle Holocene boundary.

The above descriptions illustrate the main floral trends in East African lakes during the Holocene. This can be summarised as a change from Stephanodiscus and Melosira-dominated assemblages, through Melosira only dominated floras, to ones consisting of Cyclotella and/or Thalassiosira. As a lake contracts, dissolved salts tend to increase, which results in changes of diatom flora. The changes described in earlier paragraphs therefore closely reflect the limnological history of East Africa.

7(iii) The climatic evolution of Africa

7(iii)a Introduction to climatic studies in Africa

During the last fifteen years a large body of lake level, river terrace and palaeontological data has been accumulated which now allows attempts at palaeoclimatic reconstruction to be made. Some of this data are shown in figure 7.8.

Climatic changes have been the principle cause of lake level fluctuations during the late Quaternary. Formerly, the link between lake expansion and climate was used to invoke the occurrence of a 'pluvial' (wet phase), for any time span represented by lacustrine sediments. The 1947 Pan-African Congress on Pre-History declared the existence of four pluvials, and compared them with the glacials of Europe. The pluvial concept was later abandoned as a formal stratigraphic framework, with the realisation that lacustrine sediments may be present, or absent, due to the influence of tectonic and/or volcanic events (Bishop, 1971). Palaeoclimatic conclusions for the early and middle Pleistocene are now based mainly on fossil criteria.

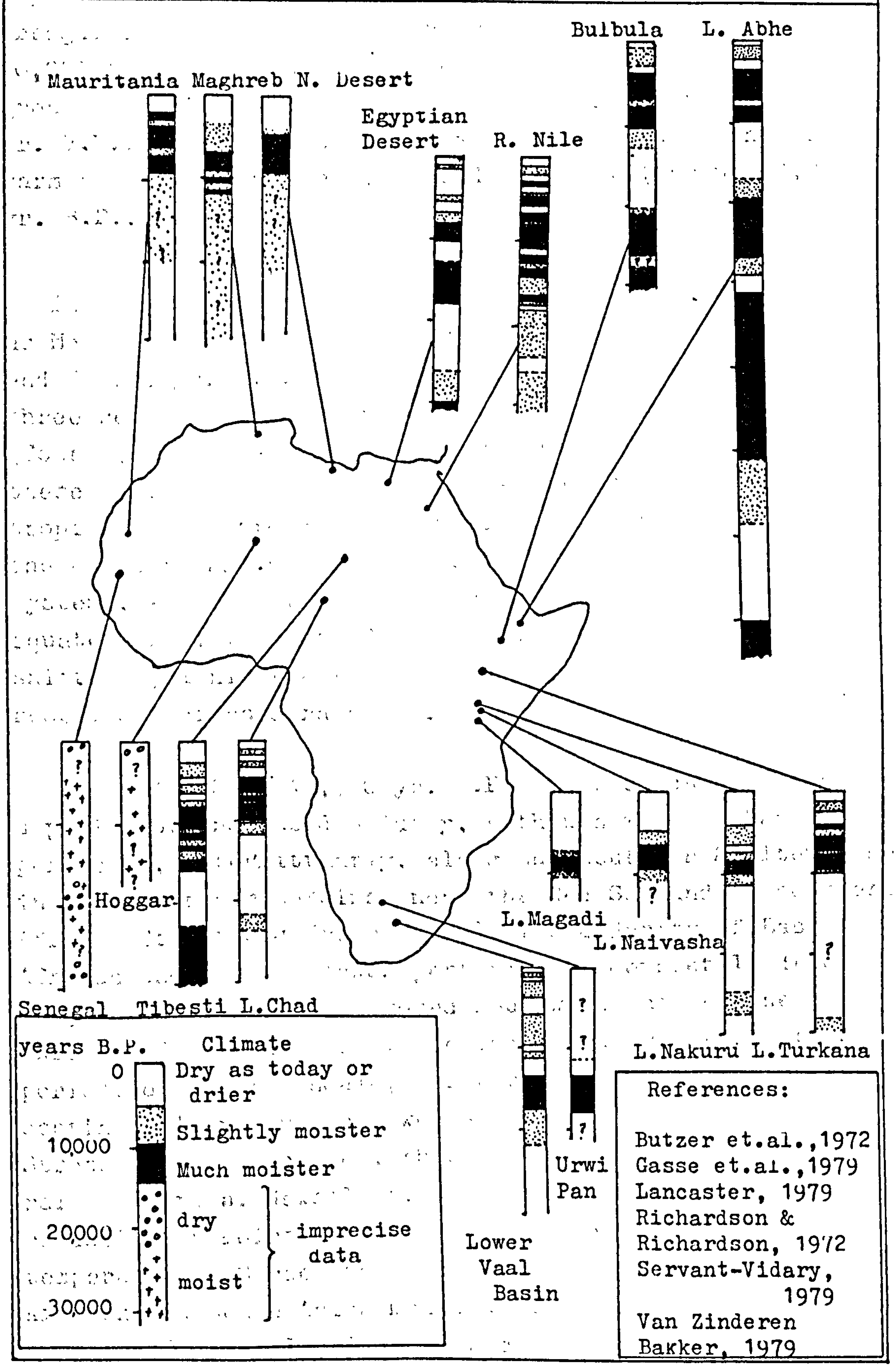
7(iii)b The Pleistocene climatic evolution of Africa

Data from the Omo sediments (Bonnefille, 1976), to the north of Lake Turkana, suggest that this area was moist between 2 and 1.2 my. A dry phase followed from 1.2 until 0.2 my., with a brief moist episode at about 0.7 my that has also been reported from Melka Kontoure in Ethiopia (Gasse, Rognon and Street, 1980).

Van Zinderen Bakker and Maley (1979) suggest that during the 'early Wurm', conditions ranged from dry in Senegal to semi-arid in Mauritania and the northern Sahara (but colder than today), to wet and colder in the Maghreb (north-west Africa).

Fig.7.8

Late Quaternary climatic fluctuations in Africa



In the Afar region of Ethiopia, Gasse, Rognon and Street (1980) have suggested that the climate was humid, with an irregular rainfall regime, prior to 70,000 yr. B.P.. From 70,000 to 60,000 yr. B.P. lake levels fell, suggesting greater aridity. Humid conditions returned after 60,000 yr. B.P., but with rains that were more regular and with warm temperatures. This period lasted until about 31,000 yr. B.P..

Lakes developed and expanded in modern arid areas such as Mauritania, Chad and the Afar, between about 40,000 and 20,000 yr. B.P. (Rognon & Williams, 1977). Two or three wet/dry climatic cycles occurred during this period (Conrad, 1969; Servant, 1973). According to Maley (1976) these cycles may have been related to movements of tropical depressions. Steep temperature gradients between the equator and the arctic apparently accelerated the wind systems, while climatic belts were compressed and moved equatorwards. This southerly movement (in north Africa) shifted cyclonic tracks over the Maghreb, so that it received increased rainfall.

From 21,000 to 12,500 yr. B.P. the tropics underwent a period of increased aridity, although wetter phases persisted, intermittently, along the southern Mediterra nean, in the Saharan mountains, near the Red Sea and in southern Africa (Street and Grove, 1979). The majority of East African and Saharan lakes partially or completely dried out, while active dunes moved southwards across the Sahel (Grove and Warren, 1968). The increased aridity of this period, on a world scale, has been attributed to increasing continentality (due to lower sea levels) by Webster and Streten (1972). However, this probably played only a minor rôle in Africa. Newell et. al. (1975) suggested a global reduction in moisture, due to lower sea surface temperatures. Street and Grove (1979) state that the west African and south Asian monsoons were probably greatly suppressed. Lake level data from equatorial Africa suggests that aridity reached its maximum between 15,000 and 12,500 yr. B.P.. During this latter phase, only Africa south of 25°S (Heine, 1978), and areas such as the Tibesti, Jebel Marra and the Red Sea Hills, experienced wetter conditions than today (Street and Grove, 1979). Ethiopian data suggests a rainfall reduction by 9 to 40 % compared with today (Street, 1979).

7(iii)c <u>The Holocene climatic evolution of Africa</u>

Rognon and Williams (1977) note that the Holocene began with a rapid rise in sea surface temperatures, and with a re-organisation of the summer monsoons. The Sahel was again wet, which may reflect a northward shift in the mean position of the 'inter tropical convergence zone' and of the subtropical anticyclones of the Sahara. Sahelian high lake levels occurred at Rub'al Khali (18 to 23°N) between 8,800 and 6,100 yr. B.P., and in the eastern Sahara (15 to 23°N) from 8,700 to 4,200 yr. B.P. (Street and Grove, 1979). This moist phase was interrupted at about 7,500 yr. B.P., during which time dune formation took place at several localities (Wendorff, 1977).

In Kenya, high lake levels developed somewhat earlier, at about 9,500 to 10,000 yr. B.P. and lasted until about 7000 yr. B.P., with in some cases a second rise between about 6,500 and 4,000 yr. B.P. (fig. 7.8). Diatoms in these lakes suggest similar temperatures to today. Laminated sediments at Lake Turkana imply a cyclicity to the palaeoclimate on a seasonal, or perhaps longer term basis.

Rainfall maxima occurred in the Maghreb (fig. 7.8) at 12,000, and 10,500 to 10,000 yr. B.P., with the most important peak from about 9,000 yr. B.P.. However, Conrad (1969) notes that the northern Sahara remained dry for much of the early Holocene. This suggests that the westerly cyclones and Saharan anticyclones were over the Maghreb and northern Sahara respectively.

Data from southern Africa are sparse, however, Van

Zinderen Bakker and Clark (1962) have noted some evidence of greater aeolian activity during the early Holocene. Butzer (1979) suggests that the lower Vaal basin was at this time slightly moister than today (fig. 7.8).

During the early Holocene monsoonal rains were probably more common, prolonged and gentler than today. Rognon and Williams (1977) hypothesize that this involved a change in the inclination of the 'inter tropical convergence'. They state that rainfall intensity would decrease, and that the width of the Sahel rainfall belt would increase, due to warm moist tropical air overriding cool dry desert air, during the early Holocene. This contrasts with today, where moist tropical air passes under hot dry desert air.

From about 4,500 yr. B.P. the Sahara has experienced a southerly movement in the limits of the monsoonal rainfall area. This is related to an equatorward shift in the tropical high pressure cells. In turn, this has brought about increasing aridity and falling lake levels, not only in the Sahel belt, but throughout equatorial Africa. Rognon and Williams (1977) attribute such changes to an intensification of the desert anticyclones (on a world scale) and to falling temperatures.

In summary, the main factors that have influenced the climatic changes in Africa are as follows.

(i) Shifts in the mean position and inclination of the inter tropical convergence.

(ii) Shifts in the position of the, arid inducing, tropical anticyclones.

(iii) Shifts in the position of the westerly cyclones, which induce wet conditions.

PART III

THE EVOLUTION OF LAKES BARINGO AND BOGORIA

CHAPTER 8

LATE CENOZOIC SEDIMENTATION AND DIATOMS OF THE BARINGO DISTRICT

8(i) Miocene sedimentation and diatoms of the Baringo district

8(i)a Introduction to the sediments of the Baringo district

The Baringo district contains a number of lacustrine units that are separated both in time and space, and which extend back to the middle Miocene. The distribution and general stratigraphic relationships of these deposits are shown in figures 8.1 and 8.2 respectively. The latter diagram gives the maximum possible age ranges of the various units, although they were probably formed during shorter time intervals.

This chapter aims to use diatoms to increase our knowledge of the palaeochemistry and palaeoecology of this ancient series of lakes. Each of the sedimentary units recognised in the area will be discussed individually in the following sections.

8(i)b The Muruyur Beds

These lacustrine deposits are dominated by tuffaceous sediments and shales, which are locally well silicified. The Muruyur Beds formed about 13.5 my ago, and have a maximum thickness of about 300 m at Muruyur, although elsewhere they are much thinner (Pickford, Pers. comm.). Only six samples were collected from these Beds, from the Kituru area. The location is numbered '3' in figure 8.3, which shows the position of sampling sites in the Baringo

Fig. 8.1

The distribution of late Cenozoic sediments in the Baringo district.

(simplified after E.A.G.R.U. maps)

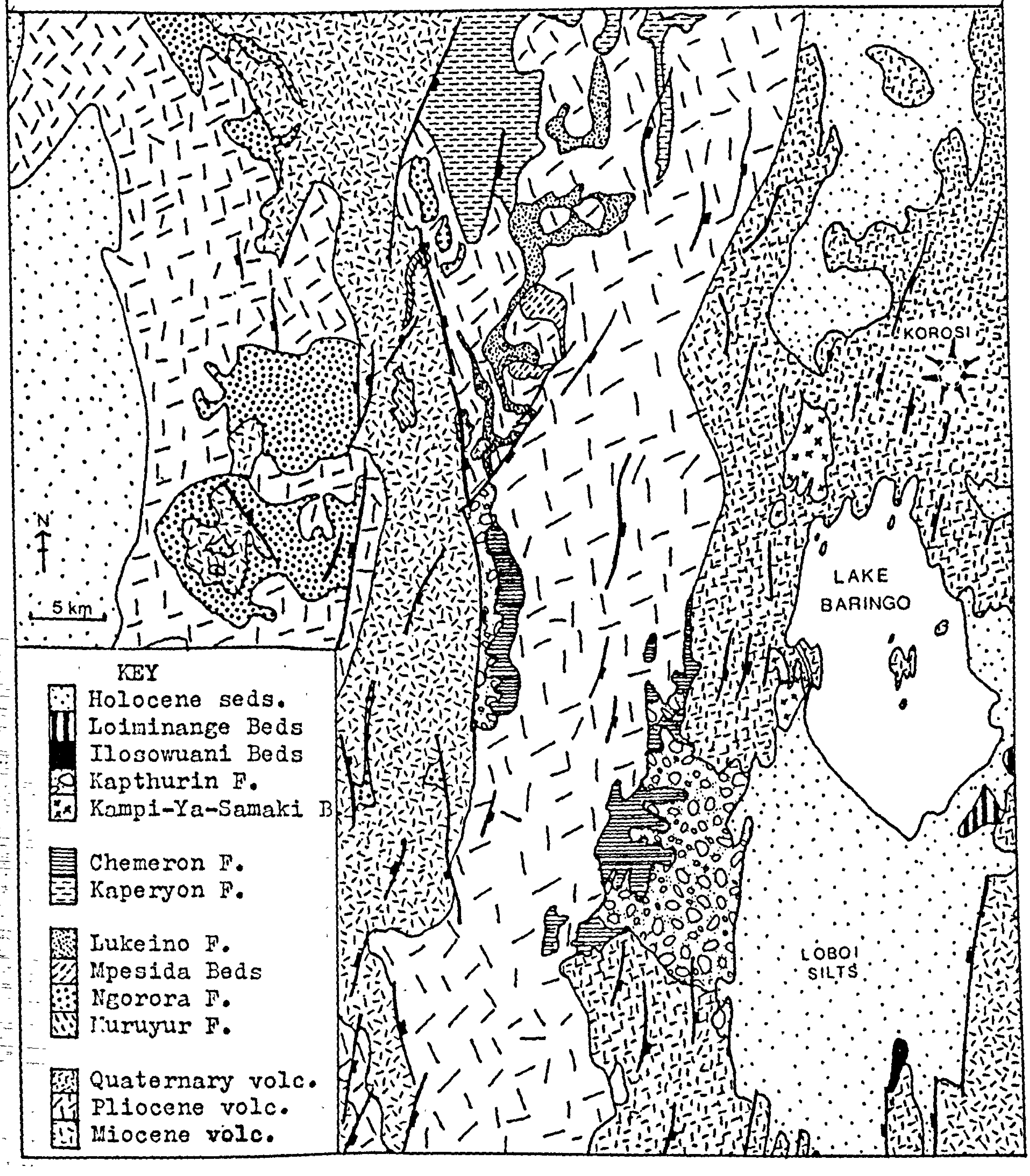


Fig. 8.2 Approximate age and distribution of sedimentary units in the Baringo District.

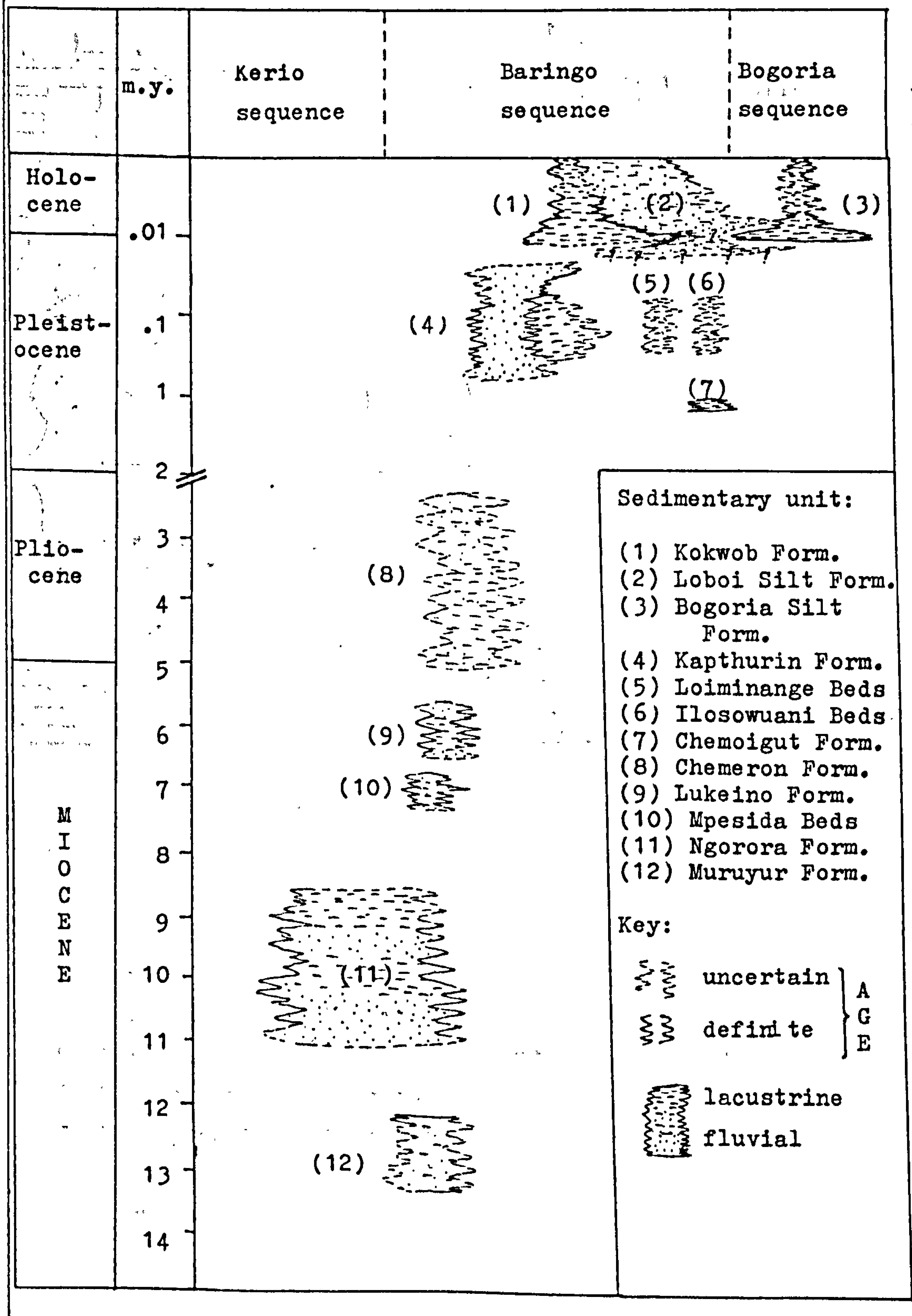
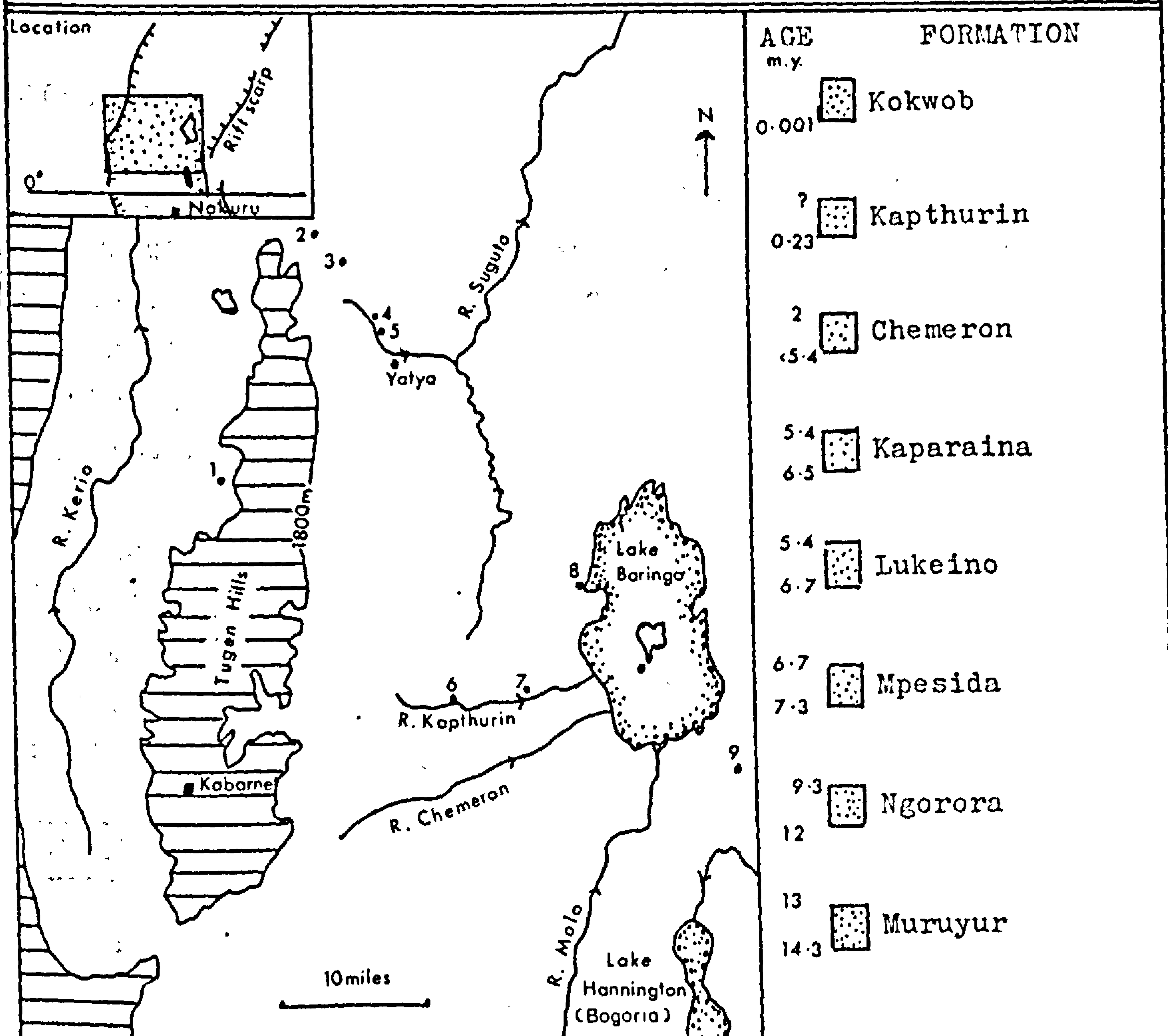


Fig. 8.3 MAP SHOWING THE LOCATION OF SECTIONS SAMPLED DURING THE SUMMER OF 1976 AND THE STRATIGRAPHIC RELATIONSHIPS OF THE SEDIMENTARY UNITS.



SAMPLING AREAS REFERRED TO IN THE TEXT :

1	Barwesa	Ngorora Formation
2	Kabarsero	Ngorora Formation
3	Muruyur Formation	
4	Kobuluk	Lukeino Formation
5	Pelion	Chemeron & Kaparaina Formations
6	R. Kapthurin	Chemeron Formation
7	R. Kapthurin	Kapthurin Formation
8	Kokwob Murren	Kokwob Formation
9	Logumukum	Kokwob Formation & Pleistocene sediments

district. Unfortunately no diatoms were found, and therefore no florally-based conclusions can be drawn.

8(i)c The Ngorora Formation

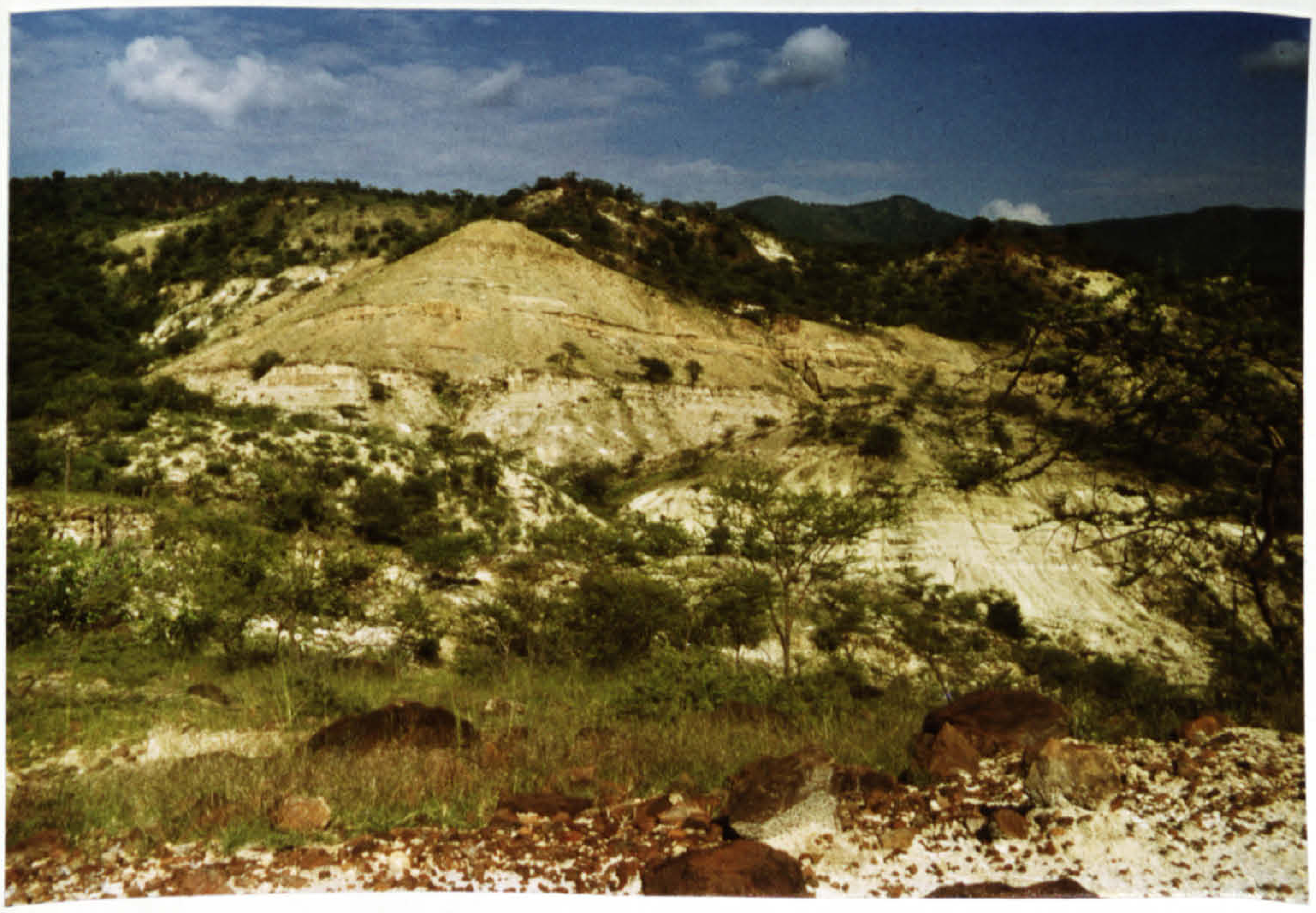
Pickford (1978) has demonstrated that the Ngorora sedimentary basin was limited to the north by the Tiati volcanics, to the west by the Elgeyo escarpment and to the south and east by a rise in the palaeorift floor. The basin was also split by north to south-trending faults, the movements of which partly controlled sedimentation.

The Formation lies between lavas dated at 9 my and 12 my (Pickford, 1978). It was divided into five units by Bishop and Chapman (1970), which were later ranked as Members by Pickford. These Members are as follow (thicknesses taken from the type section at Kabarsero).

MEMBER	LITHOLOGY	ENVIRONMENT
E	white laminated shales and diatomites. 125 m	Lacustrine
D	fluvial sands. 66 m	Subaerial
C	white laminated shales & rare palaeosols. 62 m	lacustrine
B	fluvial sands and palaeosols 42 m	Subaerial
A	coarse volcaniclastics, lahars & fluvial deposits. 104 m	Subaerial

Members C and E were sampled at 50 cm intervals, at Kabarsero (figure 8.2; plate 8.1). Member C was also sampled in the Kerio Valley, at Barwesa (fig. 8.3). The sediments at this latter locality lack diatoms, probably reflecting the highly saline nature of the palaeolake suggested by Pickford, on sedimentary grounds. Diatoms were recovered from both Members C and E at Kabarsero.

Plate 8.1



Members C to E of the Ngorora Formation at Kabarsero. Member C consists of white, laminated, lacustrine shales. Member D is composed of buff coloured fluvial sands, and forms the pyramid-like mound in the centre of the photo. Member E includes white, laminated, lacustrine shales, and occasional diatomites. This latter Member is partially hidden by Acacia thorn scrub.

The Ngorora diatoms are amongst the oldest recorded from the Kenya Rift. Several Melosira spp. occur. Diatoms are usually found in low numbers and are absent from large parts of Members C and E. However, in the latter Member they occasionally form diatomites.

Two assemblages are common, although intermediate types also occur.

Assemblage (i)

DOMINANT : Melosira granulata-agassizi
SUBDOMINANT : M. agassizi var malayensis, M. granulata

Assemblage (ii)

DOMINANT : Melosira granulata

These Melosira are somewhat archaic and posses coarser ornamentation than their modern counterparts (p. 269). For example, M. granulata resembles the coarsely ornamented M. praegranulata described by Servant (1973). Other, less common, diatoms include: M. granulata var. angustissima form curvata, Synedra ulna, Fragilaria construens, F. brevistriata and Nitzschia spp..

Today, Melosira granulata occurs in lakes of moderate eutrophy, with alkalinities of mainly less than 8 or 9 meq /l, pH values of less than about 9, conductivities of less than 600 µmhos and with silica concentrations of more than 5 to 10 mg/l. The lack of diatoms in many parts of the Formation may reflect competetive exclusion by other algal groups, a lack of silica or alkalinities that were too high.

8(i)d The Mpesida Beds

The Mpesida Beds are dated at about 7 my (Pickford, pers. comm.). The sediment outcrop is restricted to the eastern side of the Tugen Hills. Tuffs dominate, but clays, silts and grits are also present. Several samples were collected near Yatya (fig. 8.3), but none contained diatoms. However, Pickford has noted the presence of Melosira near Koitugum.

8(i)e The Lukeino Formation

The Lukeino Formation has been examined by Bishop et. al. (1971), and by Pickford (1975, 1978). Pickford defined the Formation as, "A body of sediment and contained lavas deposited on trachytes and sediments of the Kabarnet Formation and capped by lavas of the Kaparaina Basalts Formation to the west and north-west of Lake Baringo".

The Formation is dated at about 6.5 my (Pickford, 1975). The sediments formed in an assymetric fault-controlled trough. Pickford divided the Formation into five Members, which are as follows (thicknesses taken from the type section at Kobuluk; fig. 8.3).

MEMBER	LITHOLOGY	ENVIRONMENT
D	diatomaceous & tuffaceous paper shales. 35 m	lacustrine
C	pumiceous tuffs. 12 m	lacustrine & subaerial
B	diatomaceous and tuffaceous silts, red marls. 50 m	lacustrine
A	red marls, channel sands and algal limestones. 15 m	subaerial

Samples were collected from Members B and D, at Kobuluk, which are richly diatomaceous. Two main assemblages can be recognised, which are as follow.

Assemblage (i)

DOMINANT : Melosira granulata (71-100%)

OCCASIONAL : Nitzschia frustulum, Melosira granulata var. angustissima, M. granulata var. muzzanensis, Navicula cryptocephala, Synedra ulna

The Melosira suggest a fresh to slightly saline and alkaline lake, with a pH of less than about 9. Assemblages with a higher than normal percentage of Navicula cryptocephala may reflect a nearby shoreline or shallower water.

Assemblage (ii)

DOMINANT : Synedra acus var. angustissima (71 to 80%)

SUBDOMINANT : Melosira granulata (1 to 22%)

OCCASIONAL : Synedra ulna and its variety aequalis, Fragilaria construens & var. venter, Nitzschia frustulum.

This assemblage is of planktonic character. Synedra spp. occur mainly in lakes with dissolved silica concentrations of between 10 and 30 mg/l (Gasse, 1975). The flora suggests that the water was warm and biologically productive.

Large parts of Members B and D include 'varve like' sediments. Normally, these consist of alternating bands of creamish white diatomite (0.8 to 1 mm thick) and dark grey diatomaceous clays (0.1 to 0.2 mm thick). These were examined for variations of diatom flora, with the following results.

Dark lamina (4.2×10^5 valves/g of sediment)

Melosira granulata	64%	(some broken)
Synedra spp.	14%	(a lot broken)
Nitzschia frustulum	8%	

Fragilaria construens var. venter 3%

Light lamina (1.8×10^{12} valves/g of sediment)

Melosira granulata 97%
Nitzschia frustulum 3%

The light laminae owe their colour to the abundance of diatoms, while the dark laminae have a high clay content (X-ray diffraction shows this to be smectite). The diatomites contain an almost monospecific flora, while the diatomaceous clays are dominated by two species, although M. granulata is the more common. Seasonal blooms may account for these differences, although variations in detrital input may or may not be involved.

8(i)f The Kaparaina Basalts Formation

This Formation is about 5.4 to 6.5 my old (Pickford, 1975). It is dominated by basalts. However, during phases of volcanic quiescence, weathering profiles and lacustrine sediments formed on the lava surfaces. These lake deposits are highly localised and one such sequence was examined near Pelion (fig. 8.3), where a maximum thickness of 3 m of diatomaceous silts crop out between lava flows. The samples contained a single assemblage which was as follows.

DOMINANT	: Fragilaria construens, F. construens var. venter
OCCASIONAL	: F. brevistriata, Synedra ulna, Melosira granulata and Cocconeis placentula

The flora probably reflects a shallow environment of fresh to slightly alkaline water.

8(ii) Pliocene sedimentation and diatoms of the Baringo district

The Pliocene Chemeron Formation crops out between the Tugen Hills and Lake Baringo (figs. 8.1 and 8.3). It is of uncertain age, but dated lavas indicate it to be older than 2 my and younger than 5.4 my (Bishop, 1972). The Chemeron Formation consists of lacustrine and fluvial deposits, with a maximum thickness of 230 m (Martyn, 1967). It rests unconformably on the Kaparaina Basalt Formation in the south, and on the Lukeino Formation in the north. Martyn divided the sequence into five Members, which are as follow.

MEMBER	LITHOLOGY	ENVIRONMENT
E	The Upper Tuffs. 6-30 m	lacustrine
D	The Upper Fish Beds. fluvial sands and gravels, lacustrine silts & diatomites. 80 m	lacustrine & subaerial
C	Lower Tuffs. 3-5 m	lacustrine
B	Lower Fish Beds. Silts, diatomites and rare fluvial sands. 100 m	lacustrine
A	Basal Beds. Fluvial sands and rare impure diatomites. 0-50 m	Subaerial

Several diatomites were sampled near Pelion (fig. 8.3). Two assemblages were recognised, which are as follow.

Assemblage (i)

DOMINANT : <u>Melosira granulata</u> (60 to 70%)

SUBDOMINANT : <u>Stephanodiscus astraea</u>, <u>S. astraea var. minutula</u>

OCCASIONAL : <u>S. hantzschii var. pusilla</u>

Today, these planktonic diatoms are favoured by slightly alkaline water (0.9 to 4.5 meq/l; Richardson, 1969). Melosira thrives at a pH of about 8, in water of high silica content (over 10 mg/l; Richardson, 1969). However, the presence of Stephanodiscus suggests that silica was not much over this figure.

Assemblage (ii)

DOMINANT	: Melosira granulata (45 to 80%)
OCCASIONAL	: Synedra ulna, S. ulna var. aequalis, S. rumpens, Cocconeis placentula, Epithemia argus, Melosira ambigua, Fragilaria pinnata & Stephanodiscus astraea

The flora contains a number of epiphytic and littoral diatoms, but is essentially planktonic. The greater number of littoral types suggests shallower waters than those represented by assemblage (i). The lack of Stephanodiscus spp. may reflect higher silica levels than were present in lakes dominated by the first assemblage.

Two diatomite samples were collected from the Kapthurin River (fig. 8.3). One sample, taken from 6 m above the base of the Lower Fish Beds (Member B) contained a flora similar to that of assemblage (i), but also included Melosira granulata var. angustissima (8%). The second diatomite was collected from the middle of the Upper Fish Beds (Member D). This was dominated by Melosira granulata and its variety angustissima , while Stephanodiscus astraea forms only about 3 to 4 %.

The diatoms suggest that the Chemeron lake was slightly alkaline, highly productive and contained moderate to high levels of dissolved silica. The waters were probably clear, with little sediment input during periods of diatomite formation.

8(iii) Pleistocene sedimentation and diatoms of the Baringo district

8(iii)a The Kapthurin Formation

The sediments of the mid- to late Pleistocene Kapthurin Formation lie to the south-west of Lake Baringo (fig. 8.1). The Formation was divided into five Members by Martyn (1969), which are as follow.

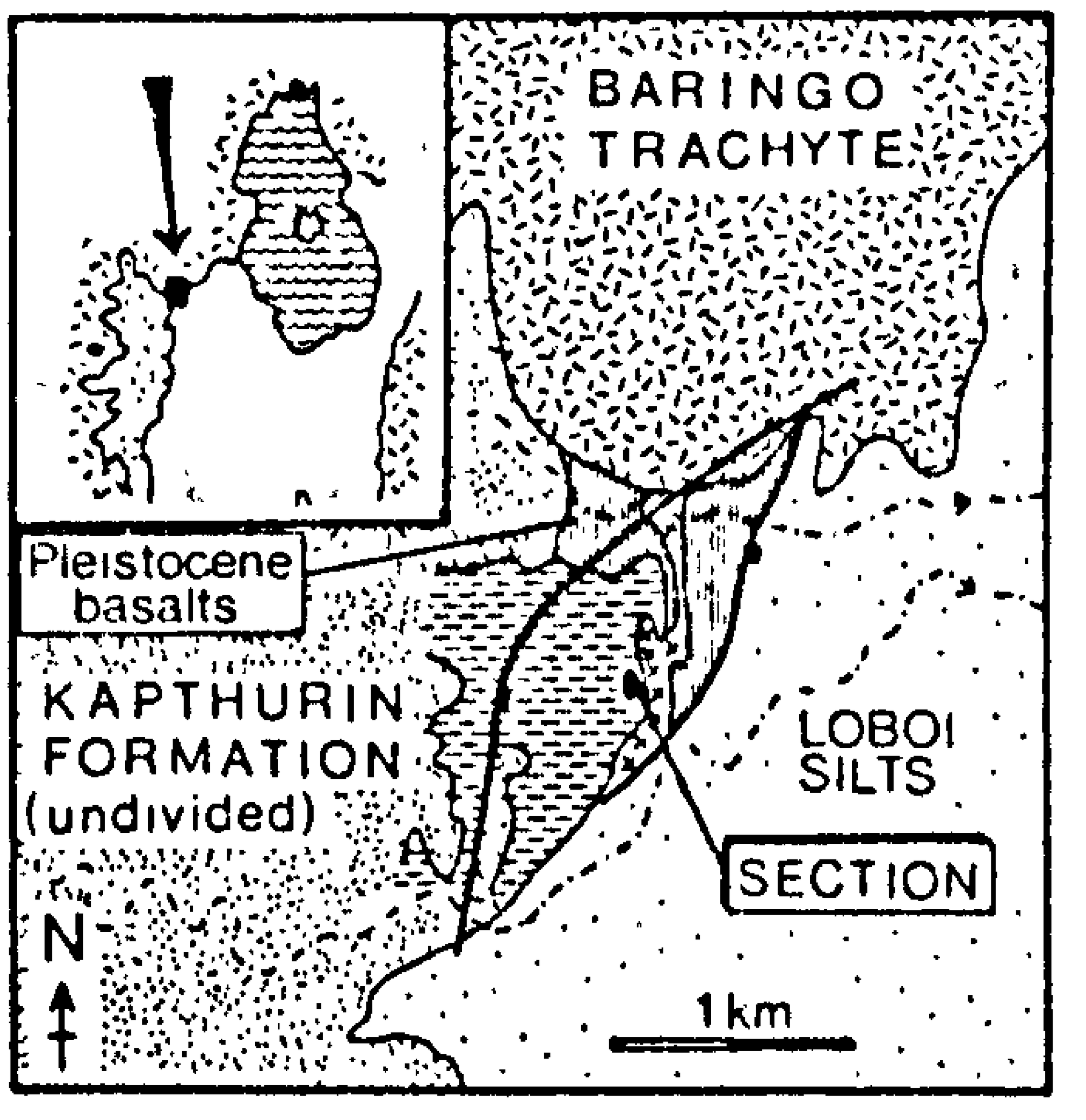
MEMBERS	LITHOLOGY
Upper Silts & Gravels	Fluvial silts, sands, gravels and boulders. 20 m
Bedded Tuff	Tuffs. 12 m
Middle Silts & Gravels	Fluvial silts, sands, gravels. Lacustrine red and black clays 40 m
Pumice Tuff	Pumice. 20 m
Lower Silts & Gravels	Fluvial silts, sands, pebbles. Lacustrine red and black clays 35 m

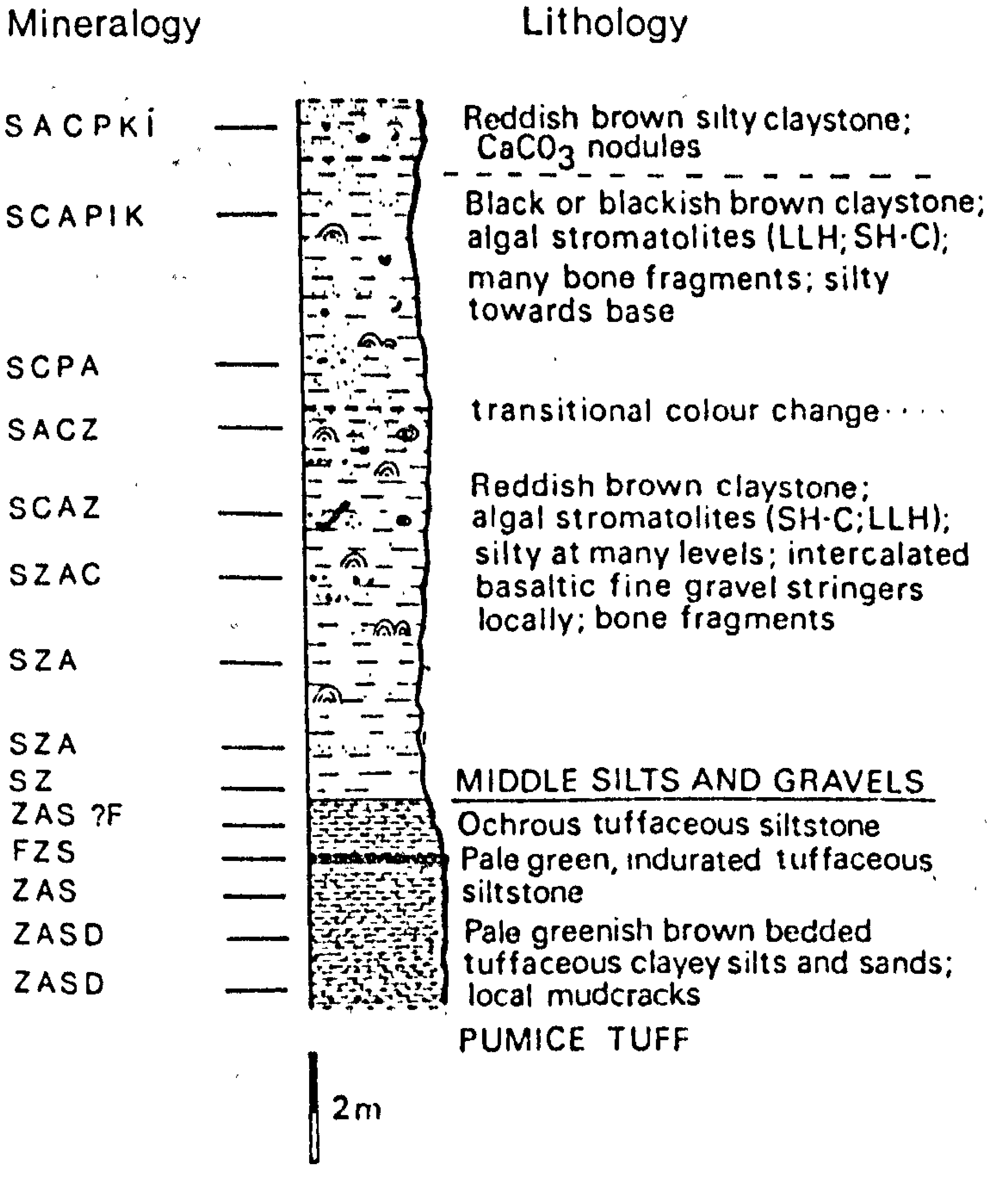
Both the Lower and Middle Silts and Gravels Members pass eastwards into red and black lacustrine clays, in the north -eastern part of the Kapthurin basin (fig. 8.4). Tallon reports the presence of oncolitic and laterally linked stromatolitic limestone at several levels within the clays. He suggests that the vertebrate fauna (possibly washed in) indicates a freshwater lake.

Several samples were collected from the lacustrine clay. No diatoms were found. However, X-ray diffraction shows the clays to be predominantly smectite (fig. 8.4). These sediments are rich in analcime, and contain minor amounts of calcite, dolomite and feldspar. A pale green, indurated

Fig. 8.4

Locality map and section of the lacustrine facies of the Kapthurin Formation





The map is simplified after Tallon (1978). The lacustrine facies outcrop is shown by the dashed line symbol, the lacustrine facies of the Pumice Tuff by small crosses. The principal mineralogy is shown at the appropriate level to the left of the section in order of decreasing abundance. Index to minerals: A: alkali feldspar; C: calcite; D: dolomite; F: fluorite; I: illite; K: kaolinite; P: plagioclase; S: smectite; Z: analcime.

tuffaceous siltstone, within the red clays contains abundant fluorite as well as analcime. The fluorite crystals are euhedral, up to 2 mm long and almost certainly authigenic. The association of authigenic analcime, fluorite and dolomite suggests a saline and alkaline lake, rather than the fresh one indicated by Tallon (1978). This area of clay lithofacies probably represents an arm of a 'central rift lake'. Much of the sediments formed in this lake must now be buried beneath younger deposits in the downfaulted axis of the Baringo Graben. Kapthurin sedimentation was terminated by late Pleistocene grid faulting (Tallon, 1978).

8(iii)b The Ilosowuani Beds

Pleistocene sediments crop out near the village of Logumukum (fig. 8.5, plate 8.2), to the south-east of the Baringo Graben. They consist of a 3 m sequence of silt, clay and grit that is faulted and tilted to the east at about 12°. The sediment succession is given in figure 8.6. The Ilosowuani Beds are unconformably overlain by Holocene strandline sediments. Both groups of deposits were mapped as 'Logumukum sediments' by McCall (1967), who considered them to be Holocene. Farrand et. al. (1967) recognised the two groups as being of different age.

The older, faulted sequence is here termed the Ilosowuani Beds. Six lithological units can be recognised at the type section (fig. 8.6). With the exception of the 'white laminated tuff' of unit 3, the lateral extent of the sediments is difficult to determine, due to poor exposure.

The oldest exposed unit (numbered 1 in fig. 8.6) is a sequence of pale brown, structureless or weakly laminated silts, that are moderately well sorted and locally tuffaceous. They are at least 98 cm thick and probably rest unconformably on Hannington trachyphonolites (Griffiths,

Plate 8.2

View looking west from the Ilosowuani horst (which lies to the south of Lake Baringo). Pleistocene, lacustrine, fluvial and colluvial sediments (Ilosowuani Beds) form the eroded knoll, and underlie much of the surface. The line of white sediments (Kokwob Formation), in the middle distance, represent an early Holocene strandline, and are composed of shelly material.

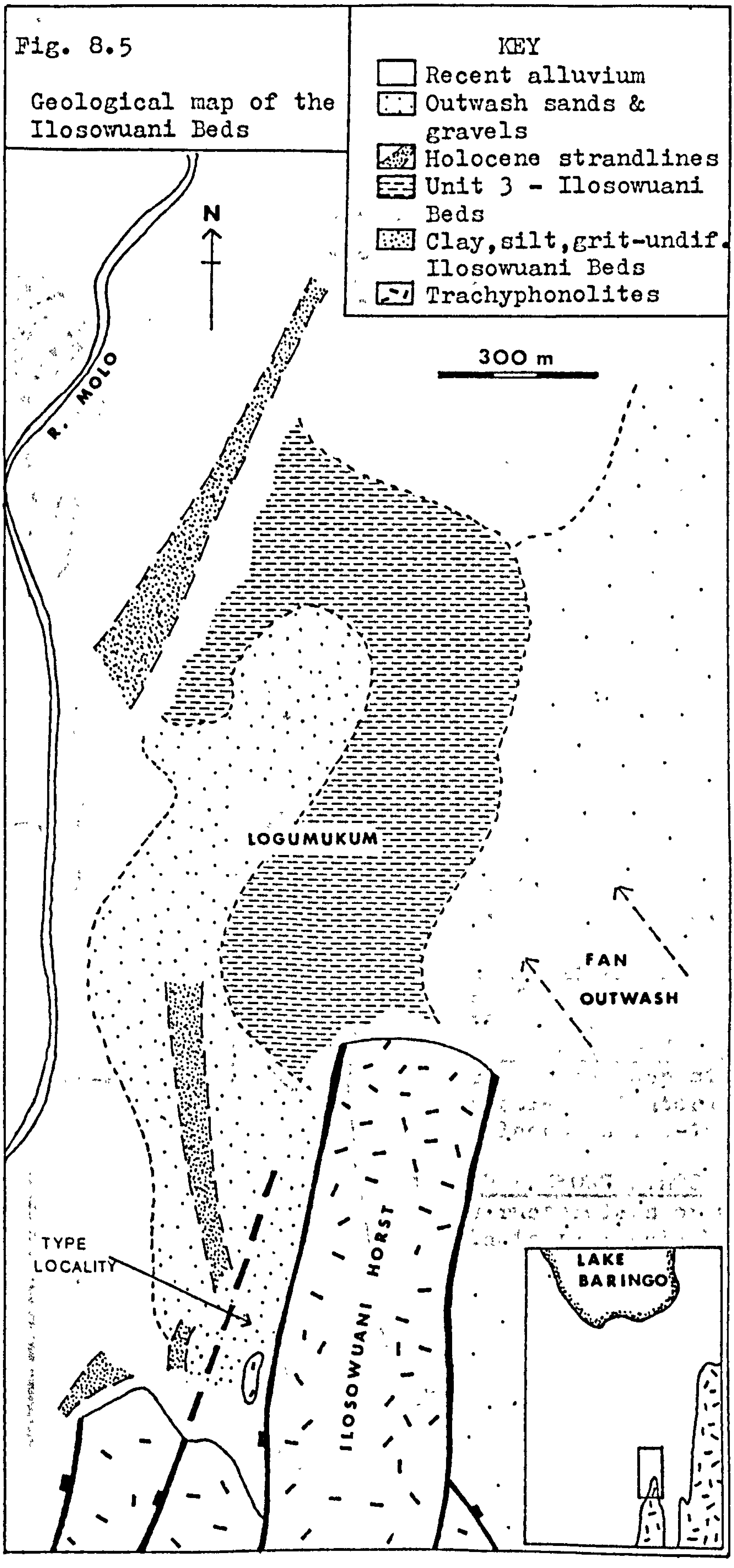
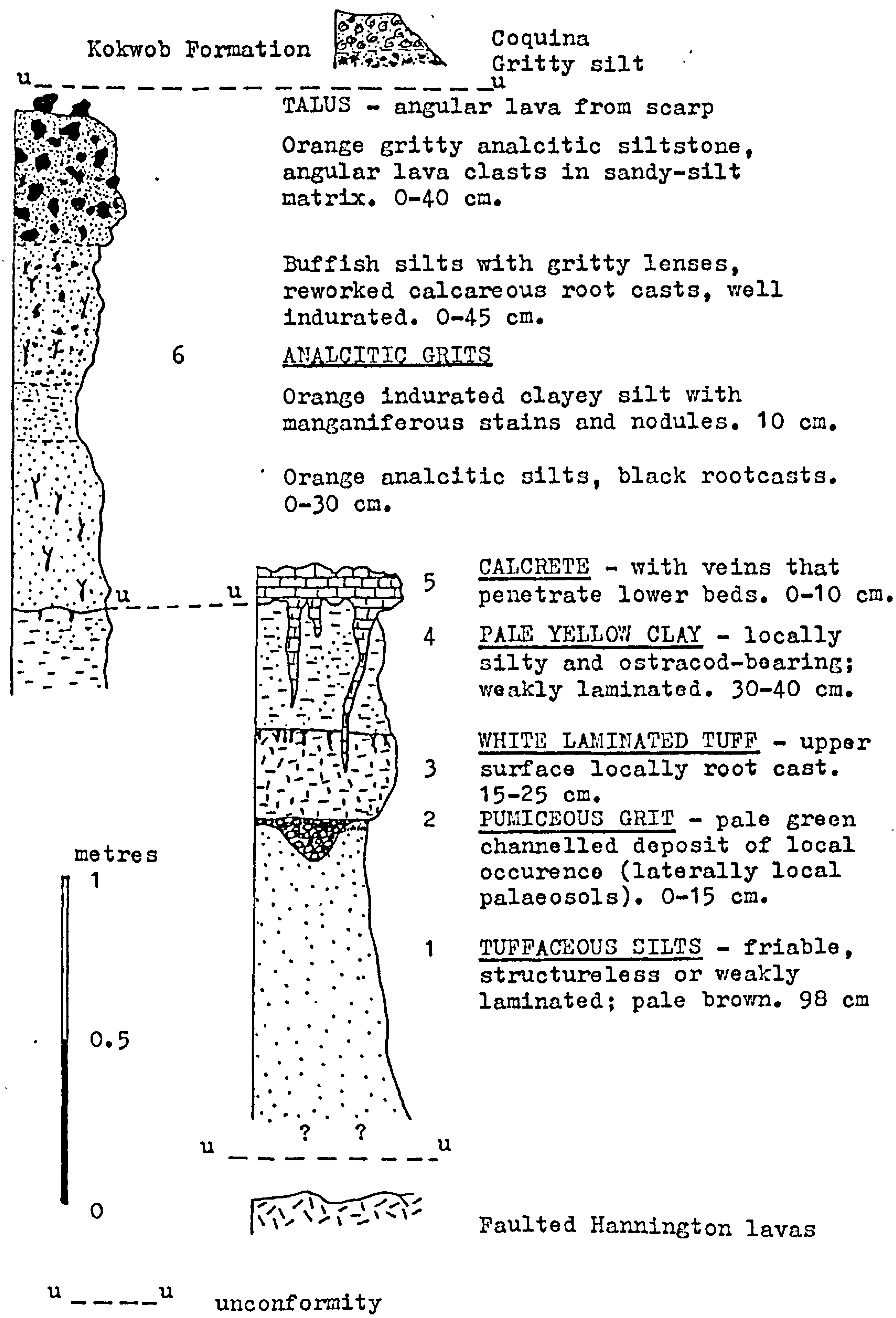


Fig. 8.5
Geological map of the Ilosowuani Beds
KEY
Recent alluvium
Outwash sands & gravels
Holocene strandlines
Unit 3 - Ilosowuani Beds
Clay,silt,grit-undif. Ilosowuani Beds
Trachyphonolites
N
300 m
R. MOLO
LOGUMUKUM
FAN
OUTWASH
TYPE
LOCALITY
ILOSOWUANI HORST
LAKE
BARINGO

Fig. 8.6 Section through the Ilosowuani Beds



1977). The lack of structure in this unit suggests that the deposits might be of floodplain and/or colluvial origin.

Unit 2 is a green pumiceous grit found in channels. A thin grey-brown, organic palaeosol, in the upper 5 cm of the underlying silts, indicates pedogenesis.

The white laminated silt of unit 3 was termed a diatomite by previous workers. Petrographic examination shows it to be a fine tuff. The well-developed fine laminae suggest deposition in a lake (part of the central rift lake mentioned earlier ?). Root casts in the top of this unit suggest lake marginal vegetation.

Unit 4 consists of calcareous, pale yellow clays (X-ray diffraction shows this to be montmorillonite), which are locally tuffaceous, silty and ostracod bearing. The siltier lithofacies also contains diatoms. Four species dominate. These are: Rhopalodia gibberula var. sphaerula, R. gibberula var. rupestris, Anomoeoneis sphaerophora var. guntherii, and Surirella ovalis. Other diatoms present include: Thalassiosira rudolfii, Cyclotella meneghiniana, Anomoeoneis sphaerophora var. polygramma, Epithemia argus, Synedra ulna, Cocconeis placentula, Navicula pupula, N. grimmei and Fragilaria brevistriata. Today, such a flora is usually found in shallow, highly alkaline (up to about 80 meq/l) water.

Following lake-retreat and erosion, only subaerial deposits formed. Unit 4 is locally capped by a calcrete, which R. Renaut (pers. comm.) considers to be of pedogenic origin. This gives way, towards the scarp of the Ilosowuani Horst (fig. 8.5), to reddish-brown grits. Analcime forms up to 40 % of these grits (Renaut, pers. comm.), and may have formed by reaction of clay and volcanic glass with sodium carbonate solutions. It seems probable that both the calcrete and zeolitisation of the grits are related to an arid, late Pleistocene (?), phase.

The Ilosowuani Beds predate the early Holocene strandlines, mentioned earlier, and postdate the Hannington trachyphonolites, dated between 1 and 0.3 my elsewhere. To the west of Lake Baringo pumice grits occur in the Kampi-ya-Samaki Beds, which also predate early Holocene sediments. The deposits rest on the Baringo Trachytes (dated at 0.23 my). Although the age of the Ilosowuani Beds is uncertain, its stratigraphic position suggests that it is of late Pleistocene age. It may be equivalent to the upper part of the Kapthurin Formation.

A sequence of probable late Pleistocene sediments also occurs to the east of Lake Baringo. These are known as the Loiminange Beds (Carney, 1972), and may be laterally equal to the Ilosowuani Beds. The sequence recorded by Carney is as follows.

a) Shingle deposits. 1-2 m
b) Tuffaceous silts and clays. 3-5 m
c) Conglomerates and silts. more than 2 m

The extent or duration of any late Pleistocene lake is imprecisely understood. The volcanics of Korosi, to the north of Lake Baringo, have not been dated. However, it is probable that this 'barrier' existed during the late Pleistocene. The diatoms and mineralogy of the Pleistocene sediments suggest that this lake was at least periodically saline and alkaline. Its southern boundary is even less certain, it may have continued into the present Bogoria basin, but as yet no data is available to confirm or deny this. It would seem that the fluvio-lacustrine Loboi silts (fig. 8.1; p.246) advanced across the area between Lakes Baringo and Bogoria, both before and after the formation of early Holocene strandlines, and that they are in part of late Pleistocene age.

8(iv) Late Cenozoic lakes and the factors influencing sedimentation in the Baringo district

8(iv)a Summary of the palaeochemistry and palaeogeography of the major late Cenozoic lakes

Figure 8.7 shows the inferred palaeochemistry of several major lakes that have existed in the Baringo district during the last 12 my. The Miocene and Pliocene lakes, at their maximum extent, all had a similar chemistry, with moderate pH, low alkalinity and low salinity. Silica appears to have been more variable, possibly in response to intermittant volcanism. The Pleistocene 'central rift lake' had a much higher pH, alkalinity and salinity, at least periodically. Dissolved silica concentrations were probably high. All,except the Pleistocene lake,appear to have been biologically highly productive during part, or all of their existence. The probable palaeogeographic settings of these lakes, at their maximum extents are also shown in figure 8.7.

8(iv)b Tectonic influences on sedimentation in the Baringo district

Faulting and graben subsidence are primarily responsible for the initiation of lake basins in rift valleys. In this area, the major lacustrine units all developed within the main rift axis. Small graben basins also occur at the rift margins, in which localised deposition takes place.

Subsidence has been of major importance in allowing thick sediment sequences to build up. The Muruyur Beds are up to 300 m thick, while the Ngorora Formation is up to 400 m. Today, Lake Baringo lies in a downwarp within the main axis of the Kenya Rift (King, 1978).

Sedimentation in the middle Miocene Ngorora basin has

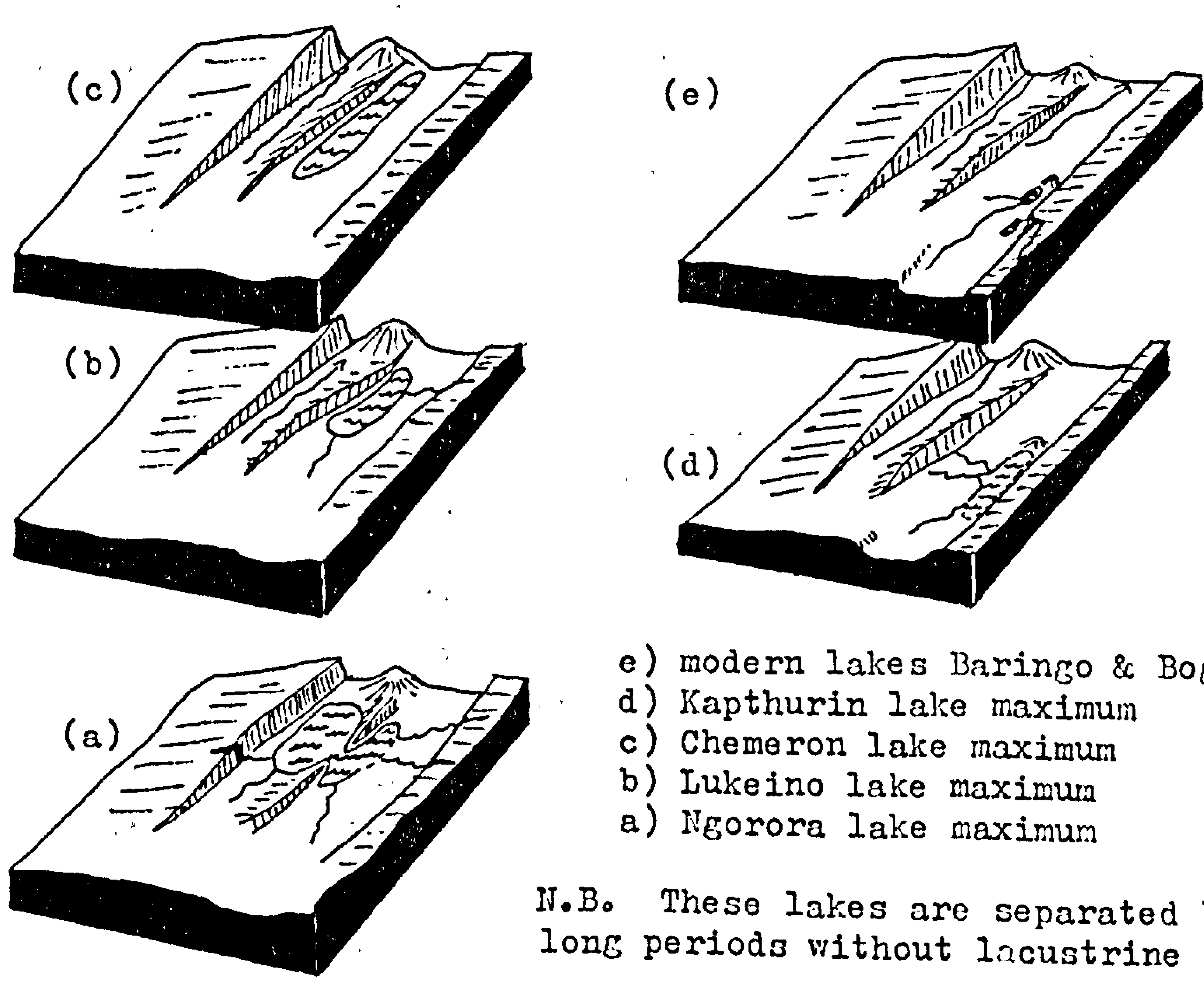
Fig. 8.7
The approximate palaeochemistry and palaeogeography of late Cenozoic lakes in the Baringo district.

Approximate palaeochemistry of the late Cenozoic lakes at their maximum extent

LAKES (named after the sed. unit)	pH	alk. meq/l	sal. ‰.	SiO_2 mg/l	Nutrient status
modern L. Baringo	8-9	5-6	0.3-0.7	15-30	high
Pleistocene 'central rift lake'					
L. Ilosowuani	9+	50-80	2-16	high	low
L. Kapthurin	9+	>100	high	?	?
Pliocene L. Chemeron	7-8.5	ca.5	<2	ca.10	moderately high
Miocene L. Lukeino	7-8.5	ca.5	<2	10-30	high
Miocene L. Ngorora	7-8.5	ca.5	<2	>10	moderately high

All except L. Kapthurin, based on diatom evidence, using ecological data in Richardson, 1969; Gasse, 1975 and Hecky & Kilham, 1973. L. Kapthurin based on mineralogy, and chemical data in Cerling, 1979.

The approximate location of major lakes in the Baringo district since the middle Miocene. (based on Martyn, 1969; Pickford, 1975 and Tallon, 1978).



e) modern lakes Baringo & Bogoria
d) Kapthurin lake maximum
c) Chemeron lake maximum
b) Lukeino lake maximum
a) Ngorora lake maximum

N.B. These lakes are separated by long periods without lacustrine sed.

been closely related to fault movements by Pickford (1978). Shifts along north to south-trending faults, that bisect the Ngorora basin, were responsible for the initiation of major lacustrine sedimentation during Member C times (p.2 49). Three separate lakes formed, with conditions ranging from fresh to saline and alkaline. Pickford reports that after contraction, a further lake expansion occurred during Member E times. This lake crossed the now subdued and tectonically less active Tugen Hills fault divide (fig. 8.7). Renewed faulting and uplift of the Tugen Hills again split the basin into two, prior to its complete elimination.

Tectonism can also play a role in influencing the style of sedimentation, as well as basin formation. Numerous examples exist in the Baringo district, amongst which the following can be cited. Uplift along the Saimo fault (one of the many north to south trending faults of the Tugen Hills) during the Pleistocene, resulted in the accumulation of the thick alluvial sediments of the Kapthurin Formation (Tallon, 1978). Faulted lavas at the north end of modern Lake Baringo, which has no surface outlet, allows seepage and the maintenance of a freshwater lake, in which only detrital sediments dominate. In contrast, Lake Bogoria, which also has no surface outlet, has no or only limited subsurface seepage, and is highly saline and alkaline. As a result, evaporites are forming along the centre of the lake (Tiercelin, pers. comm.).

8(iv)c Volcanic influences on sedimentation in the Baringo district

The Baringo district, within its rift valley setting, has a northerly-falling slope, which seems to have existed for much of its history (Pickford, 1978). Volcanoes have formed important downslope barriers. During the Miocene, the Tiati volcanics partly 'dammed' the Ngorora lake. Today, Lake Baringo is also dammed, but this time by Korosi volcano. This combination of volcanism and regional slope has been of major importance in the formation of lake basins.

Volcanism may also be important in causing the cessation of lacustrine sedimentation. This can operate by infilling the basin itself, or by drainage diversion and so reduction of water input to the lake.

8(iv)d The role of climate in influencing sedimentation

Although climatic changes probably contributed to the expansion and contraction of the late Cenozoic lakes, its precise role is often difficult to evaluate. This is because of the confusing influence of tectonism and/or volcanism.

In cases where 'varve like' sediments develop (such as in the Lukeino Formation), this is almost certainly due to climatic factors. Arid climates can be suggested for the low lake levels of the latest Pleistocene, and are probably related to the development of calcretes and analcime during this period. Changes in lake level, caused by climatic changes, are more easily discerned for the Holocene. The relationship between Holocene sedimentation and climate is examined in more detail in chapter 9.

8(v) The evolution of Melosira granulata

The sediments of the Baringo district contain the diatom Melosira granulata, and record its evolution since the middle Miocene. See appendix III for photos of this species.

Hustedt (1930) describes three modern morphological types of M. granulata (types α, β and γ), which are defined according to the coarsness of the ornamentation. Cultural experiments by Kilham and Kilham (1975) have shown that it develops into the variety angustissima as part of the species life cycle. Gasse (1975) noted in the lake sediments of the Afar region (Ethiopia), that different morphotypes seemed to be related to the age of the deposits in which they were found. She observed that types α and β were common in the Holocene, while in older sediments the species differed in general form and had a coarser ornamentation (and has been named Melosira praegranulata).

For comparative purposes the measurements used by Gasse were adopted here. The results are shown in table 8.1, which also includes data from East Turkana. The figures in this table are based on measurements of 100 individuals. Although there is variability within each group of figures, their means (as shown in the table) do show several trends. Major evolutionary changes occurred near the Plio-Pleistocene boundary. The main changes are as follows:

(i) An increase in the valve height to diameter ratio
(ii) Increasingly finer ornamentation
(iii) A reduction in frustule thickness and col height

These trends are shown diagramatically in figure 8.8. The ancient forms of M. granulata (M. praegranulata) approach in morphology its modern variety valida, as first pointed out by Gasse (1975). In older deposits M. granulata shows less variability than it does today.

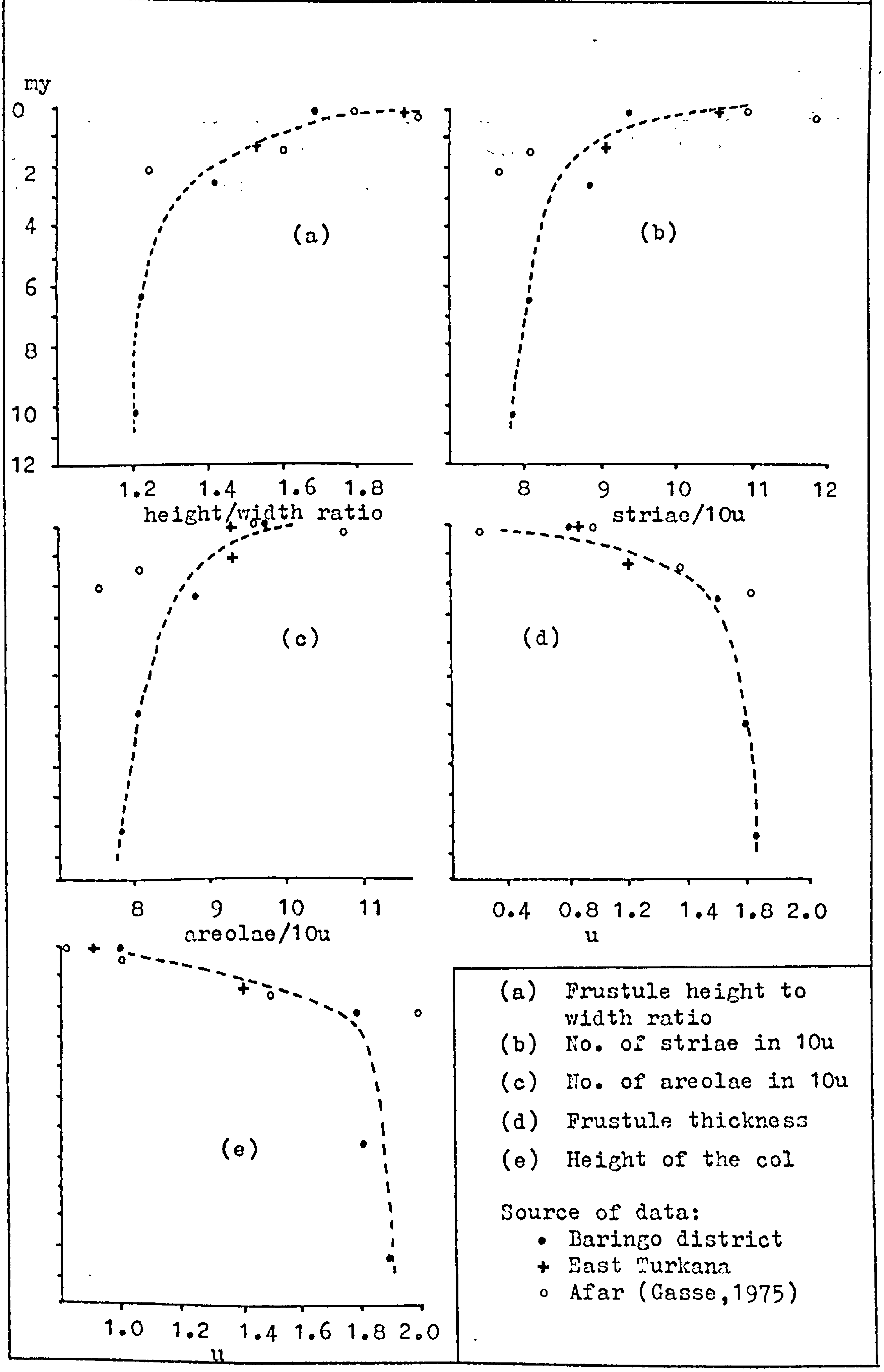
Table 8.1 The morphology of <u>Melosira granulata</u> during the late Cenozoic.

Age and location of sample	H	D	S	A	T	C
Baringo District						
Holocene (Kokwob Formation)	16.2	8.9	9.4	9.7	0.9	1.0
Plio-Pleistocene 2-5my. (Chemeron Formation)	13.1	9.3	8.9	8.9	1.8	1.8
Pliocene ca. 6.5my. (Lukeino Formation	13.0	11	8	8.5	1.9	1.8
Late Miocene 9-12my. (Ngorora Formation)	12.0	10	7.8	8.0	2.0	1.9
Afar						
Holocene	15.4	8.5	11	9.6	1.0	0.8
Upper Pleist.	16.8	7.7	12	10.6	0.2	1.0
Lower Pleist.	16.0	10	8.0	8.0	1.5	1.5
Plio-Pleist.	13.2	11	7.3	7.4	2.1	2.1
East Turkana						
Holocene	15.0	8.0	10	9.4	0.9	0.9
Middle Pleist.	15.5	9.8	9	9.4	1.2	1.4

H: Height of the valve
D: Diameter of the valve
S: Number of striae in 10u
A: Number of areolae in 10u
T: Frustule thickness.
C: Height of the col.
(measured in microns unless otherwise stated)

Fig. 8.8

Evolutionary trends in *Melosira granulata* (Ehr.) Ralfs.



Melosira agassizi shows similar trends in ornamentation and frustule thickness. It becomes increasingly difficult to separate this species from Melosira granulata in older deposits, which suggests a common origin. Even today, it might be argued that there is a continuous range from M. granulata through M. granulata-agassizi to M. agassizi and that we may be recognising 'end members' of a continuous population.

CHAPTER 9

HOLOCENE SEDIMENTATION IN THE BARINGO AND BOGORIA BASINS

9(i) The Holocene sediments of the Baringo basin

9(i)a Introduction to the Holocene sediments of the Baringo and Bogoria basins

Chapter 8 demonstrated that lacustrine sedimentation has taken place during several quite distinct periods, in this part of the Kenya Rift. By the Quaternary, lacustrine and lake marginal deposits were being formed in about the same area as the modern Baringo and Bogoria grabens. During the Holocene, several distinctive sedimentary units were laid down, and it is these that form the subject of this chapter. Their distribution is shown in figure 9.1, and their stratigraphic relationships in figure 9.2.

The deposits to be discussed include the early Holocene lacustrine sediments that make up the Kokwob Formation, and more recent deposits obtained from a core in the modern Lake Baringo. Fluvial and fluviolacustrine sediments belonging to the Loboi silts, will also be described. Finally, the various lithofacies found in the Bogoria graben will be examined. Together, these deposits record the latest Pleistocene/Holocene history of Lakes Baringo and Bogoria, and at the end of this chapter an early Holocene palaeogeographical reconstruction is attempted.

9(i)b Definition and introduction to the Kokwob Formation

The Kokwob Formation consists of lacustrine and marginal lacustrine sediments of latest Pleistocene/ Holocene age, that are restricted to the Baringo basin,

Fig. 9.1 The geology of Lakes Baringo and Bogoria (based on E.A.G.R.U. maps and personal observation)

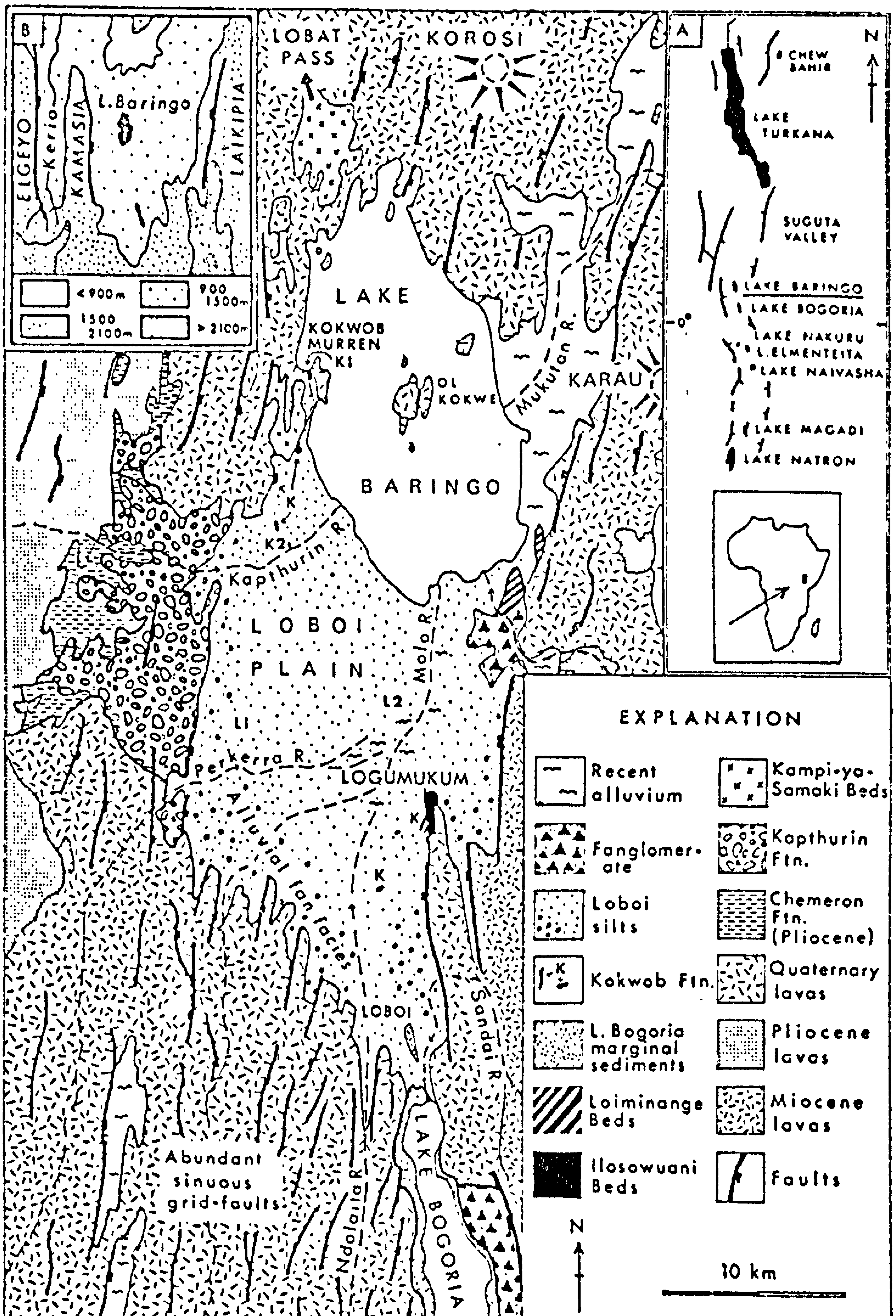
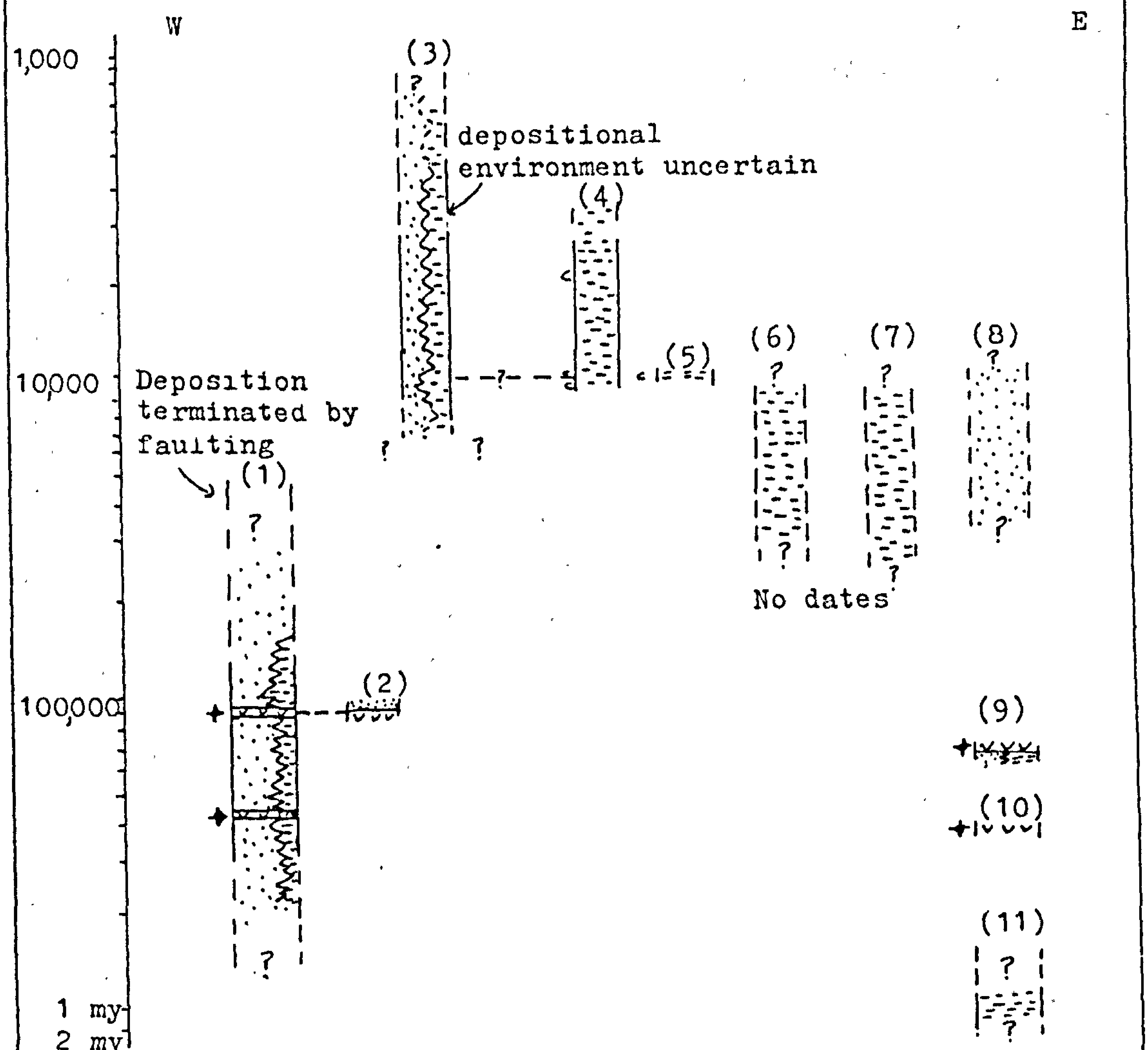


Fig. 9.2 Chronology and correlation of Quaternary sediments in the Baringo Basin



1. Kapthurin F.
2. Kampi-Ya-Samaki Beds
3. Loboi Silts
4. Kokwob F. (Kokwob Murren)
5. Kokwob F, (Logumukum)
6. Ilosowuani Beds
7. Loiminange Beds
8. Mukutan Beds
9. Karau F.
10. Chesowanja F.
11. Chemoigut F.

N.B. logorithmic time scale

uncertain time span
--- correlation
subaerial sed.
lacustrine sed.
volcanics
+ K-Ar dated
c ^{14}C dated

and which rest unconformably on volcanics and older sediments.

Holocene raised beaches in the Baringo area, which are part of the Kokwob Formation, were first examined by Nilsson (1932), who also noted the existence of an overflow channel to the north of the lake. Later workers have been unable to confirm this outlet (Bishop and Young, pers. comm.). Fuchs (1934) also recognised lake deposits in this basin. Martyn (1969) noted the existence of shell bearing silts around the lake. The sediments were reassessed by Bishop, Buckland and Spooner (1969), who mapped several Kokwob localities and designated a type section at Kokwob Murren. Tallon (1976) briefly reported the Holocene deposits in his thesis.

Outcrops are discontinuous. On the western lake margin, there are several inliers of early Holocene sediment in younger, eastward advancing, fluvial silts (fig. 9.1). Kokwob strandlines occur near the village of Logumukum, in the south-east of the basin, while small patches of mollusc-bearing silts are found near the Baringo-Bogoria watershed. Other outcrops are preserved in palaeo-embayments.

9(i)c <u>The type section of the Kokwob Formation</u>

The type locality, as designated by W.W. Bishop (pers. comm.), lies at Kokwob Murren (fig. 9.3; plate 9.1), near the village of Kampi-ya-Samaki. The sediments are preserved in a north to south trending graben. Here, the Kokwob Formation rests unconformably on Baringo Trachyte and the Kampi-ya-Samaki Beds (laterally equivalent to part of the Kapthurin Formation; fig. 9.2), with primary dips of between 2 and 8^{o} to the north. High-level beach sediments have been levelled at 985.8 m O.D. (15.85 m above 1969 lake level) by Bishop (Bishop, Buckland and Spooner, 1969). A cross section through the deposits is

Plate 9.1

View looking south-east, at Kokwob Murren (western margins of Lake Baringo). Light coloured deposits, forming the low ground, are Kokwob Formation silts and coquinas. This area once formed an embayment of an expanded Lake Baringo.

shown in figure 9.3. Six lithological units can be recognised (fig. 9.4, section K1), each of which will be briefly described in the following paragraphs.

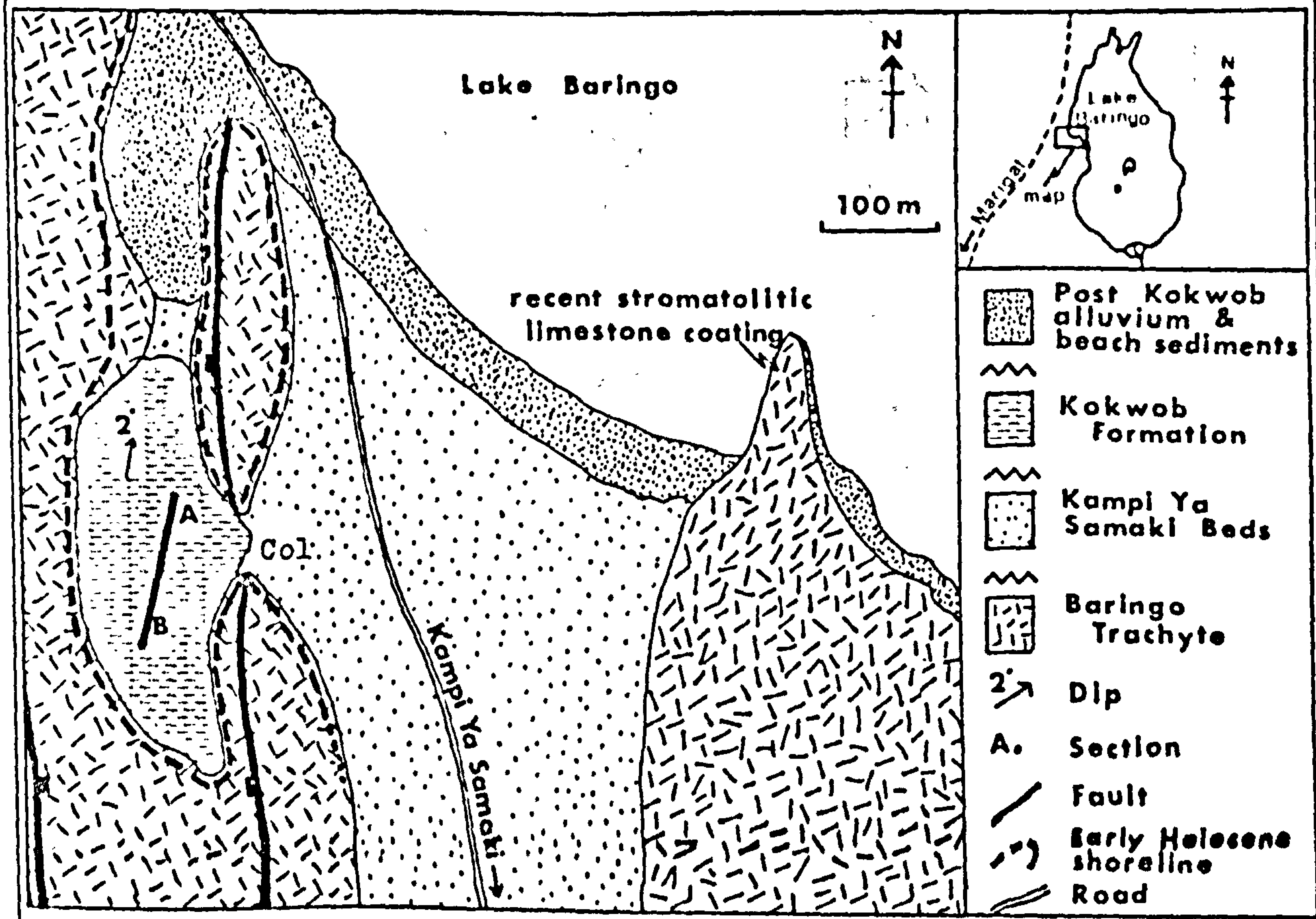
Unit 1 consists of up to 30 cm of friable grey silts, which contain a few molluscs, but no diatoms. This unit is restricted to the centre of the outcrop and rests unconformably on a palaeosol (part of the Kampi-ya-Samaki Beds).

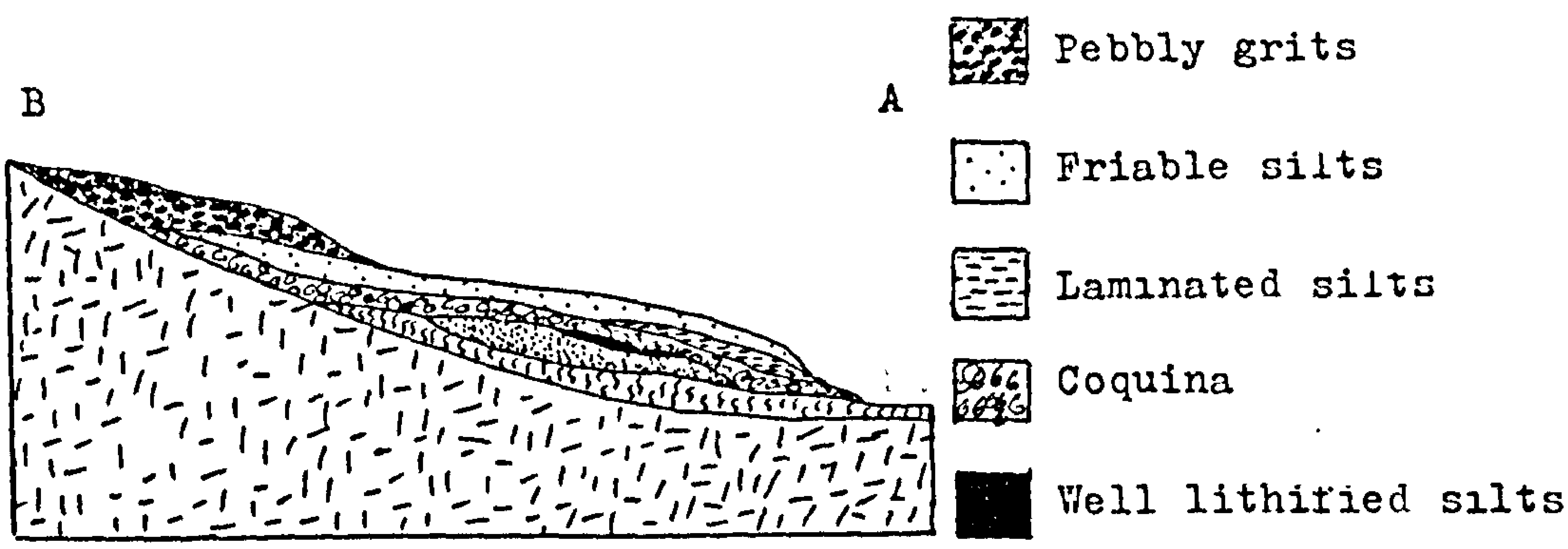
Unit 2 is composed of up to 25 cm of lithified, laminated, white silts, containing molluscs. It is even more laterally restricted than unit 1. Epiphytic diatoms, such as Cocconeis placentula dominate in this highly diatomaceous deposit (fig. 9.5). Amongst the planktonic species present, Melosira granulata is the most common, and probably represents the dominant diatom of deep waters.

The succeeding shell bed (unit 3) has been observed at several localities. The bed which is 5 to 20 cm thick, contains abundant Melanoides tuberculata and Corbicula spp.. Ostracods and fish bones are also present. The matrix is composed of comminuted shell debris and diatomaceous, feldspathic silts (plate 9.2). Loose grain mounts, examined by X-ray diffraction, show that sanidine dominates, while minor amounts of montmorillonite and plagioclase are also present. Other minerals identified include calcite, nepheline, aegerine, aegerine-augite and an amphibole. Basalt and trachyte fragments are common. Locally, unit 3 forms the basal deposit of the Formation. Diatoms are common, with the genus Epithemia more common than Cocconeis. E. sorex is the dominant species. The modern distribution of these diatoms suggests that this unit reflects an increase in littoral vegetation.

Unit 4 contains up to 40 cm of laminated white silts, which thicken lakewards and thin landwards. It contains few molluscs, but numerous diatoms. The flora is dominated by Cocconeis and Epithemia. Among the latter E. sorex has

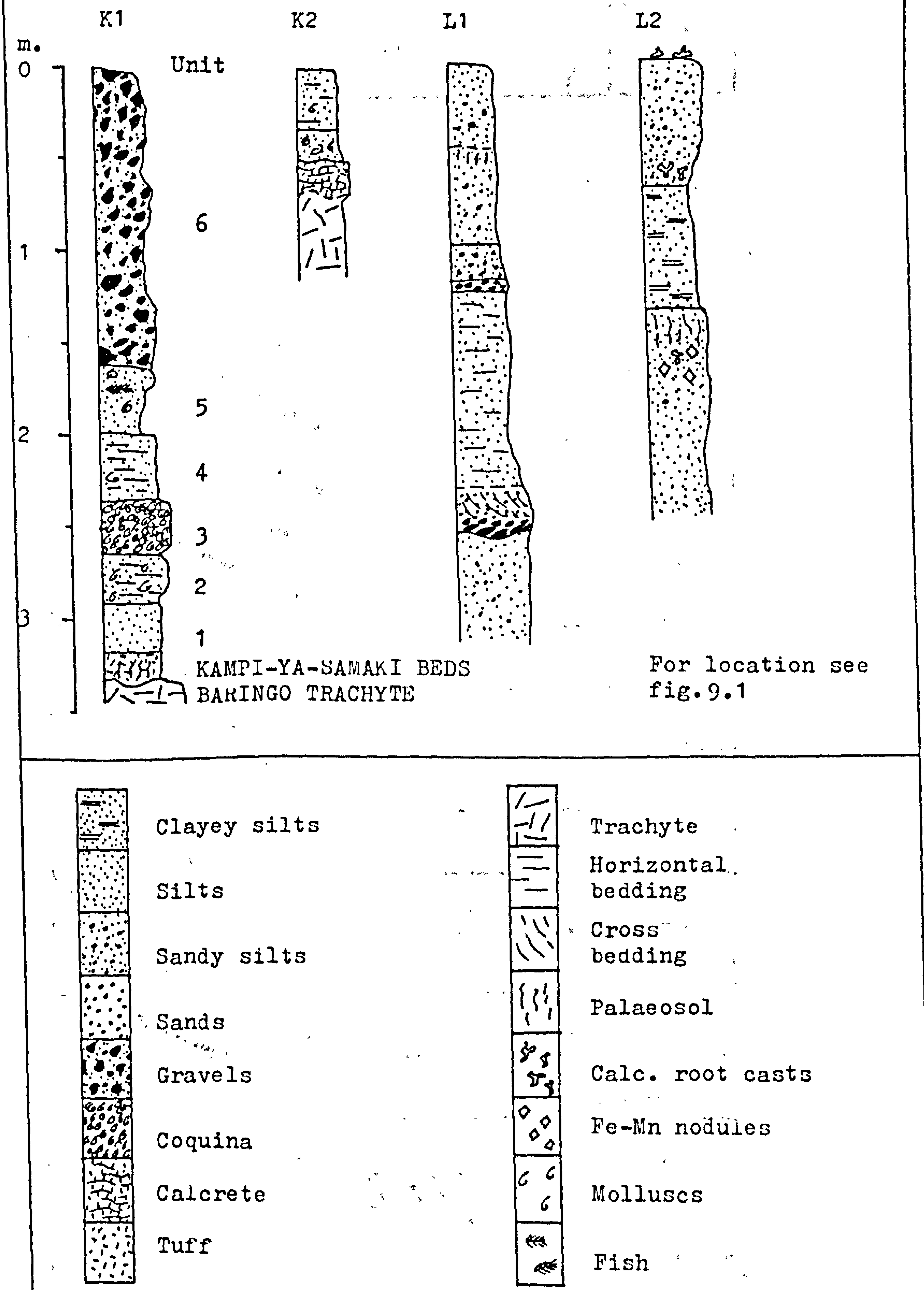
Fig. 9.3 Geological map of the West Bay area, Lake Baringo





Geological sketch section along stream

Fig9.4 Lithostratigraphic sections of the Kokwob Formation (K1, K2) and the Loboi silts (L1, L2)



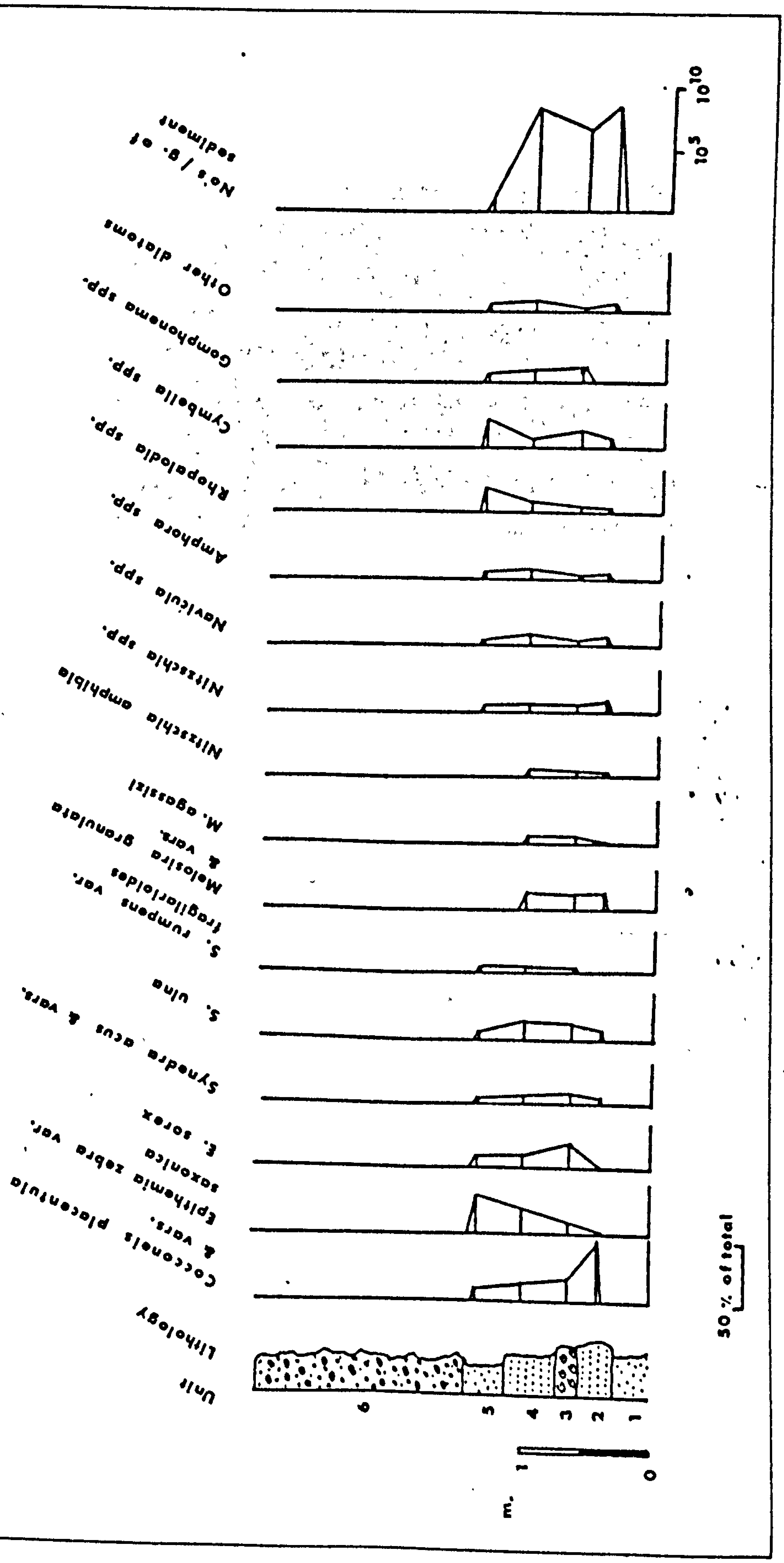
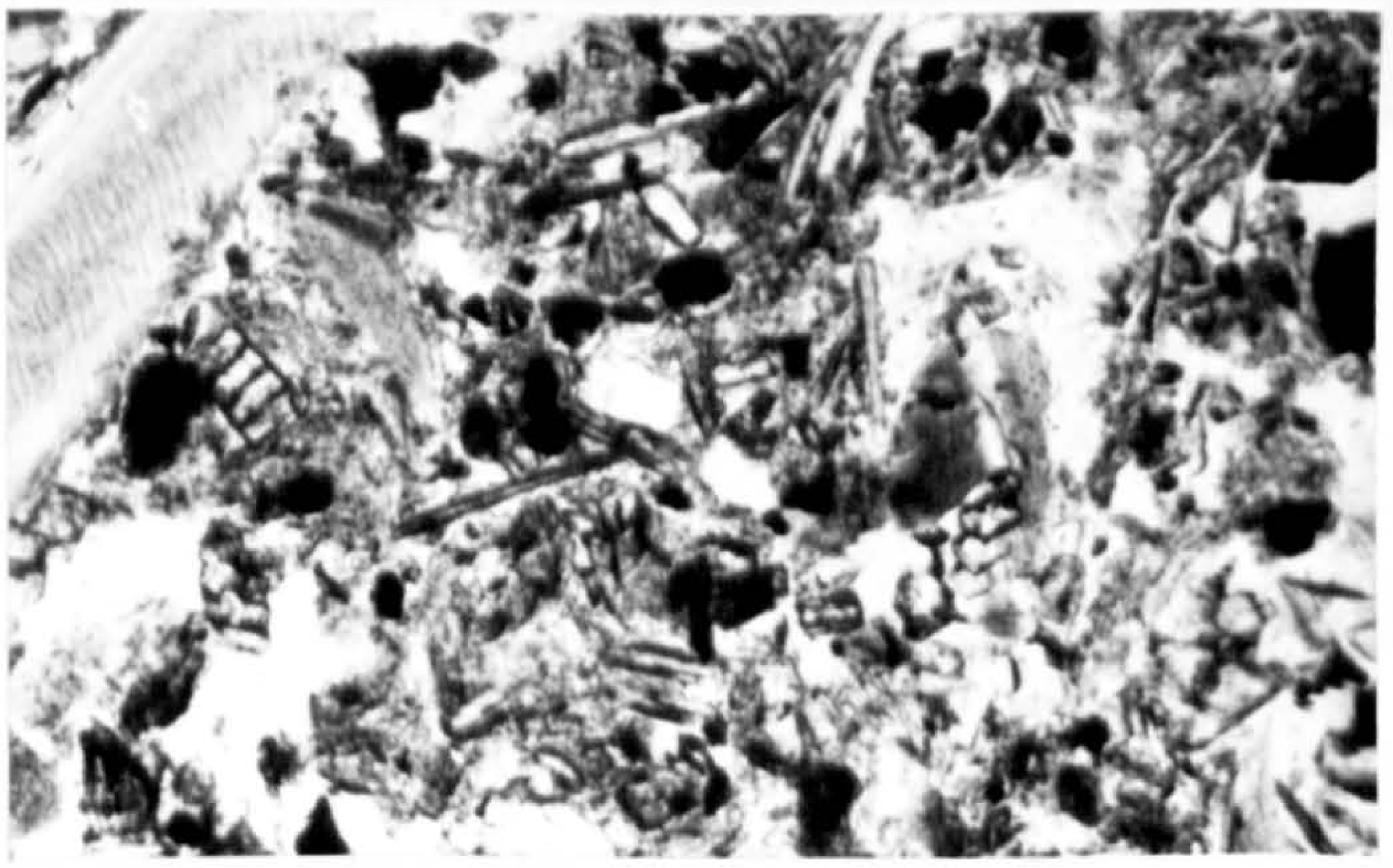


Fig. 9.5 Diatom stratigraphy of the Kokwob Form.

Plate 9.2



Thin section of the Holocene silts of the Kokwob Formation. Photographed at x 63 magnification (with a photographic enlargement of x2.5). Abundant diatoms can be seen, which include Rhopalodia, Fragilaria, Terpsinoe and Melosira species. A large shell fragment occurs in the upper left corner. The sediment was unconsolidated, and was impregnated with araldite prior to sectioning.

declined and is replaced mainly by E. zebra var. saxonica. The lake was probably shallow at this site, and again contained numerous littoral reeds.

Unit 5 consists of up to 30 cm of grey silts, which contain molluscs, fish bones, and infrequent diatoms. The diatom flora is dominated by Epithemia zebra var. saxonica, Cymbella ventricosa and Rhopalodia gibberula.

Up to 170 cm of pebbly grits constitute unit 6. Small lava pebbles (less than 1 cm) are abundant, while rare shells and a few fragmentary diatoms also occur. This unit is much coarser than any other and may represent a beach deposit.

The data from Kokwob Murren suggests that the silts were laid down in quiet, shallow fresh waters, with numerous aquatic plants. Similar environments border the modern lake, but diatoms are rare due to competitive exclusion by blue-green algae. The grits of unit 6 suggest an increase in wave energy. This might have been brought about by a rise in lake level, which would have breached a shallow col to the east of the Kokwob Murren palaeo-embayment.

Samples of the shell bed (unit 3) have been ^{14}C dated by Bishop (reported in Williams & Johnson, 1976). The results were:

13,670 ± 320 yr. B.P. (inner shell fraction)

13,850 ± 430 yr. B.P. (middle shell fraction)

9(i)d The distribution and age of the Kokwob sediments

In the lower valley of the River Kapthurin (K2, fig. 9.1), to the south-west of Lake Baringo, Kokwob sediments rest unconformably on the calcreted top of a trachyte lava flow (K2, fig. 9.4). The lower Kokwob unit consists of 20 cm of pale grey, shelly silts, and is overlain by diatomaceous silts, up to 40 cm thick. The flora of the latter unit is as follows.

DOMINANT	: Rhopalodia gibberula var. rupestris, Nitzschia frustulum
OCCASIONAL	: R. gibberula var. sphaerula, Nitzschia obtusa, Navicula simplex, N. mutica var. undulata, Anomoeoneis sphaerophora var. guntheri, Stephanodiscus astraea var. minutula

Today, the dominants are commonly found in brackish water and in littoral situations. The deposits lie at 15.54 m above 1969 lake level (Bishop et.al., 1969). Williams and Johnson (1976) report that molluscs have yielded the following dates.

12,260 ± 280 yr. B.P. (inner shell fraction)
12,600 ± 280 yr. B.P. (middle shell fraction)

A lower strandline of non -diatomaceous, shell-bearing silts, 2 km south-east of Kampi-ya-Samaki, lies at a height of 10.06 m above 1969 lake level. This deposit has yielded the following dates (Williams & Johnson, 1976).

9,940 ± 250 yr. B.P. (inner shell fraction)
10,810 ± 270 yr. B.P. (middle shell fraction)

A non -diatomaceous, shelly grit occurs near the Kampi-ya-Samaki airstrip, at a height of 3.66 m above 1969 lake level (Bishop et. al., 1969). Bishop obtained the following dates for this deposit.

7,620 ± 180 yr. B.P. (inner shell fraction)
8,460 ± 180 yr. B.P. (middle shell fraction)

At Logumukum, 10 km to the south of Lake Baringo (fig.

9.1), a series of Kokwob strandlines rests unconformably upon eroded Ilosowuani Beds (fig. 8.5; plate 8.2). Melanoides tuberculata, Corbicula fluminalis and Unio spp. are molluscs that are locally abundant and found in sub-rounded grits. The associated fauna includes catfish, chelonids, hippo, bovids and other unidentified bones. A few fragmentary, littoral diatoms occur (Rhopalodia and Cocconeis species). Obsidian, chert and phonolite flake tools are present. Williams and Johnson report the following dates:

11,870 ± 310 yr. B.P. (inner shell fraction)
10,860 ± 280 yr. B.P. (middle shell fraction)

The strandline has been levelled at 985 m O.D., almost the same as the sediments at Kokwob Murren.

There are several reasons for questioning the validity of these dates. These are as follow:

(i) Some of the dates show wide variations between inner and middle shell fractions
(ii) Dating problems have also arisen with cores from the modern lake (Tiercelin, pers. comm.)
(iii) The dates are 'out of phase' with dates from other early Holocene high lake levels in Kenya.
(iv) Dates differ for sediments at similar heights within the same basin.

Young and Renaut (1979) have pointed out that dating problems may be related to isotopic replacement, and hardwater effects.

The deposits at Logumukum and Kokwob Murren record a late Pleistocene/early Holocene expanded Lake Baringo (Lake Kokwob). The diatoms suggest that this lake was fresh, although locally more brackish conditions may have occurred.

9(ii) Late Holocene and modern sedimentation in Lake Baringo

9(ii)a The Lake Baringo core

This section reports on the litho- and diatom stratigraphy of a 3 m core, made available to this study by Dr. C. Barton. As yet no firm age is available for the core. However, it does reflect modern sedimentation at its top, and in view of the large sediment input and short core length it is not likely to date beyond the late Holocene. The lithostratigraphy is shown in figure 9.6, and the diatom stratigraphy in figure 9.7. These are referred to in the following paragraphs, which describe the core from base to top.

Below 295 cm occur dark brown clays, which contain much organic debris and undecomposed rootlets. This is suggestive of shallow water, in which plants were common. This is confirmed by the diatoms (fig. 9.7). A few epiphytic Gomphonema spp. occur above a layer devoid of diatoms.

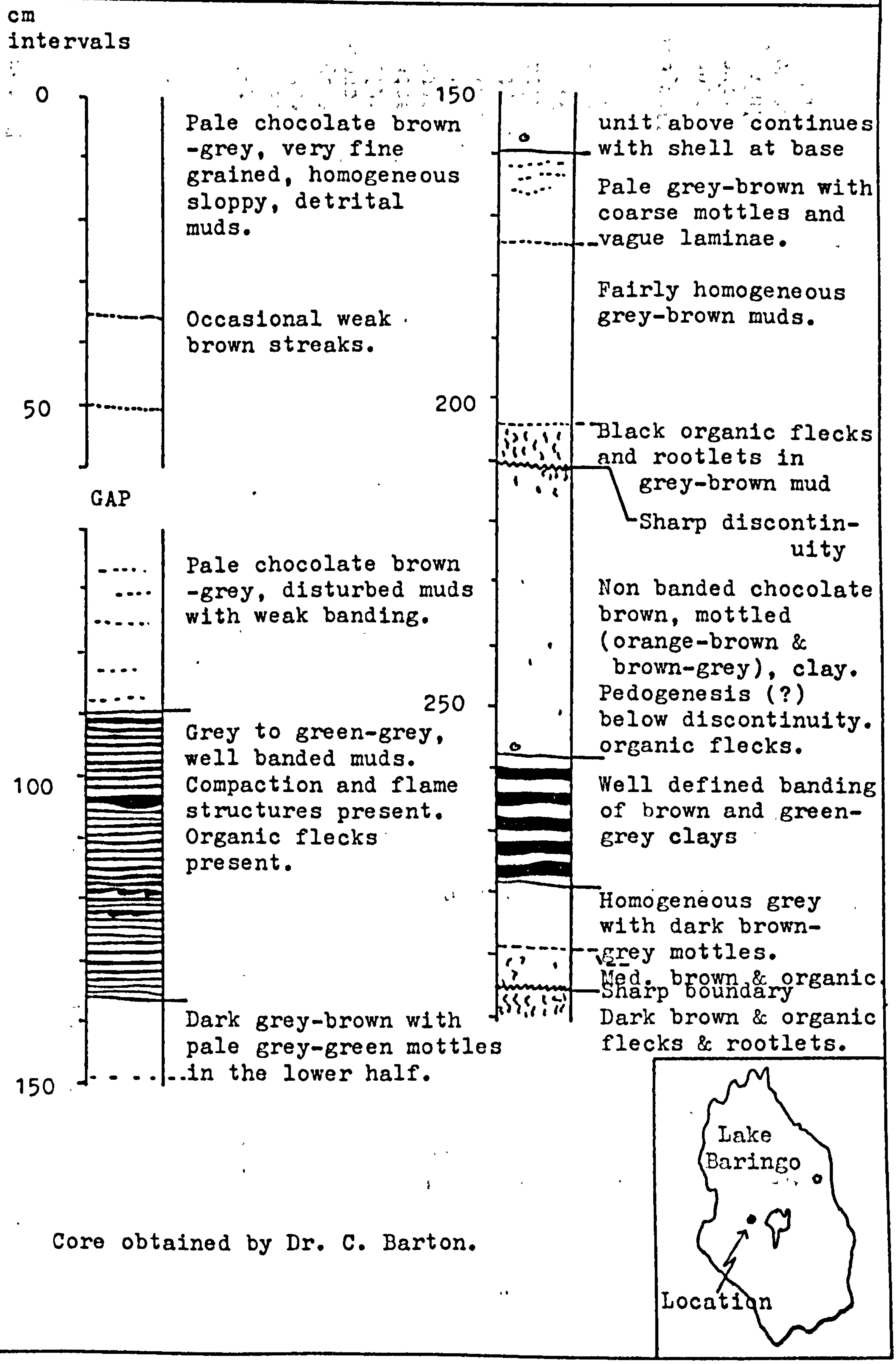
Above 295 cm, Melosira granulata var. angustissima is found in a brown organic mud. Today, this diatom is often associated with cyanophytes (Richardson, 1968). It also suggests a transgression (since it is a planktonic species), and fresh to slightly alkaline conditions. At 290 cm, a short-lived bloom of Thalassiosira rudolfii indicates more alkaline conditions (up to 80 meq/l; Hecky & Kilham, 1973).

Between 290 and 278 cm, homogeneous grey muds occur. These lack diatoms, except at the top, where Melosira granulata var. angustissima is dominant

From 278 to 258 cm, well-banded, brown and greenish grey clays prevail. Diatoms are at their most abundant here. Melosira granulata var. angustissima dominates, except at 270 cm, where Thalassiosira rudolfii is most abundant. The

Fig. 9.6

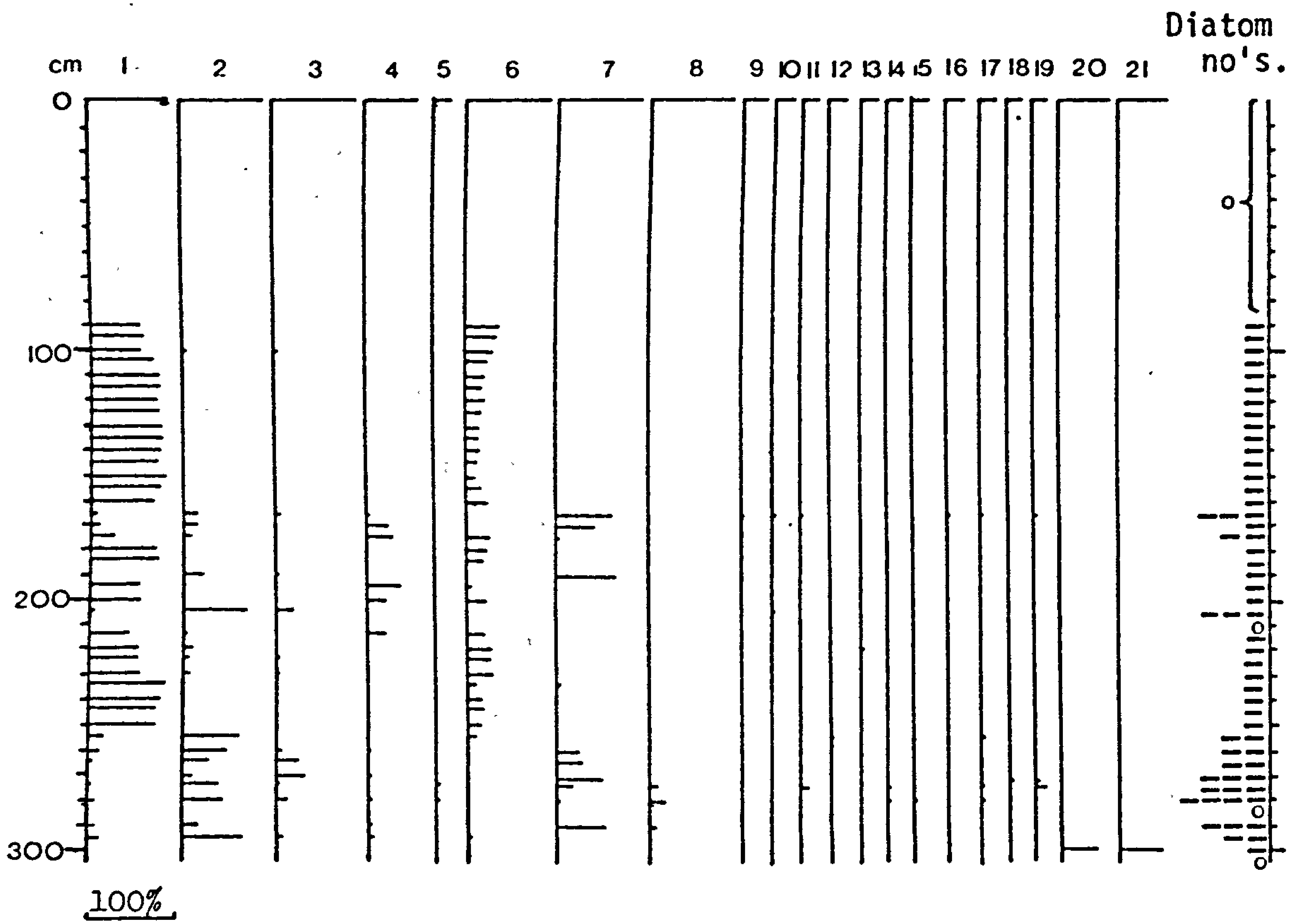
Lake Baringo core 'BB' stratigraphy



Core obtained by Dr. C. Barton.

Fig. 9.7

Diatom stratigraphy of core BB



Diatoms

1 Melosira granulata
2 v. angustissima
3 f. curvata
4 M. agassizi
5 v. malayensis
6 Stephanodiscus astraea
7 Thalassiosira rudolfii
8 Cyclotella meneghiniana
9 C. ocellata
10 Nitzschia amphibia
11 v. pelagica
12 N. microcephala
13 Navicula radiosa
14 N. gastrum
15 N. rostrata
16 Synedra rumpens
17 S. ulna
18 Achnanthes lanceolata
19 Rhopalodia gibberula v. sphaerula
20 Gomphonema parvulum
21 G. lanceolatum

Subjective estimate of numbers

0 = Absent or very rare
- = Infrequent
-- = Infrequent to common
--- = Common
---- = Abundant

flora suggests changing alkalinity, probably related to fluctuating lake level.

Above 258 cm and below 210 cm, non -banded, brown clays, which contain organic debris, predominate. A mollusc occurs at the base. Diatoms are rare, but dominated by Melosira granulata, and to a lesser extent, by Stephanodiscus astraea. These suggest a fresh lake and possibly deeper water than was present during the formation of the previous unit. The low numbers may be due to competition from blue-green algae.

Between 210 and 205 cm, a sharp boundary is overlain by grey-brown muds, that contain abundant rootlets. The layer is devoid of diatoms and may reflect a lake regression, and subsequent pedogenesis of the sediment (which contains an orange-brown mottling) below the sharp boundary.

At 205 cm, diatoms become abundant. They are dominated by Melosira granulata var. angustissima, which may suggest a fresh to slightly alkaline lake.

Homogeneous, grey-brown muds occur between 205 and 175 cm. In percentage terms, the diatoms are dominated by Melosira granulata and Stephanodiscus astraea, although both species only occur in low numbers. Thalassiosira rudolfii is dominant at 190 cm, but again in low numbers.

Between 160 and 175 cm, pale grey-brown clays with a vague lamination occur. This level is dominated by Thalassiosira rudolfii, which occurs in some abundance. Its presence suggests a return to alkaline conditions.

From 160 to 135 cm the clays are a dark brown, with a pale grey-green mottling below 150 cm. Diatoms are rare, and dominated by Melosira granulata and Stephanodiscus astraea. These species suggest that the lake was again fresh, while their low numbers may reflect dominance by cyanophytes.

Well banded grey to greenish-grey muds occur between 90 and 135 cm. The banding possibly suggests a seasonal or longer term sediment input into calm water. The diatom flora remains unchanged from that of the preceding unit, and is again present in low numbers.

Above 90 cm, occur pale brown-grey muds with a faint banding. These contain no diatoms except at two levels, where a few Melosira granulata have been observed. A gap occurs in the core at 60 cm, above which the sediment is progressively disturbed due to the coring operation.

The Baringo core indicates a lake that has been intermittently more saline and alkaline than it is today. Although this could be related to changes in the chemistry of the water input (eg. by changes in spring discharge), the most probable explanation involves fluctuating lake levels (and resultant ionic concentration/dilution). Indeed the core provides evidence of emergence, or near emergence, of this part of the lake floor at two stages.

9(ii)b Modern sedimentation in Lake Baringo and recent lake level fluctuations

Today, the waters of Lake Baringo are warm (24 to 29°C), fresh to slightly alkaline, have a pH of 7.5 to 8.5, and are dominated by HCO_3^- and Na^+ ions (McCall, 1967). The lake supports an abundant phytoplankton, dominated by the cyanophyte Microcystis aeruginosa (Tiercelin, 1979). Diatoms are uncommon, consisting mainly of Melosira granulata var. angustissima and Nitzschia spp.. Algae, together with plant debris washed in by rivers, makes up a major part of the sediment body.

Deposition differs significantly from that of neighbouring Lake Bogoria, in that Lake Baringo lacks evaporites. This is surprising since both lakes have no surface outlet and drain areas of similar lithology.

However, during a period of low lake levels, Gregory (1921) observed water escaping through lavas to the north-east. McCall (1967) has suggested that hot springs at Kapedo, some 110 km to the north, may represent the reemergence of this water. Although subsequent workers have been unable to relocate Gregory's outlet (Worthington, 1932; Bishop, pers. comm.), such a subterranean outflow would be capable of maintaining a freshwater lake.

Evidence from cores and shallow trenches around the lake indicate that recent sedimentation is predominantly clastic, with bedded sands, silts and clays, derived from inflowing streams. A stromatolitic limestone (up to 2 m above the lake) coats lavas near Kokwob Murren (fig. 9.3). Although undated its good state of preservation suggests a Holocene age. Tallon (1976) reports that oncolites are common around the modern shoreline.

J.J. Tiercelin (1979) collected cores from the south and south-east, which contained mainly brown ooze and silty clays, with massive silty clays at their base (1.5 m). In other parts of the lake his cores consisted of brown clays and oozes, alternating with silty clays and silts. He reports ostracods, sponge spicules and diatoms as common.

Evidence of recent lake level changes are minor wave-cut cliffs, strandlines, drowned vegetation and fluvial terraces that suggest higher local base levels.

Gregory (1921) noted that the lake was low in 1893. Powell-Cotton (1904) observed recent higher strandlines in 1902, and also evidence of lower levels, in the form of drowned trees. He was informed by natives of a time when it was possible to walk to the islands. Gregory (1921) noted a low lake in 1912. Photographs shown by Nilsson (1932), suggest high levels in the early 1930's. R.A.F. aerial photographs indicate low lake levels in 1950. In 1964 the lake was 5.5 m above 'normal' according to Bishop (pers. comm). Since then the lake has continued to rise and fall.

9(iii) The nature and distribution of the Loboi silts

The deposits which today form the bulk of the inter-lacustrine plain (ca. 260 km^2), between Lakes Baringo and Bogoria, were informally termed the Loboi silts by McCall (1967). They were considered to be deltaic, having formed under a unified LakeBaringo-Bogoria. Walsh (1969) noted "lacustrine silts of the Loboi Plain" near Marigat. Griffiths (1977) did not think that they were recognisably lacustrine. Farrand et. al. (1976) described the Loboi silts to the north of Lake Bogoria.

The distribution of the Loboi silts is shown in figure 9.1. They rest on downfaulted Kapthurin Formation, on the mid-western portion of the Loboi Plain (Walsh, 1969), reaching a maximum thickness of ca. 15 m. Although thinner immediately to the east (due to a high part of the surface on which they sit), they may thicken towards the poorly-exposed centre of the basin. Bogoria silts overlie these deposits in the south. Elsewhere erosion has planed off much of the surface, or it is hidden by swamps.

The Loboi silts are normally massive and structureless, but occasionally show a faint lamination. Two sections (L1 and L2) are shown in figure 9.4, and their locations are given in figure 9.1. In general, sand, gravel and clay occur in lenses; more rarely they form thin broad sheets. In the west, grits with well-rounded lava gravels underlie well-sorted, laminated buff silts. The gravels may be imbricated or cross-bedded.

X-ray diffraction shows the silts are dominated by sanidine and plagioclase, which together form about 90 % of the sediment. Smectite and calcite are also present. Analcime is locally abundant (up to 40 %) on the southern Loboi Plain. Renaut (pers. comm.) has observed dolocrete as remnant patches on analcimic Loboi silts. Ferromanganiferous nodules (less than 2 cm) occur in several localities. Renaut has also noted such nodules, at a depth of ca. 70 cm, in deltaic silts, west of Lake Bogoria. Palaeosols occur locally, while calcareous root casts are more common.

Bovids, crocodile, hippo (Coryndon, 1978), fish bone and organic debris all occur. No diatoms were found. Farrand et. al. (1976) recorded obsidian flakes on the surface of the Loboi silts. Middle Stone Age artefacts (late Pleistocene) have also been found in parts of the Loboi silts.

These deposits record the infilling of a downfaulted basin. However, it is often difficult to give them a definite origin. The sediments are derived from a number of rivers, which include the Molo, Perkerra, Sandai-Waseges and Ol Arabel (several of which are shown in fig. 9.1). The imbricated gravels are suggestive of fluvial conditions, while the weakly-laminated buff silts may represent overbank or lacustrine sedimentation. The fauna is ambiguous, since it found in both fluvial and lake environments.

Loboi silt type deposition may well occur in the transition from floodplain, through deltaic to lake environments, at the southern end of Lake Baringo. Indeed, deposits forming here, may be a time transgressive lateral equivalent of the older, Loboi silts.

The age and lateral relationships of the Loboi silts are unclear. They were initially considered Holocene (McCall, 1967), but this is probably an oversimplification. Farrand et. al. (1976) pointed out that they may partly predate the Kokwob high levels (fig. 9.2). Part of the Loboi silts must have been present in order to hold the water of the high-level, early Holocene, Lake Bogoria (p. 307). Of major importance is the depth and age of sediments in the modern watershed area, where there is regrettably little exposure.

9(iv) Sedimentation in the Bogoria basin

9(iv)a The diversity of lithofacies present in the Bogoria basin

Highly saline and alkaline Lake Bogoria lies some 17 km to the south of Lake Baringo (fig. 9.1), from which it is separated by a low watershed. The lake extends 17 km from north to south, and is 0.5 to 3.5 km wide. It lies in an assymetric fault controlled trough. Today, the lake's flora is dominated by cyanophytes, of which Oscillatoria platensis is the principle species. Diatoms are rare, but Hecky and Kilham (1973) have recorded Nitzschia frustulum.

This small basin is remarkable for the diversity of lithofacies present. These have been studied in some detail by Renaut (pers. comm.) and Tiercelin (1979; pers. comm.), and will only be outlined here, based on personal observations, before going on to discuss the diatom flora.

Fluvial lithofacies occupy a small part of the Bogoria basin. Such sediments are best developed along the Emsos and Sandai-Waseges Rivers, to the south and north of the lake respectively. Fluvial deposits are also found along the course of several small rivers to the west of the lake. These deposits consist of feldspathic silts with common lithic fragments. Laminated clays and silty clays often occur, and are frequently associated with plant remains. Coarser sands and gravels are found near areas of sediment supply, and in point or braid bar settings.

Downstream, the fluvial lithofacies grades into deltaic deposits. Here, the sediments consist mainly of silts and clays (often laminated). Tiercelin has observed, in cores from the Sandai-Waseges delta, alternating clays, silts and fine sands. The clays are dominantly smectite and plant debris is common.

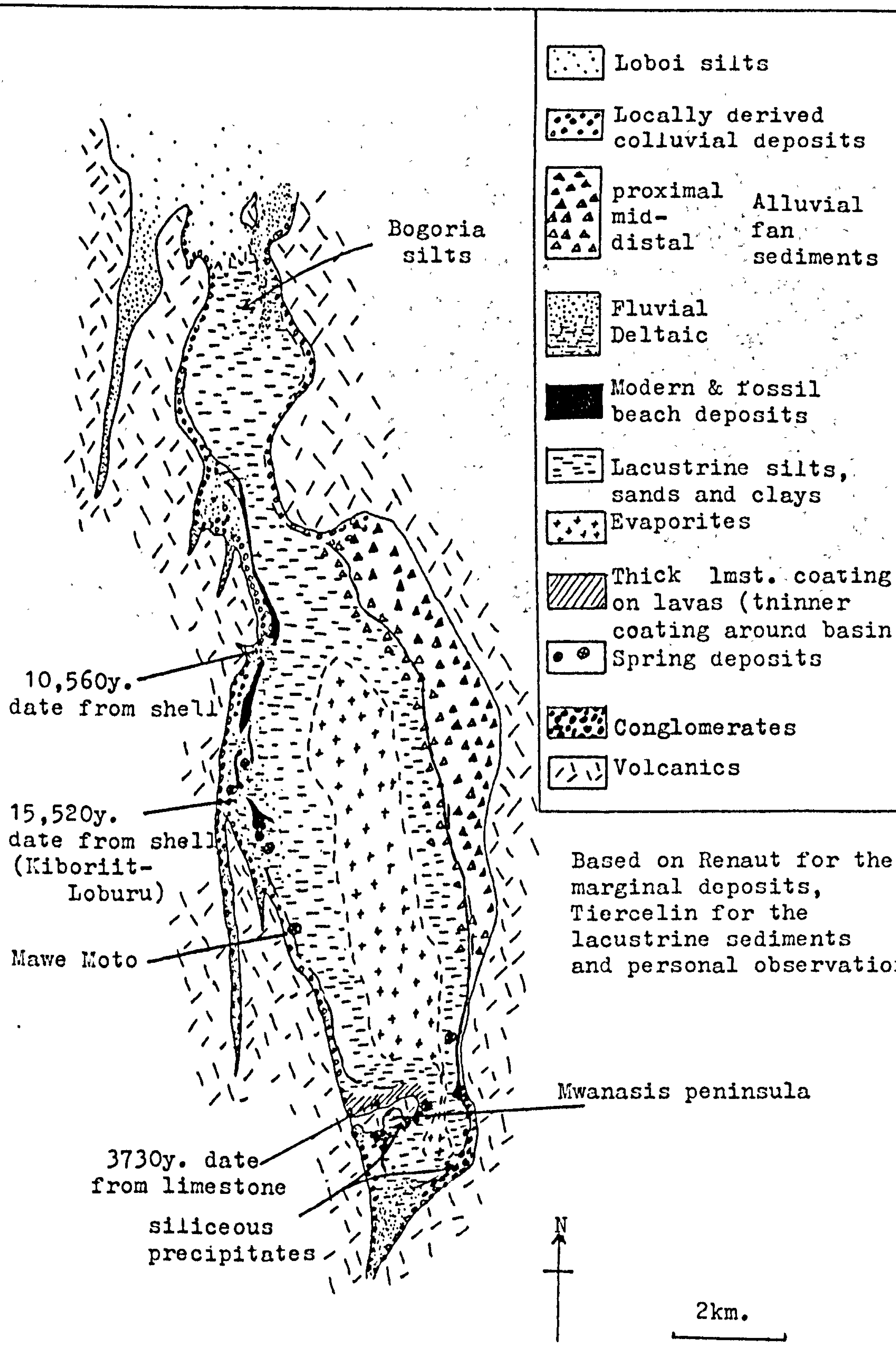
Alluvial fans occupy a large area to the east of the lake (fig. 9.8). Matrix supported clasts, suggestive of debris flows, occur in the upper (proximal) portions of these coalescing fans (bajadas). Downslope, these give way to clast supported conglomerates, and cross-stratified sands. Similar fan deposits occur to the south-east of Lake Baringo. As the fans enter Lake Bogoria (fan-delta environment), graded gravels alternate regularly with finer, parallel-bedded sands (1 to 2 cm thick), which dip lakewards at about 10°.

Extensive areas of granular, feldspathic sands occur along the modern shoreline and form beach bars and spits. Similar deposits are found on terraces ranging up to 6 or 7 m above the 1977 lake level. The lower of these terraces are occasionally reached by the modern lake, during wetter years. This occured in 1979 (Tiercelin, pers. comm.). Fossils recovered from the marginal sediments of Lake Bogoria include mollusca, crocodile, hippo and fish bones. None of these are found in the modern lake.

Tiercelin (1979) has recognised two broad facies zones in the modern lake. The first of these is composed of alternating fine sands or silts, and silty clays with much allochthonous organic debris. These deposits occupy a zone that extends throughout the northern end of the lake, and which forms a littoral belt to the south (fig. 9.8). The second facies consists of chemical and organic sediments. These include finely laminated black oozes with evaporite minerals that lie in a north to south belt at the centre of the lake (fig. 9.8). Tiercelin records local concentrations of diatoms in these sediments.

Hot springs are common at Lake Bogoria (plate 9.3). The main centres of activity are at Kiboriit-Loburu, Mawe Moto and Mwanasis, on the western margins of the lake (fig. 9.8). Spring deposits consist mainly of calcite and aragonite (travertine).

Fig. 9.8 Simplified sediment distribution map of the Bogoria basin (modern lake ignored)



Based on Renaut for the marginal deposits, Tiercelin for the lacustrine sediments and personal observation

Plate 9.3

Hot springs, such as this, are common along the western and southern margins of Lake Bogoria. In many cases they have formed mounds of travertine and tufa.

A grey stromatolitic limestone (plate 9.4) coats lavas and sediments in a belt (entirely above modern lake level) around the margins of the lake. This limestone has a consistent upper limit of ca. 11 m above 1977 lake level. This height corresponds to that of the present watershed between Lakes Baringo and Bogoria, which suggests that the lake may have had an outlet near the time of formation, although it may have been 'cut off' when precipitation actually took place. The limestone varies in thickness from less than a millimetre to a metre or more. It is thickest on the north side of the Mwanasis peninsula, and thins northwards. It has recently been dated at 3730 ± 180 yr. B.P. by Tiercelin, from material supplied by Renaut. However, many problems have arisen with dates from this basin (probably due to 'old ^{14}C'), and the date should be treated with caution.

Other dates have recently been obtained from molluscs. Shells have been dated from two localities on the western margin of the lake by Renaut (pers. comm.). These dates follow.

north-west shore:

10,500 ± 170 yr. B.P. (inner fraction)
10,320 ± 150 yr. B.P. (middle fraction)

Kiboriit-Loburu:

15,520 ± 420 yr. B.P.

The latter date may be particularly suspect since it was obtained from shells near to an area of hot spring activity. Also, this date suggests high lake levels at a time when most Kenyan lakes were low. The sediments, from which both dates were obtained, suggest lake levels 6 or 7 m above those of 1977. That this lake was fresh along its margins is demonstrated by the presence of molluscs. Cerling (1979) suggests that molluscs are only common at alkalinities below about 16 meq/l.

Plate 9.4

Limestone coating rocks and 'twigs' on the margins of Lake Bogoria. This deposit thickens towards the southern portions of the lake, and attains a maximum elevation of about 11 m above the modern lake height. It has been dated at 3730 ± 180 yr. B.P.

9(iv)b The diatoms and Holocene history of Lake Bogoria

Diatoms are absent from most of the marginal deposits around Lake Bogoria. However, two sources of diatom material are known.

The first of these sources occurs to the south of Mwansis peninsula and near the south-eastern shores. Here, patches of a siliceous deposit rest on a conglomerate. Thin section and scanning electron microscopy have revealed that numerous casts of diatoms occur (appendix III, A.III.9). Melosira species dominate and include M. granulata, M. agassizi and M. agassizi var. malayensis. Less common are Surirella biseriata, Epithemia zebra var. saxonica, Rhopalodia gibba and Anomoeoneis sphaerophora. This flora suggests fresh waters (ca. 5 or 6 meq/l), in a part of the lake that is today highly saline and alkaline. The siliceous deposit appears to be most common near hot springs. It may be that the peculiar state of preservation of these diatoms is related to this fact.

The second source of diatoms is in core material obtained by J.J. Tiercelin (pers. comm.). A brief examination of a slide from a core, in the south basin of Lake Bogoria (to the south of Mwanasis), revealed numerous Melosira spp.. Tiercelin indicates that these are common below evaporite-rich sediments. The similar flora suggests that the siliceous deposits,above the modern lake, are of similar age to the diatomaceous sediments in the core.

That a Melosira dominated lake existed in the Bogoria basin suggests considerably lower ionic concentrations than occur today. This 'Melosira lake' predates the one in which the stromatolitic limestone was formed. This is shown by limestone sitting on top of siliceous precipitate to the south of Mwanasis.

The following rather tentative sequence of events can be suggested.

(i) During the terminal Pleistocene/early Holocene a higher, fresh water (less than 16 meq/l) lake existed. This may have overflowed to the north via a lower watershed than exists today.

(ii) A Melosira dominated lake was probably contemporary with phase (i) above. However, its precise duration is uncertain. This lake was of high silica content (greater than 10 mg/l), moderate pH and low alkalinity (5 or 6 meq/l). The fresh water nature is suggestive of overflow.

(iii) A high lake, standing at ca. 11 m above modern heights and in which limestone was precipitated, overflowed into Lake Baringo, some time in the late Holocene. The Bogoria silts, at the north end of the lake, may relate to this period. The lake was probably of low alkalinity.

(iv) The lake contracted and lost its outlet. Alkalinity, salinity and pH increased significantly. Evaporites eventually developed at the basin centre.

It must be emphasised that gaps may occur in the scheme above, and that many events are of unknown duration.

9(v) The Holocene history of Lakes Baringo and Bogoria

9(v)a Summary of the history of Lakes Baringo and Bogoria

Loboi silt sedimentation probably commenced during the late Pleistocene. These deposits were laid down in, and on the margins of, a successor to the 'central rift lake' mentioned in chapter 8 (p. 259). During the latest Pleistocene this 'Loboi lake' (fig. 9.9) regressed and fluvial Loboi silts advanced across the area between modern Lakes Baringo and Bogoria. An arid climate at this time is suggested by the development of analcime on Loboi silts and by calcrete.

A wetter climate developed during the latest Pleistocene /early Holocene, when both Lakes Baringo and Bogoria expanded. It was at this time that the Kokwob Formation was laid down. Loboi silt sedimentation probably continued on the margins of these lakes.

During the later Holocene, Lakes Baringo and Bogoria developed in different ways. Lake Baringo was dominated by clastic sedimentation, while stromatolitic limestones, diatomaceous silts and evaporites formed in Lake Bogoria. Loboi silts continued to form near the southern margins of Lake Baringo.

The chemical evolution of both lakes is summarised in table 9.1. During the early Holocene, Lakes Baringo and Bogoria were of fresh character. While remaining fresh for most of its history, Lake Baringo has undergone several more alkaline and saline stages during the late Holocene, associated with contraction. Lake Bogoria also has been fresh for much of its history, but during the late Holocene it became highly saline and alkaline, which eventually resulted in the formation of evaporites.

Table 9.1 Summary of the extent and palaeochemistry of Lakes Baringo and Bogoria

Lake Baringo

AGE	pH	ALK. meq/l	SALINITY %.	SiO_2 mg/l	DEPTH (max) m	SURFACE AREA	VOL km^3
Modern	8-9	5-6	0.3-0.7	15-30	4-8	160 km^2	0.2-1
Late Holocene (core data)	8-9+	5-80	0.2-16	>10	1-8	30-160 km^2	0.03-1
Early Holocene	7.5-8.5	<5	0.1-2	>10	ca.20	340 km^2	2.8-3.3

Lake Bogoria

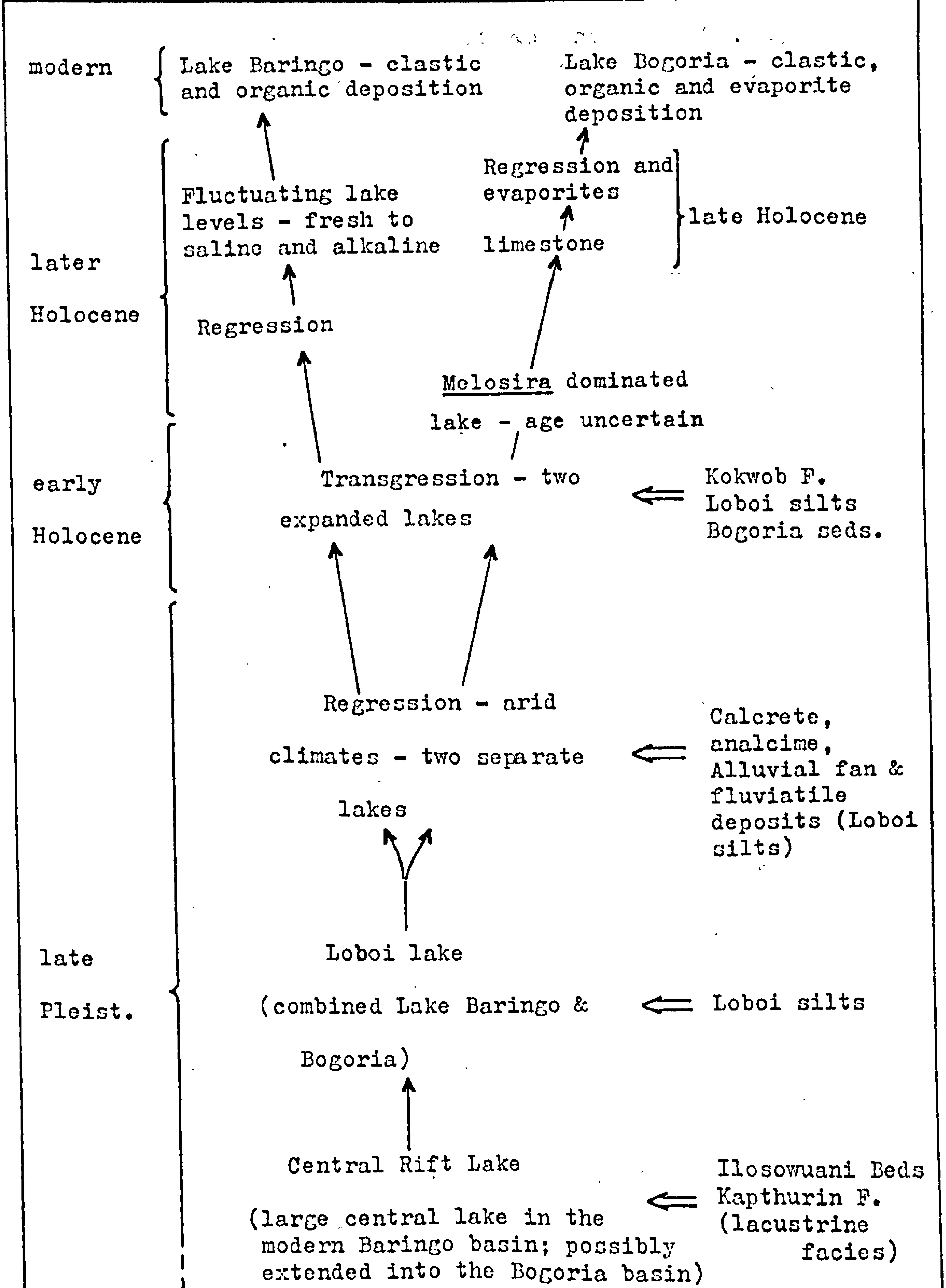
Modern	8-10.5+	1000-1600	40+	< 10 *	ca.9	36 km^2	0.1
'*Melosira* lake'	7.5-8.5	5	0.1-2	>10	ca.20?	?	?
Early Holocene	-	16	low	-	ca.16	41 km^2	0.4

* Locally very high near hot springs

Based on diatom and mollusc evidence and sedimentary data on palaeoshorelines

Fig. 9.9

Summary of the history of Lakes Baringo and Bogoria



9(v)b The early Holocene palaeogeography of Lakes Baringo and Bogoria

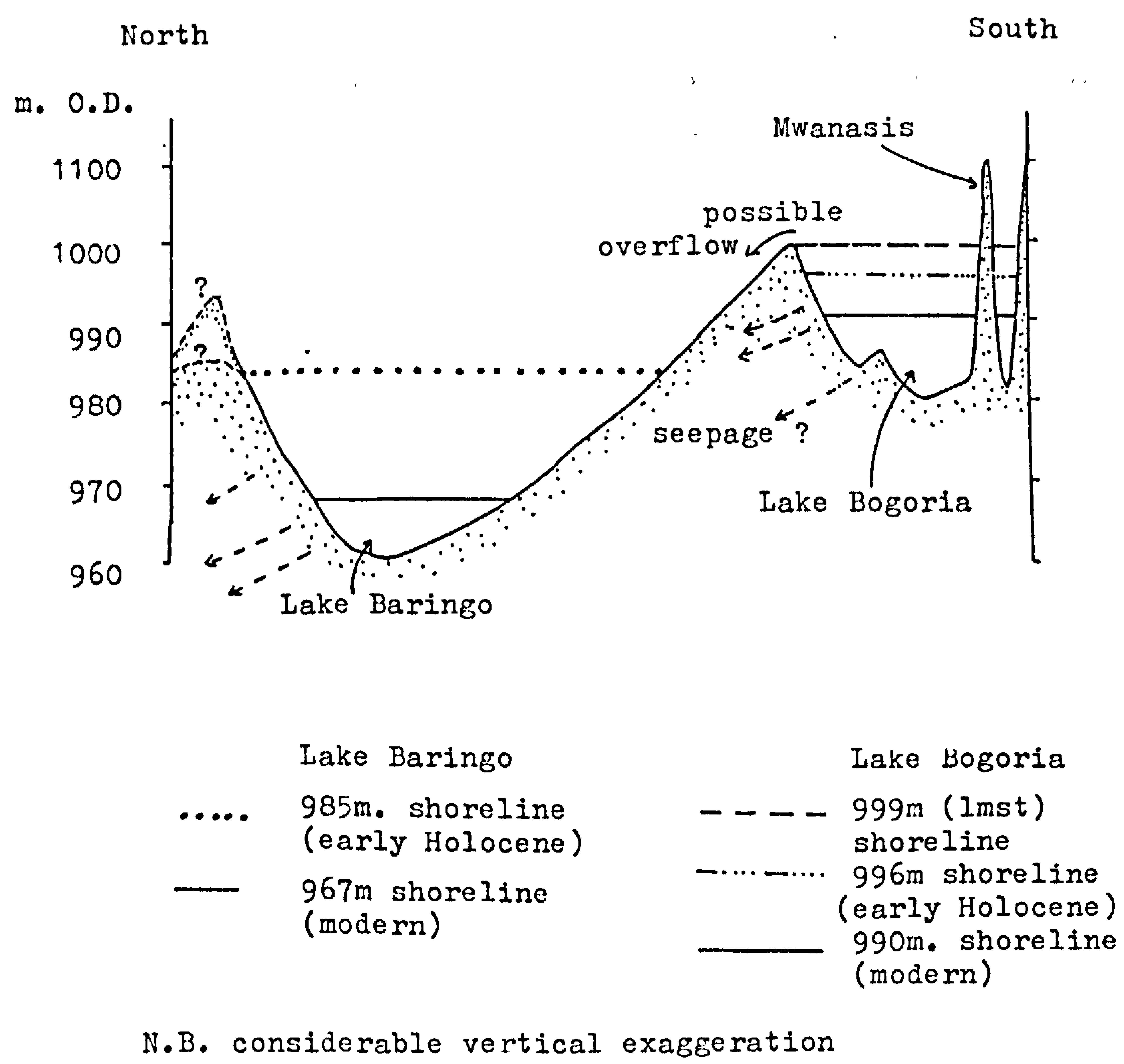
Early Holocene Lake Baringo was confined by steep scarps to the west, and by the lavas of Korosi volcano to the north. The southern limits remain ill defined (fig. 9.10). The Lobat Pass, to the west of Korosi (fig. 9.10), is the lowest potential outlet point for Lake Baringo. This Pass lies 3 to 8 m above the highest recorded Kokwob sediments (Bishop, pers. comm.). There is no convincing sedimentary or morphological evidence to substantiate a prolonged overflow. However, subsurface seepage was probably important, possibly with short-lived lake level rises to the outlet, in explaining the fresh nature of the early Holocene lake. Whatever the method of outlet, the outflowing water would eventually reach the Suguta drainage network (p. 226).

The highest Kokwob sediments lie at ca. 985 m O.D. (fig. 9.11), while early Holocene sediments around Lake Bogoria lie up to about 996-7 m O.D.. The two lakes must therefore have been separate, despite their considerable expansion. Today, the minimum drainage divide between the Baringo and Bogoria basins lies at 999 m O.D.. This is above the highest early Holocene sediments of Lake Bogoria. However, wide height fluctuations of the modern lake, and the fresh water character indicated by early Holocene molluscs, suggests the possibility of periodic overflow. Whether or not the lake reached its outlet, a probably higher water table would have resulted in the expansion of swamps on the Loboi Plain. This statement is supported by the presence of calcareous root casts, scattered over parts of the Plain.

An important factor in controlling lake level changes may have been shifts in the course of the Sandai-Waseges River (fig. 9.10). Today, it is the main source of water for Lake Bogoria. On leaving the Sandai Gorge, the river turns sharply south. However, the assymetry of associated fan deposits (skewed northwards) at this point, suggests that it may have formerly entered Lake Baringo. Although

Fig.9.10 Palaeogeography of Lakes Baringo and Bogoria

Fig.9.11 Modern and early Holocene lake levels.



it would have been only one of several rivers entering Baringo, its loss to Lake Bogoria would have been highly significant.

Several late Quaternary shorelines are shown in figure 9.10. These reflect a complex series of lake expansions and contractions, which due to seepage, overflow and river capture, may not have responded in the same manner to climatic changes as other Rift lakes. If we allow for possible dating errors, an early Holocene period of high lake levels can be recognised. The probability is that these are related to an increase in rainfall, as suggested for many other East African lakes. Since the early Holocene, the height of Lake Baringo has progressively fallen. There was no corresponding fall at Lake Bogoria, possibly due to drainage diversion of the Sandai-Waseges. However, a fall in lake level has been evident at Bogoria during the late Holocene.

PART IV

THE QUATERNARY DIATOMACEOUS SEDIMENTS OF OLORGESAILIE

CHAPTER 10

THE SEDIMENTS OF THE OLORGESAILIE FORMATION

10(i) Definition and introduction to the Olorgesailie Formation

10(i)a Location, definition and age of the Olorgesailie Formation

The Olorgesailie sedimentary basin occupies an area of less than 100 sq. km. in the southern part of the Kenya Rift (fig. 10.1). Actual outcrops cover an even smaller part of the basin and are shown in figure 10.1 and plate 10.1. The topography and vegetation of the area have been described on page 52, along with a brief history of research.

Interest in this part of the Kenya Rift was stimulated by the occurrence of Acheulian hand axes. The deposits in which they are found form part of a series of outcrops of Pleistocene strata, that occur to the north of Mt. Olorgesailie (fig. 10.1). These sediments were designated the 'Olorgesailie Lake Beds' by Baker (1958). Later, Baker and Mitchell (1976) used the informal term 'Legemunge Beds' to refer to these deposits. Isaac (1967, 1977) ranked the sediments at the Formation level, and defined them as, "a series of well stratified diatomites, pale yellowish volcanic siltstones, and claystones, and subordinate quantities of brown siltstones and volcanic sands". The 'Formation' rank is retained in this work.

Olorgesailie Formation sediments reach a maximum thickness of 55 to 60 m, and rest unconformably on various faulted volcanics. These include the Mt. Olorgesailie Volcanic Series, the Ol Keju Nyiro Basalts, and the (Magadi) Plateau Trachyte Series (Baker, 1958). The upper

Fig. 10.1 The topography of the Olorgesailie area

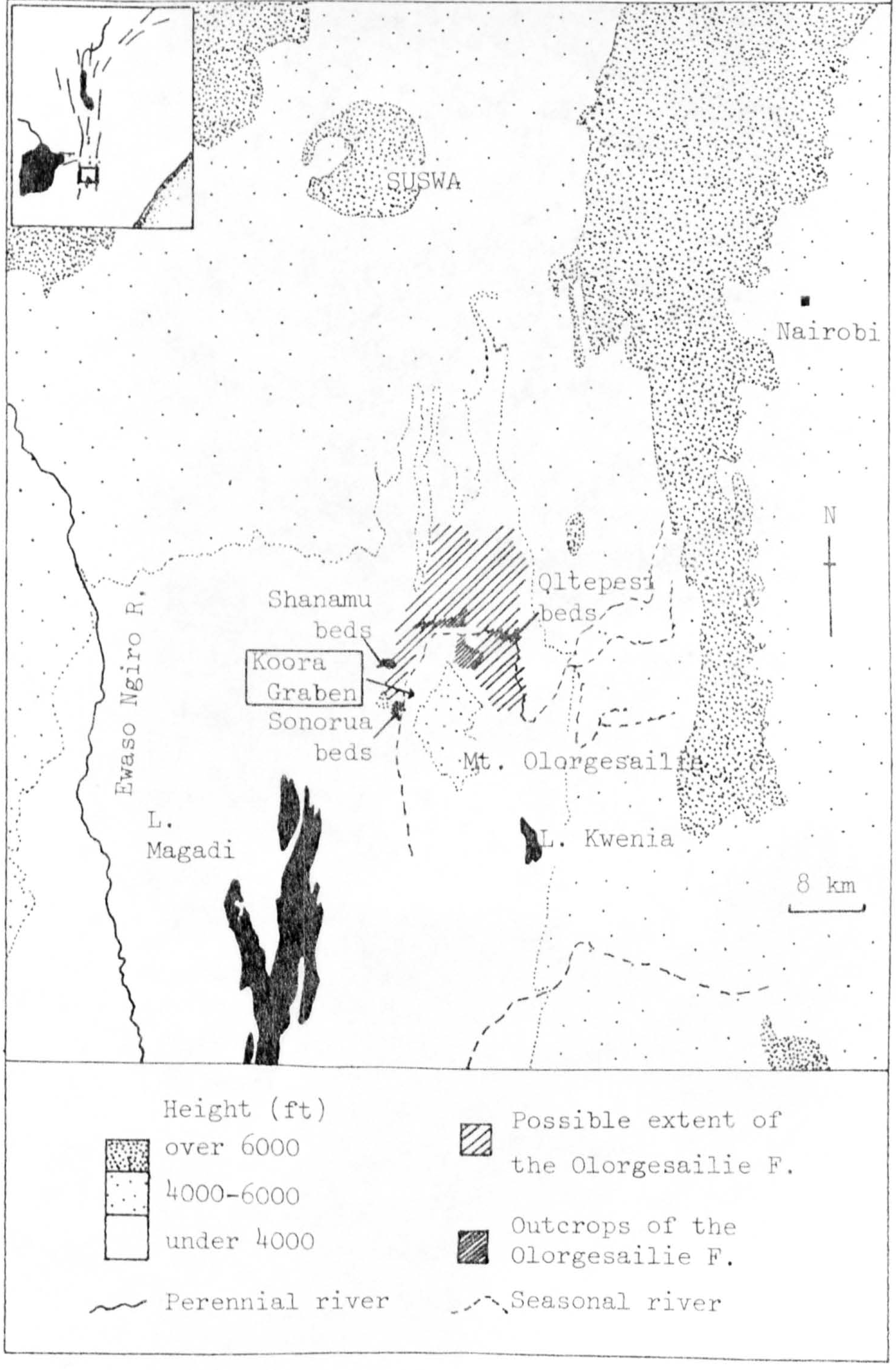


Plate 10.1

Outcrops of Olorgesailie sediments are common to the north of Mt. Olorgesailie. They often occur in gorges, such as the one shown in this photograph. The view is looking south-west, and the deposits exposed belong to Members 2 to 10. The Koora Graben lies to the left (south) of the distant scarp.

boundary is erosional in all parts of the area, although to varying degrees. Most of the Formation is overlain by alluvium, aeolian, swamp and travertine deposits. A generalised sediment stratigraphy is shown in figure 10.2.

Baker and Mitchell (1976) have dated the underlying Plateau Trachyte Series at between 0.63 and 1.25 my. Evernden and Curtis (1965) have obtained dates ranging from 2.9 to 0.425 my, from within the Formation. Isaac suggests that most of the dates were obtained from reworked material, but accepts as possibly valid two dates of 0.425 and 0.486 my, since they are consistent with faunal and archaeological data.

10(i)b The significance of the Olorgesailie Formation

Diatomites and highly diatomaceous sediments form a greater percentage of the Olorgesailie Formation than occurs in any of the other Quaternary basins reported in this thesis. The Guomde and Galana Boi Formations (East Turkana), the Kapthurin and Kokwob Formations (Baringo district), and the Loboi silts and marginal sediments of Lake Bogoria all contain a lower percentage of diatoms. The deposits of other Pleistocene basins, such as Olduvai (Hay, 1976) and Peninj (Isaac, 1967), similarly show a much lower diatom content than occurs at Olorgesailie. Only at Kariandusii (near Lake Elmenteita, central Kenya Rift) are Pleistocene diatomites more abundant within the Kenya Rift.

Tectonics have played a relatively more important role here, than in the other Quaternary basins studied in this work. The Olorgesailie sediments were laid down in a series of connected grabens. Fault movements took place during deposition, and lacustrine sedimentation was finally terminated by regional tilting towards the south (Isaac, 1968), which allowed water to flow uninterrupted through the area. There is no lake at Olorgesailie today.

Fig. 10.2

The stratigraphic relationships between the sedimentary units of the southern Kenya Rift

	MAGADI BASIN	KEDONG-OLORGESAILIE-KOORA BASIN
HOLOCENE	Evaporite Series (ca. 50m; lacustrine clays & trona) High Magadi Beds (ca. 20m; lacustrine silts & clays; ca. 10,000 y.B.P.)	Coarse alluvial gravels & floodplain deposits - - - ? - - - - ? - - - - ? - - - -
PLEISTOCENE	Ndupa beds (ca. 10m; fluvial pyroclastics) '700m' lake beds (ca. 5m; lacustrine silts and sands) - - ? - - - - ? - - - - ? - - - -	Alluvial fans, gravels & floodplain deposits
	↑ ? ↑ ? ↑ ? ↑ ?	Munyu-wa-Gicheru diatomite (35m; lacustrine diatomites) Olorgesailie Formation (60m; lacustrine diatomites, clays & tuffs, alluvial sands & gravels; 0.4 my)
	Orkaramatian beds (ca.10m; lacustrine clays; less than 0.6 my) Oloronga beds (ca. 12m; water lain tuffs; ca. 0.8 my.) Old Chert beds (ca. 5m; lacustrine silt & clay)	
	MAGADI TRACHYTES (0.63 to 1.25 my)	

Based on: Crossley, 1979; Mitchell & Baker, 1976; Baker, 1958

Volcanism has also played an important role, mainly in providing source rocks that could be easily eroded and transported into the palaeolake. Numerous pure tuff bands suggest ash-fall directly into lake water. The role of climate is difficult to ascertain, but at least some of the many lake level fluctuations, reported later, are likely to be climate-related.

10(ii) The stratigraphy of the Olorgesailie Formation

10(ii)a Introduction to the Members of the Olorgesailie Formation

Shackleton divided the Formation into fourteen numbered units, which were later published by Baker (1958) as layers L1 to L14. Isaac (1968) modified this scheme and referred to the units as Members. Figure 10.3 shows the distribution of the Members. A composite of three sections were designated as the 'type section', by Isaac (1968). These were re-examined during fieldwork, and their lithologies are shown in figure 10.4.

Most of the Members show significant lateral facies variation, with finer grained and more diatomaceous units occurring towards the west. This reflects deeper and more permanent water in the west. Much of the outcrop area lay in a critical zone, on the margins of an expanding and contracting lake, centred mainly on the Koora Graben (fig. 10.1). Any lake beds formed in the graben itself are now covered by a thick fluvial sequence, brought down from Mt. Olorgesailie, and introduced by the Ol Keju Nyiro River.

Three small exposures exist, that are difficult to correlate with the main outcrop of Olorgesailie sediments. Isaac (1978) gave these the following informal names: the Oltepesi beds, the Sonorua beds and the Shanamu beds. All contain similar lithologies to those found in the Olorgesailie Formation (see fig. 10.1 for their locations).

The various Members of the Olorgesailie Formation will be described in the following sections, paying particular attention to their lateral relationships. Certain Members can be traced throughout the area, while others are only distinguishable in a few local outcrops.

Fig. 10.3

Geological map of the Olorgesailie area

(simplified after Shackleton)

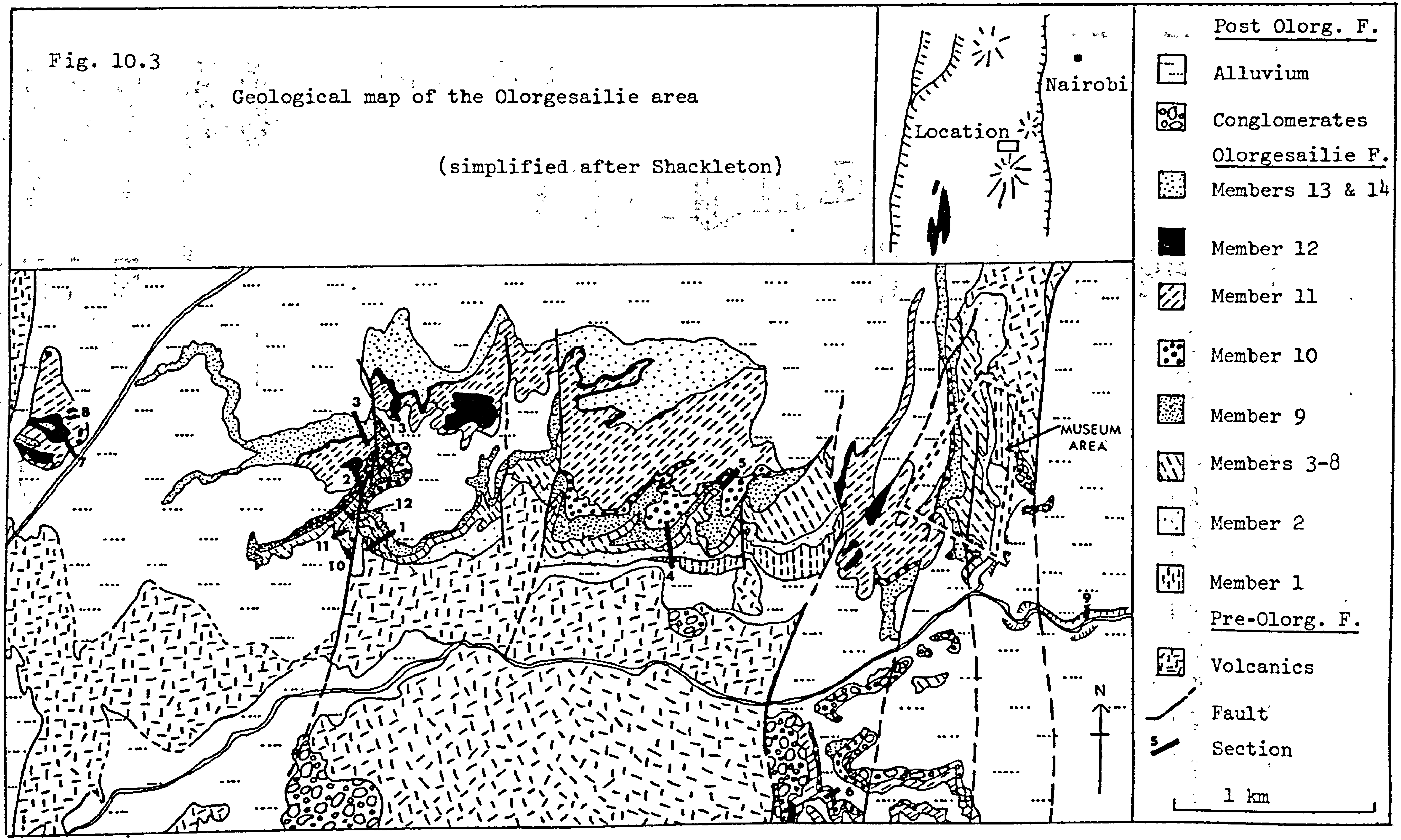
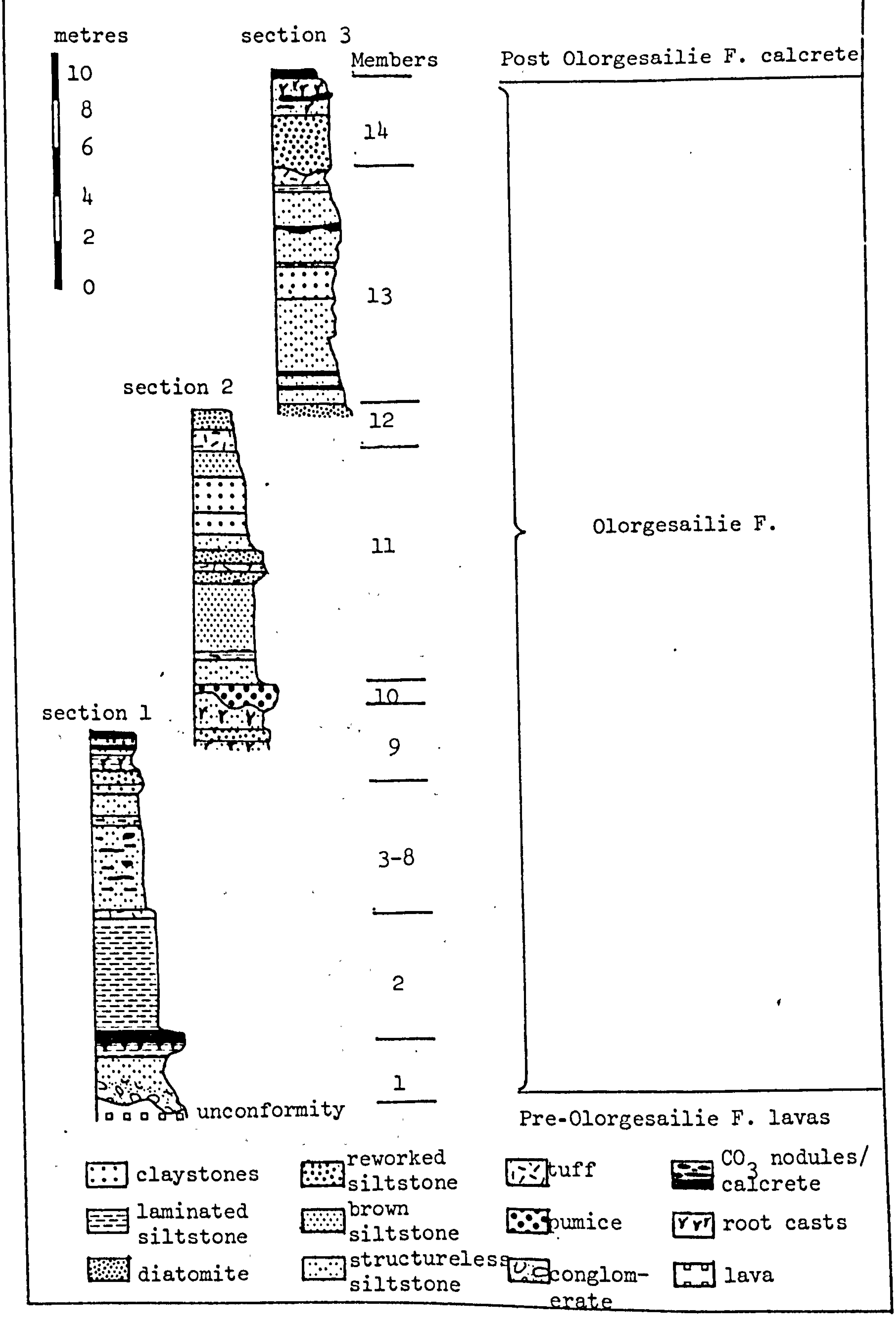


Fig. 10.4 Composite type section of the Olorgesailie Formation



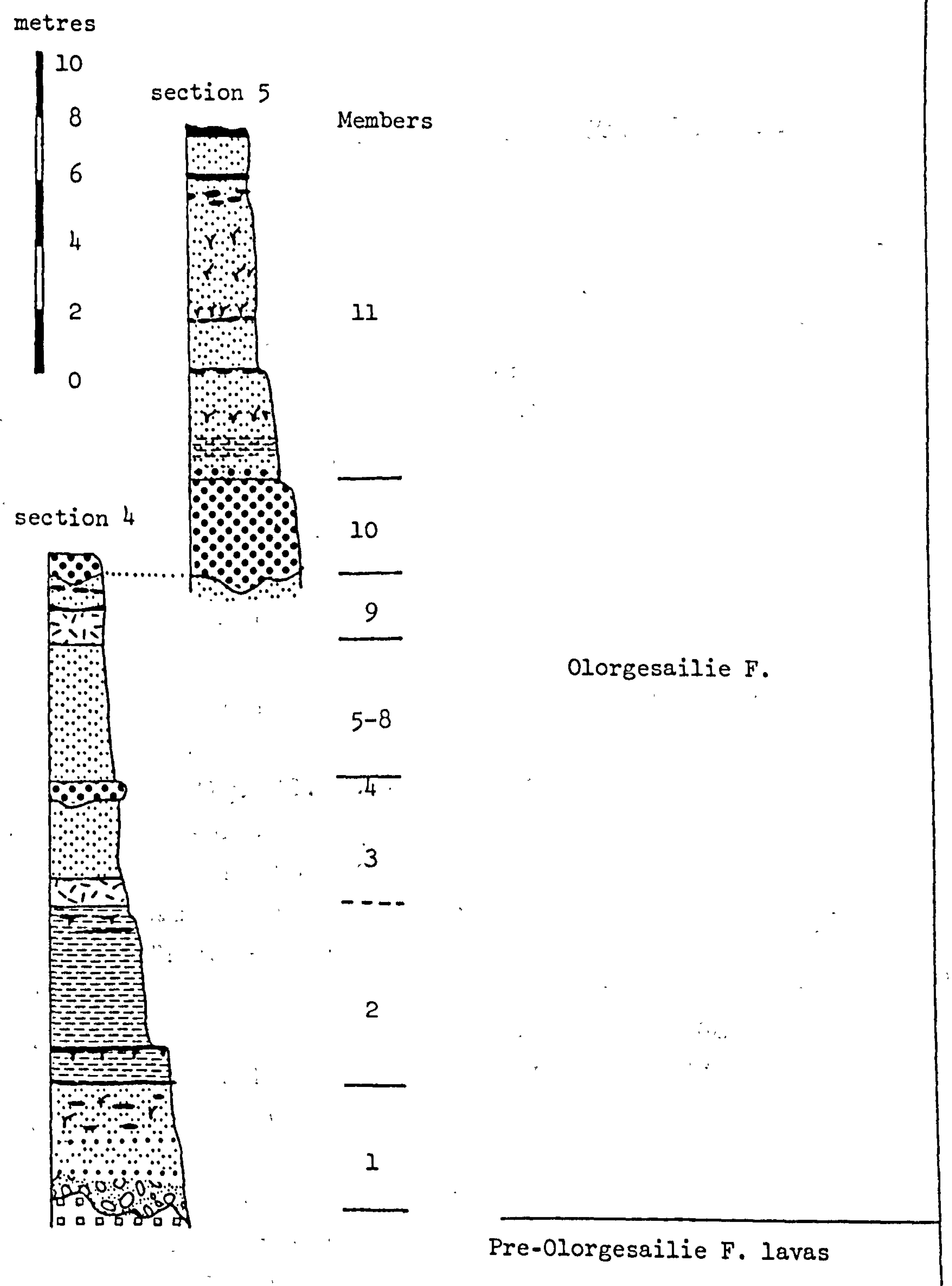
10(ii)b The lithologies and facies variations of Members 1 and 2

Member 1 includes conglomerates, tuffaceous and diatomaceous siltstones, diatomites and claystones. Palaeo-sols, calcretes and calcareous root casts occur locally. Isaac (1978) notes several artefact localities in this Member. It is mostly between 1 and 3 m thick, but occasionally reaches 10 m. Member 1 is exposed in sections 1 and 4 (figs. 10.4 and 10.5 respectively). In both sections, the Member begins with a poorly-sorted sandy conglomerate. This gives way to to pebbly siltstones, with clay pellets and local root casts. These coarse units are confined to the base of Member 1, and are usually less than 1 m thick. Their poorly-sorted nature, angularity and lithology suggest local transportation, possibly involving fluvial and subaerial processes.

The conglomerates are succeeded by structureless claystones and pebbly tuffaceous siltstones. The latter deposits are indistinctly laminated. Powdery carbonate concretions (1 to 2 mm) are common at several levels. Diatoms are rare and confined to the siltstones. These, together with diatoms from other parts of the Formation, will be discussed in chapter 11. The fine grained nature, weak lamination and presence of diatoms suggests at least a shallow water cover at the time of formation. Further east, in the museum area (from which samples could not be obtained), Member 1 consists of buff claystones overlain by laminated cream diatomites, which suggest lacustrine conditions.

Shackleton (in Baker, 1958) described Member 2, in the museum area, as consisting of brown laminated clays and diatomites. These pass westwards into tuffaceous silty sandstones with diatoms, and ultimately into well laminated, highly diatomaceous, white siltstones. This Member attains a maximum thickness of about 6 m. Diatoms form up to 90 % of the sediment, while montmorillonite constitutes the remainder. A westerly and south-westerly

Fig. 10.5 Composite section of Members 1 to 11



Key to symbols shown in fig. 10.4, locations given in fig. 10.3.

increase in thickness, improved lamination, increase in diatom numbers and floristic changes, suggest a lake that was centred on the Koora Graben (fig. 10.1). Lake marginal conditions are recorded by the coarser, tuffaceous, silty sandstones, mentioned earlier.

10(ii)c The lithologies and facies variations of Members 3 to 8

Members 3 and 4 can be recognised in most outcrops. However, they become progressively difficult to distinguish from one another, and from Members 5 to 8, in western exposures. Members 5 to 8 can only be clearly identified in the east. Their original designation as Members owed much to the existence of Acheulian hand axes in the east, and to the relatively more detailed stratigraphic studies that these artefacts stimulated.

Member 3 includes yellowish grey, tuffaceous and diatomaceous siltstones, and tuffaceous fine to medium sandstones. It is indistinguishable from Members 4 to 8 in the extreme west. However, it is quite well defined at section 4 (fig. 10.5). Here, 3 m of siltstones and tuffaceous sandstones rest on Member 2, and are eroded by channels at the base of Member 4. Diatoms are rare and often fragmentary. Further east, at the archaeological museum, Shackleton (in Baker, 1958) describes 1.5 to 4 m of greyish weathering, bedded, tuffaceous and diatomaceous siltstones as forming Member 3. The bedding, although often weak, and presence of diatoms, suggests deposition under lake conditions.

Member 4 consists of tuffaceous sands and fine to coarse pumice gravels, which in most areas have an erosional base. Locally they are trough cross-bedded. These deposits decrease in grain size to the west, where they pass into silty sands and sandy silts. At the same time the erosional base becomes gradational and the Member difficult to recognise. These are probably alluvial sediments, which pass westwards into lake marginal deposits. They reflect an influx of pumice sands into the lake, and probably a regression towards the Koora Graben.

Members 5 to 8 cannot be separated at the type section (fig. 10.4), where they are represented by yellow and white siltstones, tuffaceous siltstones, ash layers and claystones. Diatoms are uncommon and often fragmentary, and when present suggest shallow waters. These Members could not be properly studied in the east, because of the National Museum status of the area. However a detailed account of the lithological sequence has been given by Isaac (1968), and this is summarised below.

M8 Pale brown tuffaceous shales (marls) with beds of hard volcanic siltstones which may be bright red, 11 ft.

M7 Pale yellow volcanic silts, diatomaceous silts plus a palaeosol horizon. Cut and fill bedding, 7 to 15 ft.

M6 Greenish silty volcanic sandstone, 3 ft.

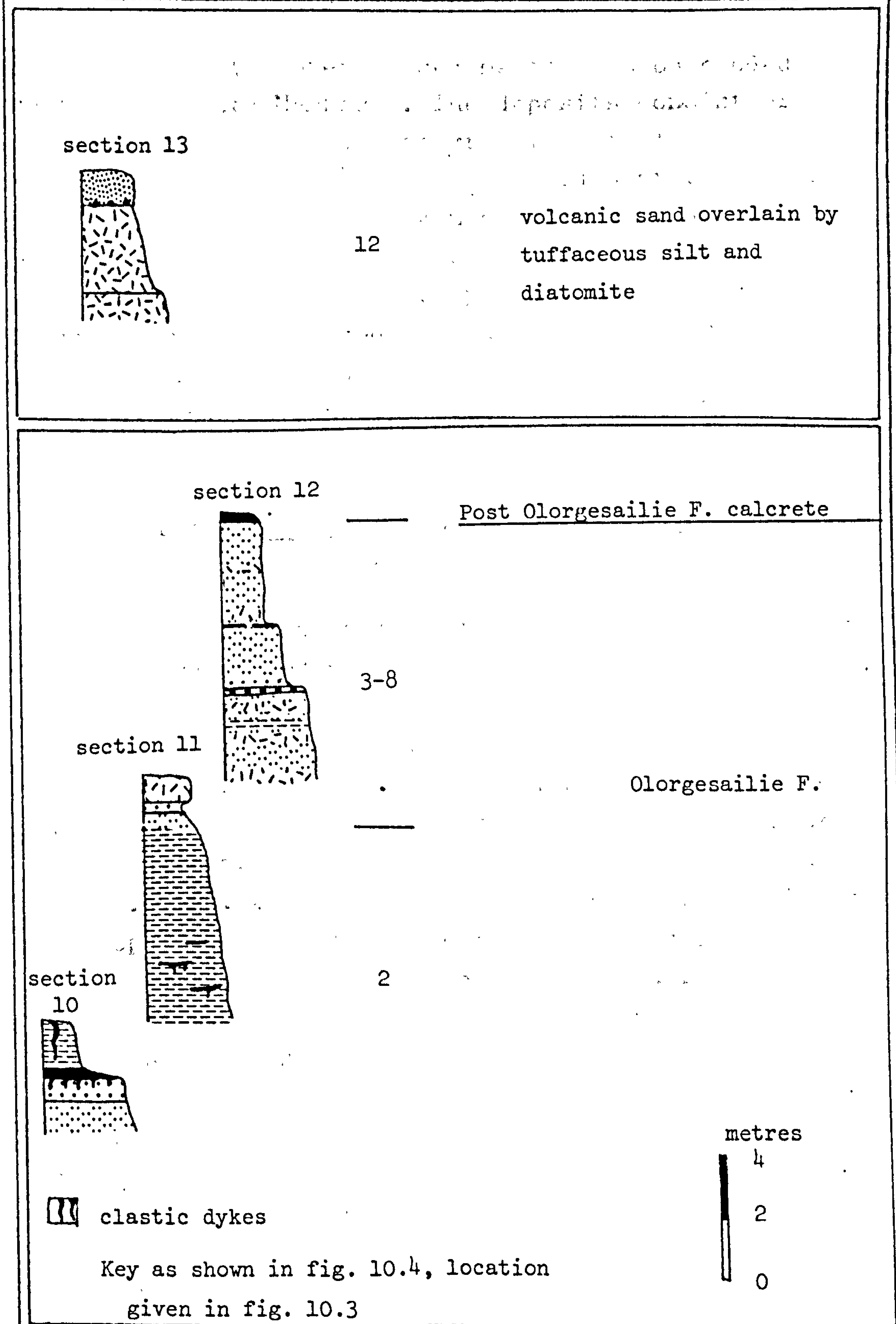
M5 Massive root marked greenish yellow volcanic silts. Weathered during deposition, 2 to 6 ft.

10(ii)d The lithologies and facies variations of Members 9 and 10

Member 9 is up to 8 m thick, and consists of basal tuffaceous sands and between 1 and 5 m of overlying white and yellow diatomaceous silts. To the east, the silts thin and pass into pale tuffaceous, and less diatomaceous, siltstones. Westwards, at section 12 (fig. 10.6), Member 9 has been eroded, and a post-Olorgesailie Formation calcrete sits directly on Members 5 to 8. At the type section (fig. 10.4) two diatomites are present, which include a mixed benthonic, epiphytic and planktonic flora.

Fig. 10.6

Composite section of Members 2 to 8 plus Member 12



The diatoms are commonly broken and may be reworked. However, the sparse diatom flora found in many parts of this Member does suggest deposition under lacustrine and marginal lacustrine conditions.

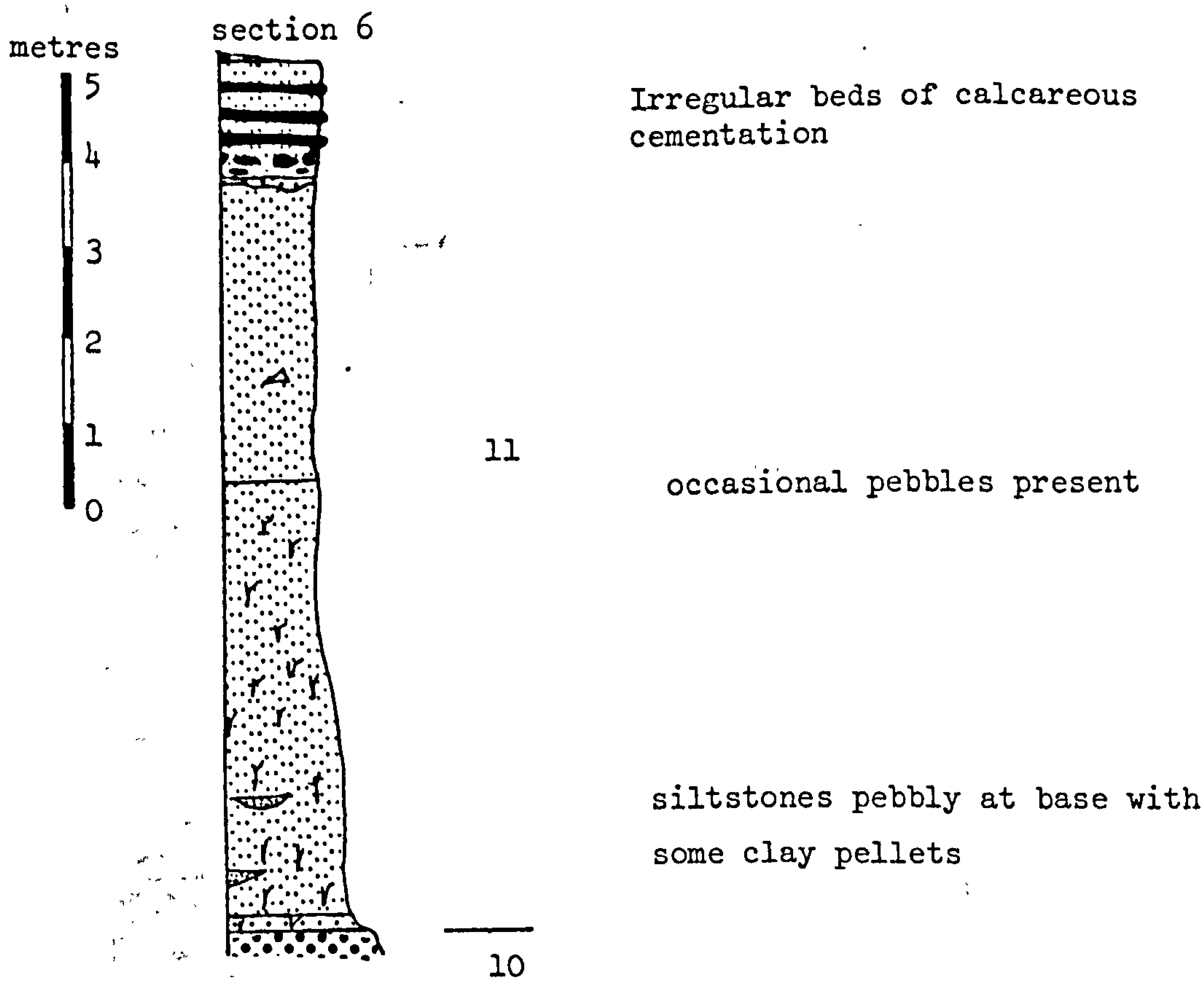
Up to 3 m of Member 10 sediments rest on eroded surface cut into Member 9. The deposits consist of tuffaceous sands and pumice gravels, similar to those of Member 4. Isaac (1968) has determined that they have an overall fan shape, the alignment of which indicates a north-easterly provenance. Westwards, the pumiceous sands and gravels pass into finer, poorly-sorted sands and silts. In these areas, reworked diatomaceous silt fragments may also be found. The sediments and lack of diatoms suggest a lake regression, and the south-westerly advance of rivers.

10(ii)e The lithologies and facies variations of Members 11 to 14

Member 11 attains a maximum thickness of about 18 m. A wide range of sediments are present and include brown silty clays and silty sands, grey tuffaceous silts and clays (which are locally reddened), pumiceous tuffs, diatomaceous silts and diatomites. Many horizons are calcareous, and in a few layers carbonate nodules are well developed. Member 11 is shown in sections 2, 5, 6 and 7 of figs 10.4, 10.5, 10.7 and 10.8 respectively. The Member oversteps Members 1 to 10 in the south-east, and comes to rest directly on the volcanic slopes of Mt. Olorgesailie. At the museum site, Shackleton (in Baker, 1958) describes the Member as 19 to 27 ft of impure diatomite with ash bands. Diatoms (described in chapter 11) and root casts suggest that much of the sequence was laid down under lake marginal conditions , although occasional deeper water episodes can be suggested from the diatom data.

Member 12 is up to 4 m thick and commences with a poorly consolidated tuff. This is overlain by a prominant diatomite, which on its upper bedding plane is locally

Fig. 10.7 Members 10 and 11 from a section on the northern flanks of Mt. Olorgesailie



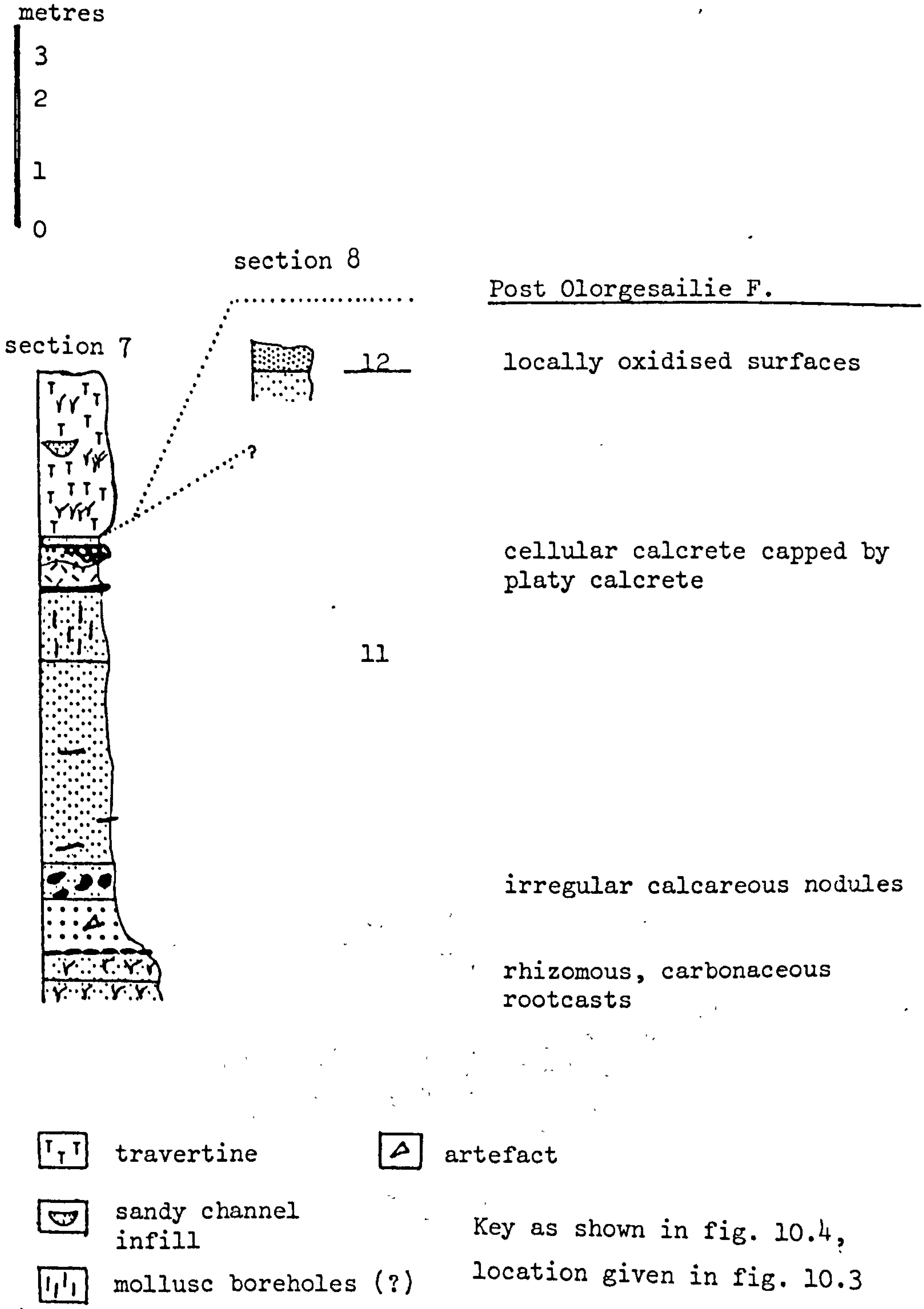
gravel lenses

artefact

Key as shown in fig. 10.4, location given in fig.10.3

Fig. 10.8

Composite section of Members 11 and 12 from the western basin margins



Key as shown in fig. 10.4, location given in fig. 10.3

bright red. The diatomite is very pure and contains mainly benthonic and epiphytic species (many of which are broken), that suggest shallow, possibly turbulent, moderately alkaline water.

Member 13 is about 12 m thick at its maximum. It consists of brown clays and silts, diatomaceous silts and clays and diatomites. Exposures are restricted to the western and central areas of figure 10.3. The Member is shown in section 3 of figure 10.4.

Member 14 is exposed only in the north-west, along the line of a series of south and south-east facing scarps. It is included with Member 13 in figure 10.3, because of its narrow outcrop, and is shown in section 3 of figure 10.4. The unit consists of up to 3 m of reworked diatomaceous silts and partially silicified limestones. In situ, carbonate-filled root casts are common. In view of their diatom content and root casts, it is probable that Member 14 represents sedimentation under marginal lake conditions.

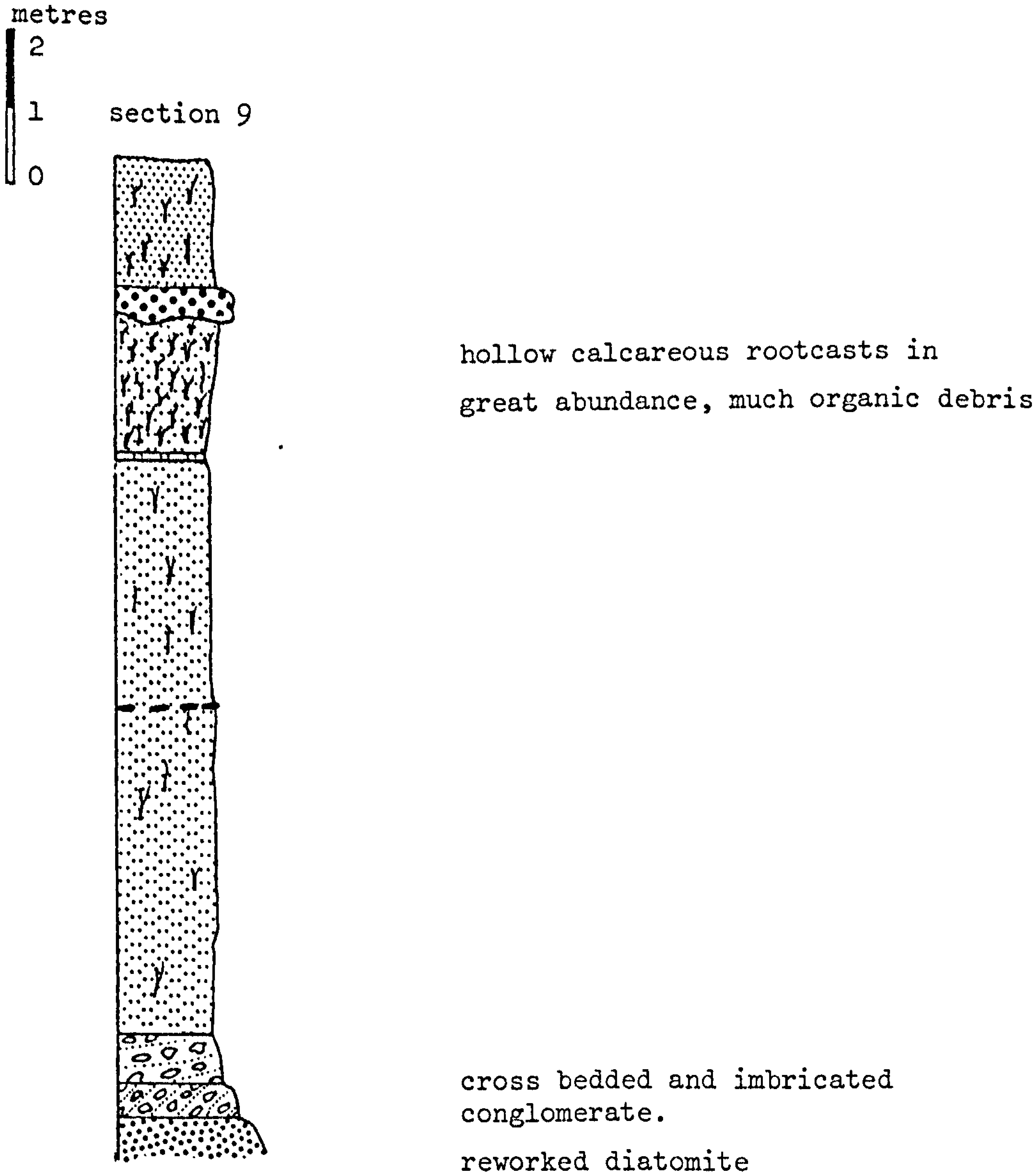
10(ii)f <u>The Oltepesi, Shanamu and Sonorua beds</u>.

These deposits are similar to the Olorgesailie Formation, but their exact relationships are uncertain. As a result, they were informally designated the Oltepesi, Shanamu and Sonorua beds, by Isaac (1978).

The Oltepesi beds were considered to post-date the Olorgesailie Formation by Shackleton. In contrast, Isaac (1978) thought that they were equivalent to the upper Members of the Olorgesailie Formation. They crop out in a gorge cut by the Ol Keju Nyiro River, and are shown in section 9 (figs. 10.3 and 10.9). The sediments are up to 15 m thick and include brown silts and silty clays, yellowish tuffaceous silts, grey tuffs and some diatomaceous silts. Pumiceous units and imbricated pebbles may have been laid down in river channels. Diatoms are rare and often

Fig. 10.9

Section in the Oltepesi beds



 cross bedded pebbles & conglomerates

Key as shown in fig. 10.4, location given in fig. 10.3

broken, consisting mainly of benthonic species.

The Sonorua beds are a series of small sediment patches that lie along the western margin of the Koora Graben. They are mainly less than 5 m thick, and include diatomaceous silts, clays and tuffaceous units. The Shanamu beds were not examined in this work. Isaac (1978) reports that they are poorly exposed sediments in a small depression on the crest of the Shanamu horst, which forms the western boundary of the Legemunge Plain and the Koora Graben.

10(iii) The mineralogy of the Olorgesailie Formation

10(iii)a Detrital and biogenic sedimentation

A series of grain size analyses of selected lithologies are shown in table 10.1. These sediments are typical of the Olorgesailie Formation, and reflect the dominance of silt (9 to 4 phi), and clay (+9 phi) grades, except in the fluvially deposited pumice gravels (which have a bimodal size distribution), and the volcanic sands. Most deposits show only a slight skewness. Maximum values of 0.21 to 0.40 occur in tuffaceous/pumiceous deposits. Sorting is variable, and probably reflects the relative roles of three sediment sources.

- (i) Fluvially derived detrital grains
- (ii) Ash falls directly into the palaeolake
- (iii) Biological contributions (mainly diatoms) of floras and faunas that lived in the palaeolake.

A semi-quantitative summary of the mineralogy of different size fractions is given in table 10.2. Excluding pumiceous units, the sand and granule fractions (4 to 3 phi) are composed mainly of lithic grains, and alkali feldspar (mostly anorthoclase), with subsidiary clinopyroxenes, volcanic glass and quartz. Lithic fragments are dominated by trachyte (70 %). Basalts, phonolites, obsidian and reworked calcite cemented tuffs have also been recorded. Basalt fragments appear to decrease upwards in the succession. Non-volcanic particles include micritic limestone with coatings of Mn-oxides (reworked calcrete ?), and cryptocrystalline silica of uncertain origin.

The silt fraction is often dominated by alkali feldspar (anorthoclase, sanidine and cryptoperthites), volcanic glass, biogenic opaline silica (diatoms, sponge spicules), and varying quantities of quartz. Mafic minerals include augite,

Table 10.1 Grain size data (wt. %) and graphic statistics for selected lithologies from the Olorgesailie Formation

Grade	1	2	3	4	5	6	7	8	9	10	11
Medium gravel	..	..	..	..	..	..	..	..	..	..	1.85
Fine gravel	..	..	..	..	..	..	..	..	..	..	18.25
Coarse sand	..	..	..	..	..	..	..	2.43	..	..	36.13
Medium sand	..	..	..	..	..	..	..	14.04	..	..	12.24
Fine sand	..	0.20	..	2.31	..	..	..	55.63	7.21	..	20.24
Coarse silt	38.91	25.62	3.79	61.16	7.14	..	1.43	13.13	84.17	17.43	8.50
Medium silt	54.57	32.75	45.79	24.02	16.05	..	2.58	4.79	6.43	62.38	1.16
Fine silt	5.85	32.41	48.40	10.53	58.29	15.53	26.15	6.69	2.19	18.73	1.63
Clay	0.67	..	2.02	1.98	18.52	84.47	69.84	3.29	..	1.46	..
Median (phi)	6.1	6.8	7.0	5.9	7.9	9.7	9.3	3.2	4.8	6.6	0.6
Mean (phi)	6.19	6.91	7.00	5.88	7.92	9.74	9.20	3.57	4.84	6.58	0.81
Skewness	0.14	0.19	0.15	0.39	-0.06	0.01	-0.33	0.40	0.17	0.12	0.21
Kurtosis	1.05	1.08	1.18	1.78	0.99	0.94	1.43	1.51	1.41	1.52	0.99
Sorting	0.58	1.32	0.62	0.81	1.28	0.70	0.66	1.77	0.57	0.60	2.32
I.G.S.D.	0.55	1.36	0.67	1.04	1.30	0.72	0.72	1.98	0.67	0.72	2.31

1 - Diatomite
2 - Laminated diatomaceous siltstone
3 - Diatomaceous siltstone
4 - Tuffaceous diatomaceous siltstone (red bed)
5 - Diatomaceous clayey siltstone
6 - Non-tuffaceous claystone (rootcast)
7 - Tuffaceous claystone
8 - Volcanic sands (fluviatile)
9 - Grey vitric ash
10 - Fine grey vitric ash
11 - Fine pumice gravel

I.G.S.D.: Inclusive graphic standard deviation

Table 10.2 The minerals of the Olorgesailie Formation

MINERAL	SANDS	SILTS	CLAYSTONES
Alkali feldspar	xxxx	xxxx	xx
Plagioclase	x	xx	x
Nepheline	-	x	x
Quartz	xx	xxx	x
Volcanic glass	xxxx	xxxx	xxx
Opaline silica	xx	xxxx	xxx
Smectite	-	xx	xxxx
Kaolinite	-	x	xx
Illite	-	-	x
Chlorite	-	-	x
Analcime	-	-	x
Augite	xx	xx	-
Aegerine	x	xx	x
Aegerine-augite	x	xx	x
Aenigmatite	xx	xx	-
Kataphorite	x?	x	-
Arfvedsonite	-	x	-
Basaltic hornblende	x?	x	-
Hornblende	x	x	-
Kaersutite	-	?	-
Magnetite/ilmenite	-	x	-
Limonite/iddingsite	x	xx	x
Sphene	-	x	-
Calcite	xxxx	xxxx	xxxx
Mn-oxides	x	xx	x
'X-ray amorphous' clay	-	x	xx
Lithic fragments	xxxx	xx	x

The table indicates semi-quantitative estimates of the range of compositions of different grain size fractions. The symbols used indicate the following:

xxxx - abundant in most samples
xxx - common to abundant
xx - present to common
x - present in some samples

Lithic clasts (based on data supplied by R. Renaut):

1. Aphyric trachyte - sanidine, aegerine-augite
2. Anorthoclase-phyric trachyte - anorthoclase phenocrysts, sanidine groundmass, ? aenigmatite.
3. Trachyte (3 types)
4. Felsic trachyte
5. Weathered basalts (possible 2 types)
6. Aphyric, aphanitic felsic lava ? phonolite

aenigmatite and a range of alkali pyroxenes and amphiboles. Plagioclase (An_{80-55}) accounts for up to 50% of the total feldspar. The purest diatomites, vitric tuffs and ashes contain very little extraneous matter.

The clay fraction is consistantly dominated by smectites (70 to 100 %), with lesser kaolinite (0 to 20 %) and minor illite and chlorite (0 to 10 %). X-ray diffraction data suggests that much of the smectite in tuffaceous claystone and siltstone is poorly crystalline, although interference by glass and diatom silica may have caused poor reflections (Renaut, pers. comm.). Higher intensity peaks were recorded in non tuffaceous claystones, suggesting a more ordered structure. Kaolinite is most abundant in brown siltstones and claystones. Chlorite is commonly found with plagioclase-bearing sediments, suggesting it may be a product of basalt weathering (Renaut, pers. comm.).

10(iii)b <u>Authigenic mineralisation and post-depositional processes</u>

As noted by Isaac (1978), authigenic minerals indicative of high salinity and alkalinity (Hay, 1970) have generally not developed at Olorgesailie. Diffraction traces of the clay fraction of tuffaceous clayey siltstones from the base of Member 11, whose diatom flora suggests an alkalinity of up to <u>ca</u>. 85 meq/l (p.366), indicate the presence of minor amounts of analcime. Although not confirmed optically, its apparent restriction to this Member suggests an authigenic origin. Cerling (1979) has shown that analcime is stable in East African lakes at alkalinities of <u>ca</u>. 100 meq/l or more, slightly above that suggested by the diatoms.

The most significant post-depositional processes of alteration are the localised dissolution and replacement of glass shards by clay minerals, and widespread cementation by calcium carbonate. In several thin sections fine glass shards are replaced by clay pseudomorphs, presumably smectites. The alteration is most common in root-marked palaeosols and below local disconformities, suggesting a weathering reaction. Hay (1976) similarly recorded alteration of tuffaceous sediments to smectite from 'soils' at Olduvai Gorge. Although glass has been altered, diatom frustules have remained unchanged.

Calcium carbonate occurs throughout the Formation as a calcite cement, and as various forms of calcrete. Cementation appears to have occurred soon after deposition, as calcite cemented intraclasts have been observed at several levels. Isaac (1978) has recorded the silicification of calcrete in Member 14.

10(iv) The sediment provenance of the Olorgesailie Formation

10(iv)a The origin of the detrital minerals

The alignment of palaeochannels, inferred palaeocurrent directions (Isaac, 1978), facies distributions and the gradual development of a southward sloping Rift floor (Crossley, 1979), all suggest a predominantly north to south drainage during the deposition of the Olorgesailie Formation. With the possible exception of coarse pumice and ash, the detrital mineralogy can be more or less accomodated by lithologies in the present catchment, though at times this may have extended further north, perhaps as far as modern Lake Naivasha.

The dominance of anorthoclase among the feldspars of the sand fractions may reflect its occurrence as phenocrysts in the trachytes north and west of Olorgesailie (Limuru Trachytes, Plateau and Magadi Trachytes). Sanidine is a common groundmass mineral of the lavas and is correspondingly common in the silt fractions. Plagioclase probably originates from the Ol Keju Neru and Ol Tepesi Basalts to the east, but is rarely significant, perhaps reflecting its more rapid weathering than alkali feldspar. Its irregular distribution points to periodic inputs into the basin. Quartz may originate from the Plateau and Magadi Trachytes (where it is found as interstitial grains; Crossley, 1979). The range of alkali pyroxenes and amphiboles suggest several types of trachytes (and/or phonolites) may have been weathered.

The abundance of smectite in the clay fraction indicates an imperfect leaching of cations in the contemporary source region (Singer, 1980). This, together with the freshness of many minerals and periodic calcrete development, suggests that the climate prior to and during deposition was not exceptionally humid. Clay samples from modern volcanic soils in the catchment show a similar predominance of smectite, with some kaolinite detected in reddish latosolic soils along the eastern Rift shoulder (Renaut, pers. comm.).

10(iv)b The origin of the pumice and ash

Most of the ash horizons are composed of fresh, comminuted, glass shards. In the thicker, coarser units, alkali feldspar and pale green pyroxenes are present, while anorthoclase is found in coarse pumice fragments. This suggests a broadly trachytic composition.

Suswa and Longonot are trachyte-phonolite and trachyte central volcanoes on the rift floor, to the north of Olorgesailie. Scott (1980) has shown that both became active at ca. 0.4 my, or about the time of Olorgesailie sedimentation. Both volcanoes experienced an early 'pre-caldera' stage, but only Longonot shows evidence of pyroclastic eruptions at this time. Longonot may therefore be the primary source of much of the coarse pumice and ash. Possibly of significance are records of obsidian in the primitive Longonot volcano (Scott, 1980), which has also been found as sub-rounded grains in the pumice sands and gravels of Member 10. A possible palaeodrainage link would have been via the Kedong Gorge (Sikes, 1926), with rivers eventually reaching the palaeolake along its north-eastern shoreline (fig. 11.8, p. 372).

10(v) Lithofacies classification of the Olorgesailie Formation

Although the Olorgesailie sediments often grade into one another, ten broadly defined sediment types can be recognised, each having its own environmental significance. Figure 10.10 shows the distribution of these 'lithofacies' in a hypothetical lake, and they are described in the following paragraphs.

(1) Laminated siltstone lithofacies

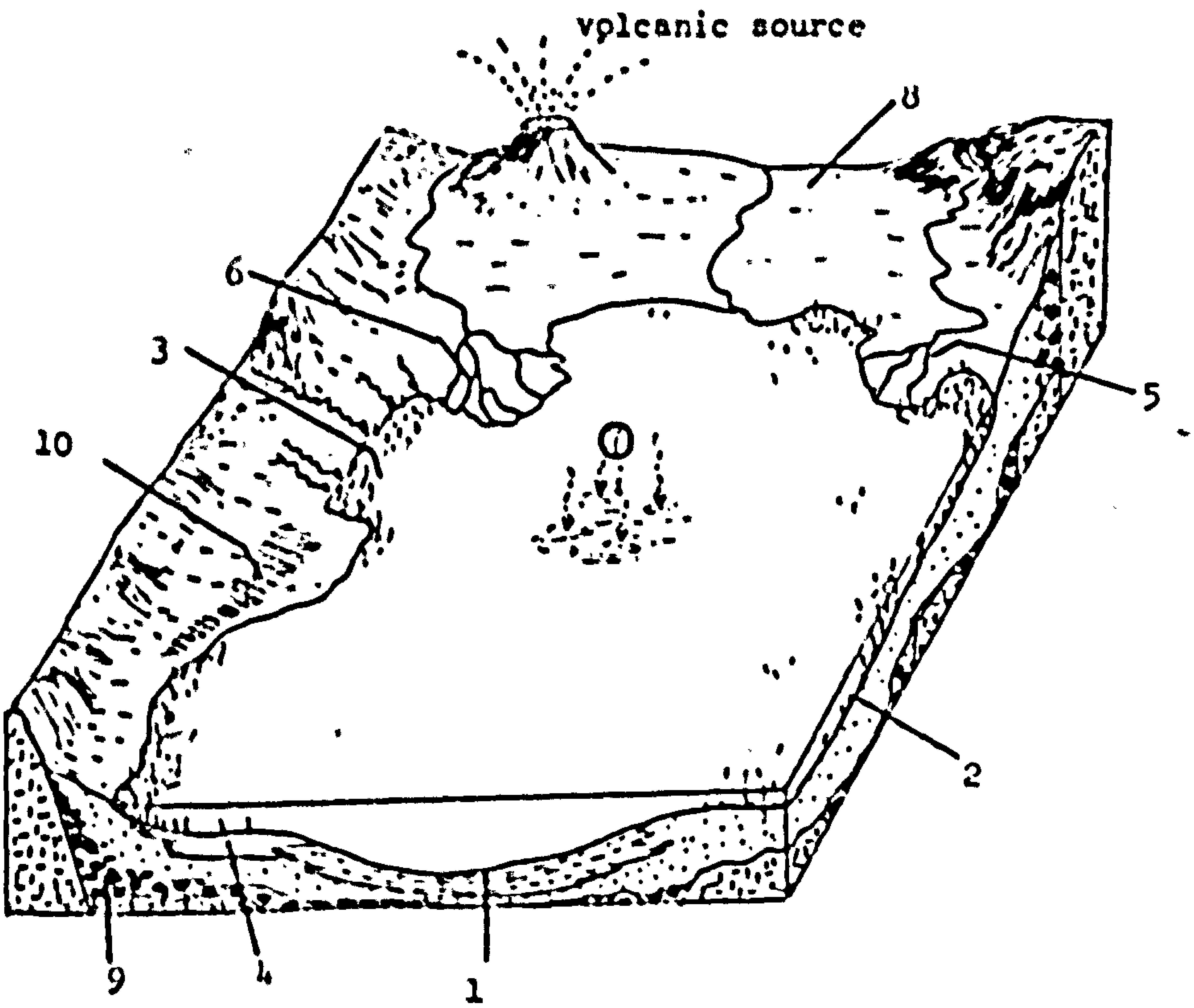
This is characterised by well laminated, white to pale yellow, highly diatomaceous, often tuffaceous, clayey siltstones and siltstones (plate 10.2). Wispy black flecks are sometimes present on bedding planes. The fine grain size and moderate sorting suggest a low energy environment. This, together with their planktonic diatom content, probably reflects deposition under deep, calm water. Although present throughout the Formation, this lithofacies is best developed in Member 2, where it attains a thickness of *ca*. 5 m.

(2) Structureless, tuffaceous, diatomaceous siltstone and claystone lithofacies

This facies, which is present in most Members, consists of a heterogenous mixture of varying proportions of volcanic ash and diatoms in structureless clays, silts and fine sands (plate 10.2). The sediments are white, pale yellow, or grey, moderately to poorly sorted, and though generally massive, locally display mudcracks. Units range from a few centimetres to several metres thick. Root casts are locally present, taking three forms:

a) Fine, subvertical, carbonaceous root marks.
b) Irregular and branching, calcareous (locally

Fig. 10.10 Schematic representation of depositional environments occuring in the Olorgesailie F.



LITHOFACIES		ENVIRONMENT
1	well laminated siltstone	:deep lacustrine
2	structureless, tuffaceous, diatomaceous siltstone and claystone	:shallow lacustrine
3	redeposited diatomaceous siltstone	:marginal lacustrine
4	massive diatomite	:shallow lacustrine
5	interbedded volcanic, siltstone and conglomerate	:fluvial channels & floodplain
6	pumiceous sandstone and conglomerate	:fluvial channels & floodplain
7	volcanic ash and tuff	:airfall into lake
8	brown siltstone and claystone	:floodplain
9	poorly-sorted sandy conglomerate	:colluvial
10	calcrete	:subaerial evaporation zones

Plate 10.2

Members 2 to 10 of the Olorgesailie Formation. Laminated siltstone lithofacies forms the distinct white mound at the scarp foot. Grey layers are volcanic ash and tuff. Much of the remaining deposits belong to the structureless, tuffaceous, diatomaceous siltstone and claystone lithofacies. The exposure is capped by pumiceous sandstone and conglomerate (uppermost grey unit). The scarp is about 20 m high.

siliceous) root casts.

c) 'Infill root casts', in which fine grained silts infill former root cast voids.

Diatoms are mostly littoral forms, suggesting shallow lacustrine sedimentation, with local patches of reed-bed.

(3) Redeposited diatomaceous siltstone and claystone lithofacies

Periodic regressions across gently sloping littoral flats have permitted the local reworking of lake marginal deposits, probably by a mixture of ephemeral streams, sheetwash, wind and limited wave action. The resulting sediments are generally mixed siltstones composed of highly fragmented diatoms and/or small irregular intraclasts of diatomaceous and tuffaceous silts in a mixed clay-silt matrix. Root marking and allochthonous plant debris (macrophytes) are often associated.

(4) Massive diatomite lithofacies

Pure diatomites occur in beds up to 10 cm thick, and are found in several of the higher Members, notably in Member 12, where one attains about 1 m. The diatomites are homogeneous, white, biogenic siltstones consisting almost entirely of whole and fractured diatom frustules. They are essentially structureless, moderately sorted and locally contain fine, black and brown root marks. The diatoms are typically littoral (often epiphytic) forms, and suggest deposition under shallow water with local reed beds. Clastic input would have been low at the site of sedimentation.

(5) Interbedded volcanic sandstone, siltstone and conglomerate lithofacies

This lithofacies is prominent in some of the northern and eastern exposures (mainly Members 5 to 7). It is characterised by generally lenticular units of interstratified, bedded and massive, volcanic sands, silts and gravels, lying in shallow erosional channels. High angle planar cross beds, trough cross beds and horizontal beds occur.

Both distally and vertically, the sands and silts extend beyond the channel confines as thin, poorly laminated sheets, that are root marked and bear palaeosolic features.

The facies probably represents streams traversing a low gradiant alluvial to lake marginal plain. The thin tabular silt and sand sheets may represent distal outwash and overbank deposits on the margins of the palaeolake.

(6) Pumiceous sandstone and conglomerate lithofacies

Pumice conglomerates and sands are present in several Members, but are best developed in Member 10 (plate 10.2). They occur as both coarse channelled deposits (plate 10.3), and thinner, generally finer-grained, laterally extensive spreads. The chanelled sequences show normal grading and trough- and planar cross stratification. Minor disconformities and channel scour features are common. They are mostly very poorly sorted, but often very well rounded. The channel units resemble lithofacies (5), and are probably fluviatile in origin. The sheet-like pumice sandstones are poorly sorted (table 10.1), and have a mixed origin, probably as overbank deposits mixed with airfall tephra. The pumice gravels of Member 4 are mixed with lava sands, and are locally reworked into a series of

Plate 10.3

The pumiceous sandstone and conglomerate lithofacies. The photo shows a well developed channel eroded into structureless, tuffaceous, diatomaceous, siltstones and claystones. The channel deposits are dominated by fining upwards pumice. Volcanic pebbles and cobbles are common in the lower part. The channel is 2 to 3 m high.

poorly defined, regressional beach deposits (Isaac, 1977).

(7) Volcanic ash and tuff lithofacies

Although tuffaceous units occur throughout the Formation, several horizons consist almost entirely of tephra. These range from thin (less than 2 mm), grey dust layers, to coarse ash beds (up to 0.5 m) at the base of Member 9. Most of the thin beds are moderately well sorted, vitric or sparsely crystal-vitric. Most of the thinner tuff units were probably introduced by direct ash fall into the palaeolake. Some of the thicker, less pure tuffs, may represent the finer suspended load of lithofacies (6), or represent airfall tephra that has been reworked in channels or on a floodplain by sheetwash.

(8) Brown siltstone and claystone lithofacies

This facies occurs mainly in the higher Members. It consists of massive, often root marked siltstones and claystones, that are generally poorly sorted and show prismatic and sub-angular blocky structures. Locally they are weathered to pale olive clays. Fine gravel stringers or dispersed clasts, mud-cracks and calcareous nodules are present. Isaac (1978) noted the similarity of these deposits to recent alluvium, derived from erosion of local volcanic soils. They are essentially floodplain deposits, locally mixed with colluvium and modified by pedogenesis.

(9) Poorly sorted sandy conglomerate lithofacies

This lithofacies is confined largely to the base of Member 1, and to the upper Members near the slopes of Mt. Olorgesailie. It consists of angular to sub-rounded, coarse (up to 60 cm) weathered lava clasts, set in a poorly sorted matrix of brown and olive silty sands. They are probably of colluvial origin.

(10) Calcrete lithofacies

Calcrete occurs throughout the Formation, having formed in 'soils' on the floodplain and regressive margins of the palaeolake. It takes several forms, including powdery, nodular and massive hardpans. A distinctive platy calcrete, at the base of Member 2, infills polygonal dessication cracks, and may have formed from capillary rise of groundwater on the margins of the former lake (plate 10.4). Although mostly pale grey, many calcretes are heavily stained with manganese oxides, often concentrated in concentric rings or as dendrites. One analysed sample contained 0.64 % MnO - nearly five times the mean figure for calcrete quoted by Goudie (1973).

The lithofacies described above, are complexly intertongued and interbedded. Their distribution can be related to lake level fluctuations, which are in turn caused by climatic and tectonic interactions. Generally speaking, the deeper water lacustrine facies have formed in the western parts of the basin, while the marginal lacustrine and fluviatile facies have predominated in the north and east. The broad facies relationships are summarised in figure 10.11. Consideration of the various palaeogeographical relationships that gave rise to the lithofacies is postponed until after a detailed discussion of the diatom floras (chapter 11).

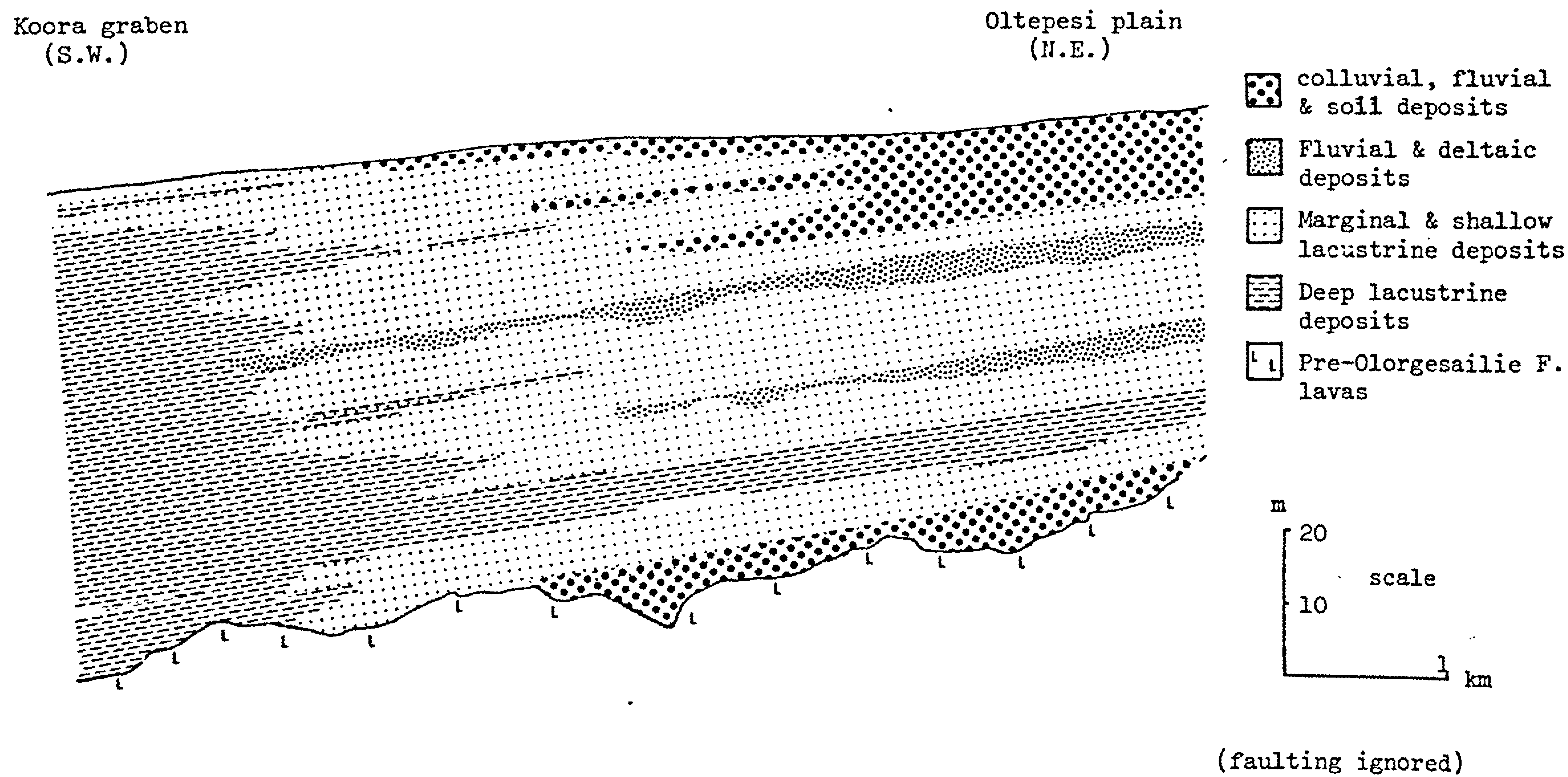
Plate 10.4

Calcrete infilling polygonal dessication cracks, in a laminated diatomaceous silt (basal Member 2). Note the lens cap for scale.

The same calcrete is shown in thin section below. Manganese oxides can be seen, infilling cracks in the micritic limestone, and occurring as 'dendrites'. Magnification is x 25 (photographic enlargement x 2.5).

Fig. 10.11

Schematic diagram showing the major facies changes of the Olorgesailie Formation



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CHAPTER 11

THE DIATOMS OF THE OLORGESAILIE FORMATION AND THEIR PALAEOECOLOGICAL CONDITIONS

11(i) The distribution of diatoms within the Olorgesailie Formation

11(i)a Introduction to the diatoms of the Olorgesailie Formation

This chapter aims to document the limnological history of a Rift Valley lake from its inception to cessation. The detail available is unique amongst the Pleistocene and older lacustrine sequences that occur in the Kenya Rift. The diatom populations suggest a lake whose chemistry has fluctuated widely. Of the lakes examined in this thesis, this chemical range has only been exceeded by Lake Bogoria (during the Holocene). However, in this latter case, diatoms are not common and the stratigraphic relationships difficult to establish.

Diatoms form a major part of the Olorgesailie Formation, with diatomites occurring at several horizons. Diatom preservation is variable and fragments are common in many units. These are commonly of benthonic species, and may record turbulent littoral environments and/or reworking of littoral sediments upon a lake regression. Often, reworking can be suggested from the occurrence of diatomite or diatomaceous silt particles in a deposit. In most cases fragmentation and/or 'anomalous species' have made it possible to exclude such diatoms from percentage counts.

A wide range of diatoms are present in the Olorgesailie Formation. Most of these belong to a few typical genera, which include: Melosira, Thalassiosira, Cyclotella, Epithemia, Rhopalodia, Cocconeis, Surirella and Campylodiscus. Of particular interest is the coexistence of Melosira and Thalassiosira. These tend to develop under fresh and highly alkaline conditions respectively, and have not been recorded together elsewhere during this work.

Much of the Olorgesailie Formation is exposed in an east to west trending, south-facing scarp. This excellent exposure, together with the lateral continuity of many Members, has made possible a study of the spatial distribution of the diatoms. The results of this work are summarised in figures 11.1 and 11.2, and will be discussed in the following sections.

11(i)b The lateral distribution of diatoms in Members 1 to 9

The lateral and vertical distribution of diatoms in Members 1 to 9 is summarised in figure 11.1. This figure points out the presence of various genera, and attempts to show where diatoms are most common by an increase in the density of the relevant symbol.

Diatoms have been studied in westerly outcrops of Member 1. Here, the basal conglomerates lack diatoms. They appear in the succeeding silts, but in low numbers. Epiphytes such as Epithemia zebra var. saxonica and E. sorex dominate initially, together with lesser numbers of Surirella ovalis and Rhopalodia spp.. Towards the top of the Member, Melosira granulata becomes more common, although still in low numbers.

Member 2 has been sampled at several localities. Diatoms are extremely abundant, and are dominated by Melosira granulata and its varieties valida and angustissima, M. agassizi, M. ambigua, M. distans, and to a lesser extent by Thalassiosira rudolfii and Stephanodiscus astraea. Several benthonic species also occur, but in low percentages. The

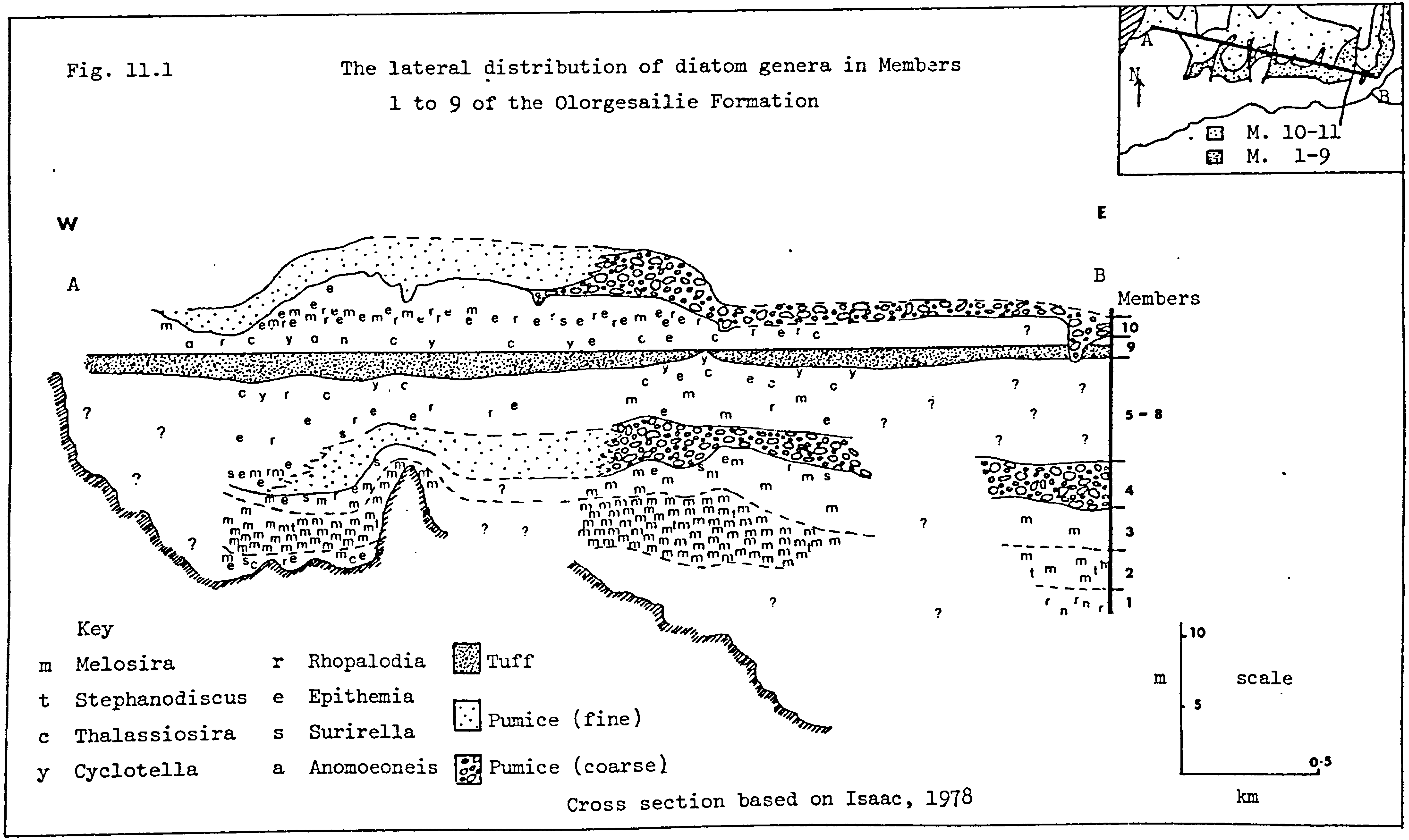


Fig. 11.1 The lateral distribution of diatom genera in Members 1 to 9 of the Olorgesailie Formation

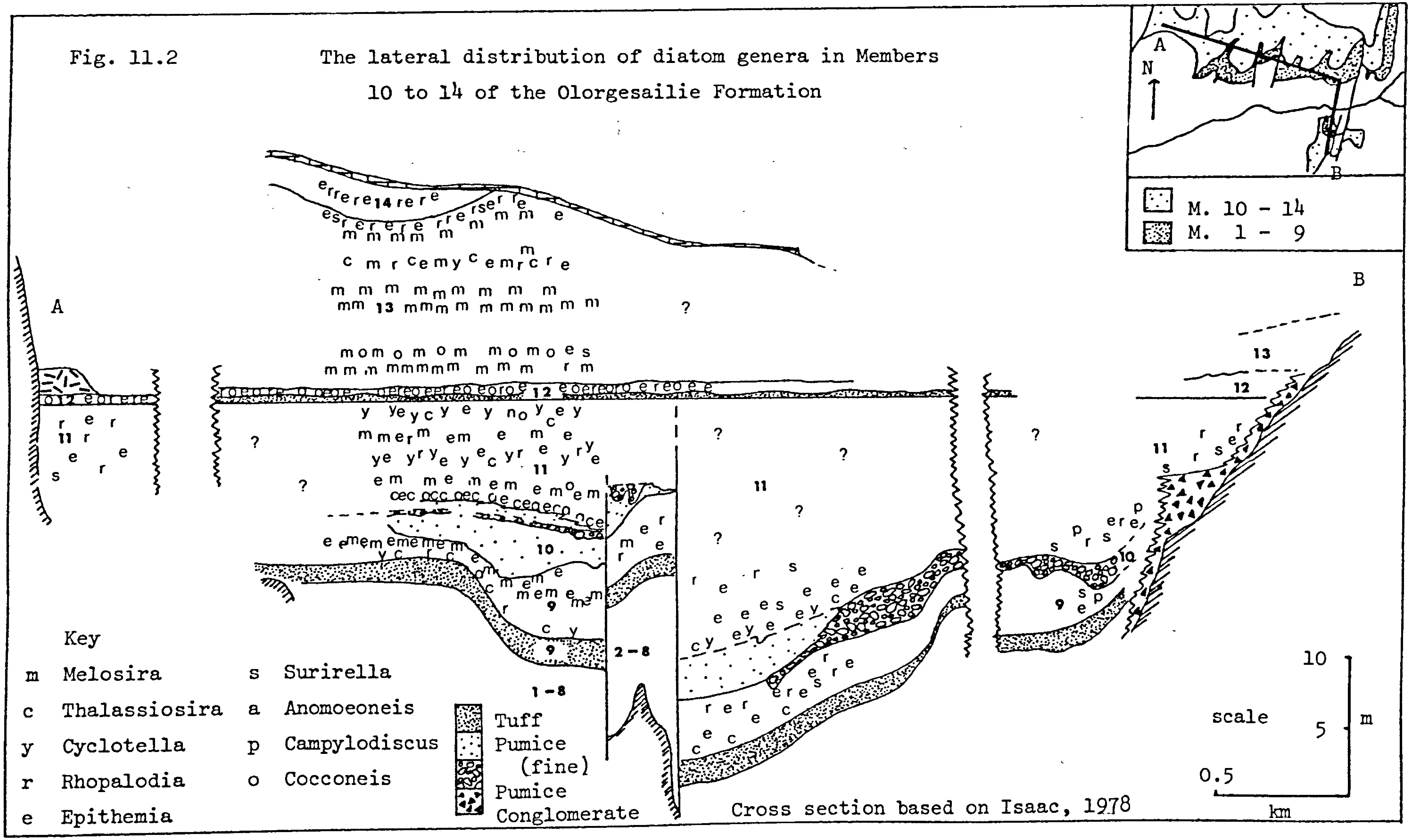


Fig. 11.2 The lateral distribution of diatom genera in Members 10 to 14 of the Olorgesailie Formation

diatom composition of this Member is uniform across the section shown in figure 11.1, although there is some species variation vertically.

Member 3 diatoms are often broken and contain a higher percentage of benthonic species than Member 2. They occur in low to moderate numbers, with planktonic species becoming slightly more common eastwards. *Epithemia zebra var. saxonica*, *E. sorex*, *Rhopalodia vermicularis*, *R. gracilis* and *R. gibba* are the main benthonic species.

Diatoms are absent from Member 4 in much of its outcrop. However in the finer sediments of the west, diatoms are more common. These are dominated by planktonic species such as *Melosira ambigua* and *M. agassizi*. The benthonic flora present includes *Epithemia zebra var. saxonica*, *Rhopalodia gibba* and *R. vermicularis*.

No attempt was made to distinguish Members 5 to 8 (see chapter 10, p. 322). Diatoms are absent from much of this part of the Olorgesailie Formation. Various *Epithemia*, *Rhopalodia*, *Cyclotella* and *Thalassiosira* species form the highest percentages of several rather sparce floras. *Melosira* spp. become more common eastwards, although they still occur only in low numbers. The low diatom density and common fragmentation suggests that some of these levels may represent periods of emergence from the palaeolake. Species such as *Thalassiosira rudolfii*, *Cyclotella meneghiniana* and *Rhopalodia gibberula* occur in low numbers towards the top of the sequence (probably in Member 8), across most of the cross section shown in figure 11.1. The flora of the easternmost (museum site) locations is unknown.

The basal tuff of Member 9 contains no diatoms. Above this, diatoms occur in low numbers and consist mainly of alkaline-loving species such as *Thalassiosira rudolfii*, *Cyclotella meneghiniana*, *Rhopalodia gibberula* and *Anomoeoneis sphaerophora*. This assemblage appears to be constant over much of the area. Vertically, it gives way to a highly diatomaceous deposit that contains a diverse flora with a high degree of fragmentation. Unbroken diatoms are dominated by Melosira granulata var. valida and var. angustissima (up to 35 %) in the west, and by Epithemia sorex and Rhopalodia gibba (up to 50 %) in the east. In the extreme south-east (fig. 11.2), diatoms are uncommon in Member 9. Here, the flora is dominated by Epithemia and Rhopalodia species , with a higher than usual percentage of Surirella ovalis, Campylodiscus clypeus and its variety bicostata.

11(i)c The lateral distribution of diatoms in Members 10 to 14

The pumiceous sands and gravels of Member 10 were sampled at several localities, but no diatoms were found. In contrast, Member 11 shows a wide range of assemblages (fig. 11.2), from fresh water types, dominated by Melosira ambigua, M. agassizi and Epithemia species, to more alkaline-loving floras, dominated by Thalassiosira rudolfii, Cyclotella meneghiniana and Anomoeoneis sphaerophora. In the western outcrops, planktonic species predominate, but these are gradually replaced by benthonic diatoms, such as Epithemia, Rhopalodia and Surirella, to the east. In the extreme south-east, Campylodiscus clypeus var. bicostata is locally important. The diatoms in Member 11 occur mainly in low numbers, although a few 'diatomites' are known. Several parts of the sequence lack any diatoms, and may represent subaerial deposition. Such levels become more common eastwards.

Above a non-diatomaceous, pumiceous tuff, at the base of Member 12, is a diatomite. This consists of comminuted diatoms, and a few unbroken species. The latter are dominated by Cocconeis placentula var. euglypta (50 to 70%), Rhopalodia spp. and Epithemia spp, across the whole of the western outcrops (fig. 11.2).

Much of Member 13 consists of non-diatomaceous sediments that probably formed under alluvial and colluvial situations. However, several horizons contain low to moderate numbers of diatoms. Two floras are typical. The first includes varying proportions of Melosira granulata and its varieties valida and angustissima, M. agassizi and M. ambigua. The second is favoured by higher alkalinities and consists of Thalassiosira rudolfii, Cyclotella meneghiniana, Rhopalodia gibberula and Epithemia spp..

Diatoms are uncommon in Member 14, except at one level where Epithemia sorex and Rhopalodia gibberula dominate. The Member only crops out in the west and no lateral variation studies were attempted.

In general, the diatom floras of the Olorgesailie Formation become increasingly planktonic in character towards the west. This probably reflects a lake that was centred on the Koora Graben. Large parts of this lake were shallow and reed-rich, except during the formation of Member 2, when deeper waters were widespread.

11(ii) The diatom stratigraphy of the type section of the Olorgesailie Formation

11(ii)a Introduction to the diatom stratigraphy and location of the type section

The diatom stratigraphy shown in figure 11.3 is based on sampling intervals of 1 m in most units, plus samples at 50 cm intervals, in parts of the section that were clearly diatomaceous, when viewed in the field. The diatom percentages are based on counts of 200 individuals.

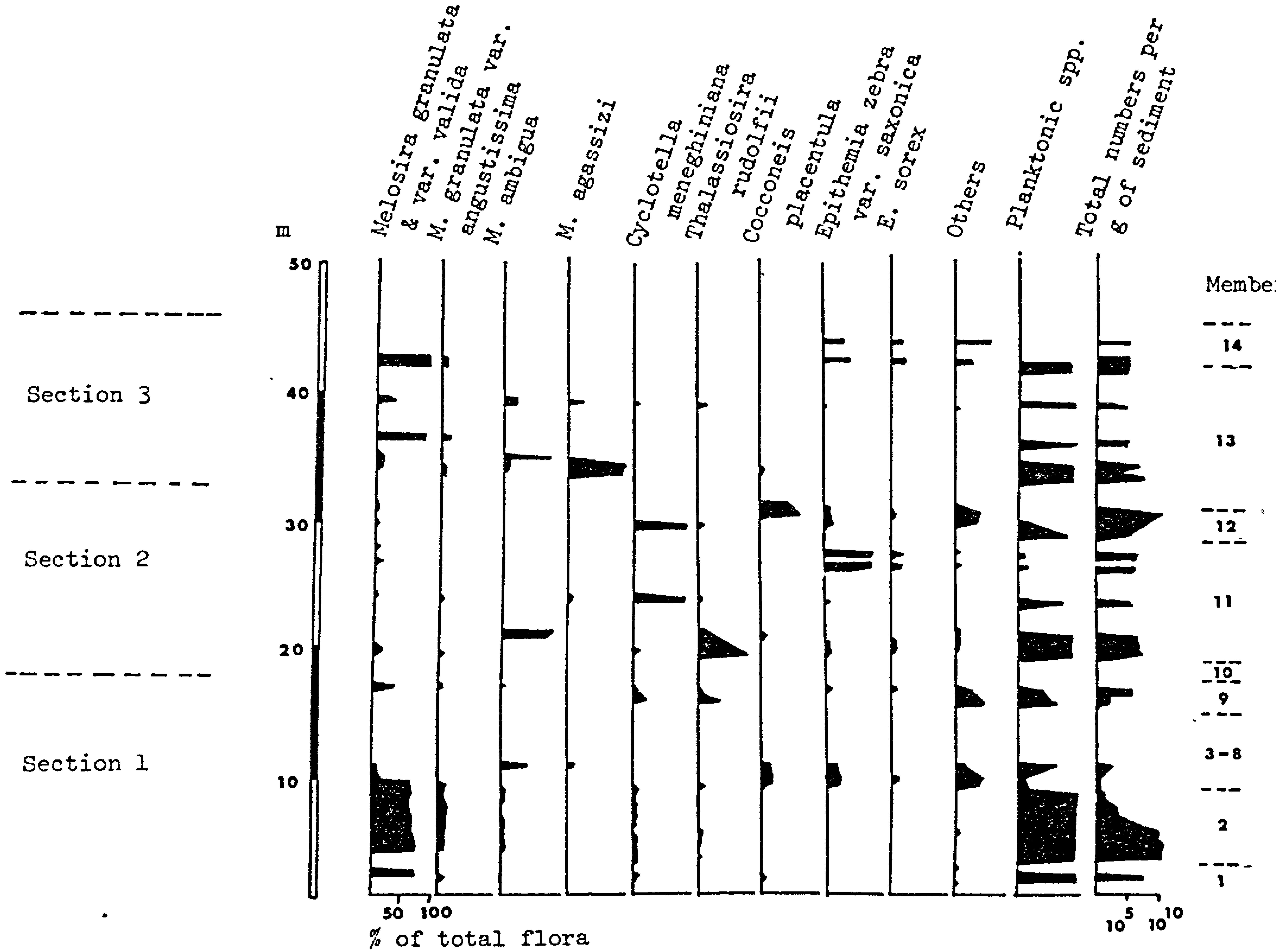
The stratigraphy shown in figure 11.3 is based on three separate sections, that could be easily correlated. These sections are numbered 1, 2 and 3, and their locations are shown in figure 10.3, p. 317 . They correspond to the composite type section designated by Isaac (1978). Their lithologies are shown in figure 10.4.

11(ii)b The diatom stratigraphy of Members 1 and 2 of the type section

Between 0 and 150 cm no diatoms occur, other than for a few fragmentary species. There appears to be no major lake occupying the section site at this time. From 150 to 170 cm, Melosira granulata becomes important, and suggests a minor lake expansion. The modern ecology of this diatom suggests a freshwater lake. Diatoms decline above 170 cm, and occur in very low numbers until the end of Member 1, at 310 cm. No diatoms are shown in figure 11.3 for this interval, because of the unreliability of such low numbers. The species that are present are all benthonic types, and include Epithemia and Rhopalodia species.

A major change occurs at the base of Member 2, with diatoms reaching concentrations of 10^{11} valves/g of sediment. They decline above about 500 cm, and reach very

Fig. 11.3 The diatom stratigraphy of the composite type section of the Olorgesailie F.



low numbers towards the top of the Member (at 1000 cm). Within this part of the sequence, planktonic diatoms dominate. These consist mainly of Melosira granulata and its variety valida (up to 95 %), but also include M. granulata var. angustissima, M. ambigua, M. agassizi, Stephanodiscus astraea, Cyclotella meneghiniana and Thalassiosira spp.. Benthonic diatoms are very rare, consisting mostly of Rhopalodia spp.. Modern studies of these diatoms (Richardson, 1968; Kilham and Kilham, 1975) suggest a moderately eutrophic, deep water lake, with alkalinities of less than about 18 meq/l, and possibly less than 8 meq/l. Dissolved silica probably exceeded 5 to 10 mg/l. The lack of benthonic diatoms suggests that the section site was far from a shoreline or shallow water. This is confirmed by the lateral distribution of these diatoms (p. 348). Member 2 represents a major lacustrine transgression, and, as shall become evident later, the maximum lake expansion.

11(ii)c The diatom stratigraphy of Members 3 to 8, at the type section

These Members were designated in areas to the east of the type section (Isaac, 1978). Unfortunately, they cannot be clearly defined at the type section, where they are represented by a complex of tuffaceous and diatomaceous silts (p. 321).

Between 1000 and 1100 cm (from the base of the type section) diatoms are uncommon (ca. 10 to 100 valves/g of sediment), and are often broken. Epithemia zebra var. saxonica, E. sorex, Cocconeis placentula, and Rhopalodia vermicularis predominate. The modern ecology of these species suggests a shallow, fresh to slighly alkaline lake, with numerous littoral macrophytes.

From 1100 to 1200 cm planktonic diatoms dominate. These consist mainly of Melosira ambigua, M. agassizi and M.

granulata. The remaining flora (40 %) includes benthonic and epiphytic elements. The assemblage probably reflects a shallow (though deeper than the preceding case), fresh lake, with reeds, at least in the vicinity of the section.

Diatoms are uncommon and often broken between 1200 and 1650 cm (the top of Members 3 to 8). This may reflect periods of emergence and/or reworking under shallow, littoral conditions. For these reasons, diatoms are not shown in this part of the section, in figure 11.3. However, a few unbroken Rhopalodia, Epithemia and Surirella are present. Towards the top of the sequence, Cyclotella meneghiniana becomes relatively more common, although it still occurs in very low numbers. This change may reflect a transition from fresh to alkaline water. It must be noted that in view of the low numbers this must remain a rather tentative conclusion.

11(ii)d The diatom stratigraphy of Members 9 and 10, at the type section

Volcanic products (ash and pumice) form a major part of Members 9 and 10. Diatoms are absent from much of these units. This includes the lower 50 cm of Member 9 (1650 to 1700 cm in fig. 11.3), where only a few fragmentary individuals occur.

Between 1700 and 1750 cm diatoms are uncommon (ca 10^2 to 10^3 valves/g of sediment). These are dominated by alkaline-loving species such as Cyclotella meneghiniana, Thalassiosira rudolfii, Rhopalodia gibberula and Anomoeoneis sphaerophora, with less common Cocconeis placentula. The flora also suggests shallow waters.

From 1750 to 1800 cm diatoms are common (10^5 valves/g of sediment), with many fragments also present. The unbroken individuals are dominated by Melosira granulata var. valida and var. angustissima. Epithemia sorex is also common, with several other benthonic species. The breakage suggests that the deposit may have been reworked. If not, the assemblage of unbroken diatoms indicates a moderately alkaline lake, probably less than 10 meq/l.

Above 1800 cm and below 1850 cm diatoms are absent, except for a few broken specimens. Member 10 occurs between about 1850 and 1940 cm (the lower boundary is erosional and varies in height). This unit consists of pumiceous gravels and is devoid of diatoms. It probably records a lake regression.

11(ii)e The diatom stratigraphy of Members 11 to 14, at the type section

The diatoms of Members 11 to 14 record a series of transgressions and regressions. Several periods of emergence, and widely fluctuating water chemistry, can be inferred.

Between 1940 and 2050 cm (fig. 11.3) diatoms are abundant (10^8 valves/g of sediment), and are often broken. The flora is dominated by Thalassiosira rudolfii (75 %), with Cyclotella meneghiniana, Melosira granulata var. valida, Anomoeoneis sphaerophora and Cocconeis placentula also common. The assemblage suggests open, probably shallow water, with an alkaline chemistry (50 to 80 meq/l).

From 2050 to 2100 cm a fresh water (ca. 5 meq/l) flora prevails. This is dominated by Melosira ambigua (80 %), with Cymbella ventricosa, Cocconeis placentula and Synedra species constituting the remainder.

Diatoms are absent from 2100 to 2400 cm, except for a few fragments that are probably reworked. This level suggests lake regression and possible emergence of the section site.

Diatoms are common between 2400 and 2450 cm, being dominated by Cyclotella meneghiniana (75 %). Melosira, Thalassiosira and Epithemia form the remainder. The assemblage may reflect shallow, open water, with an alkalinity of probably less than 50 meq/l.

Only diatom fragments occur between 2450 and 2650 cm, which suggests emergence from the palaeolake. They become common between 2650 and 2800 cm, except for a 50 cm interval in the middle of this level (fig. 11.3). The flora is dominated by Epithemia zebra var. saxonica (up to 75%), E. sorex, Rhopalodia vermicularis and R. gracilis. These diatoms suggest shallow water, abundant reeds, and low alkalinity and salinity.

In the remainder of Member 11, and at the base of Member 12, diatoms are absent (in the section interval 2800 to 2950 cm). Above these levels, and below 3000 cm, Cyclotella meneghiniana becomes dominant (80 %), suggesting shallow, reed free, alkaline (but less than 50 meq/l) water.

Diatoms are extremely abundant between 3000 and 3250 cm, but with a high degree of breakage. Unbroken diatoms attain concentrations of 10^{11} valves/g of sediment. Cocconeis placentula var euglypta is dominant (60 %), with Epithemia sorex, E. zebra var. saxonica, Rhopalodia vermicularis, R. gracilis, R. gibba and Cymbella sp.. The flora suggests a shallow, moderately fresh lake, with abundant reeds. The broken diatoms may have been washed in.

Diatoms disappear again, between 3250 and 3350 cm, suggesting a lake regression at the base of Member 13. Higher lake levels can be suggested from the planktonic floras between 3350 and 3550 cm. This interval is dominated by Melosira agassizi (up to 90 %), except for the upper 50 cm, which consists mainly of Melosira ambigua (up to 70 %). Today, both these diatoms are found in fresh (ca. 5 meq/l) lakes, with moderate water depths. The section area was clear of reeds at this time.

A lake regression can be suggested for the succeeding

50 cm, from the lack of diatoms. They reappear between 3600 and 3650 cm, where they are dominated by Melosira granulata var. valida (75 %) and var. angustissima (15 %). They suggest slightly alkaline conditions in a relatively deep lake. These species are commonly found in water with a high dissolved silica content (over 10 mg/l), and high nutrient content.

From 3650 to 3950 cm diatoms are absent, or occur only as isolated fragments. Lake levels had probably fallen, and the area may have been subject to permanent or intermittent emergence. Between 3950 and 4000 cm several planktonic diatoms become common. These include Melosira granulata and its variety valida, M. ambigua, M. agassizi and Thalassiosira rudolfii. The lake at this time was probably quite fresh (ca. 5 meq/l), nutrient rich and relatively deep, with a high dissolved silica content (over 10 mg/l).

A subsequent regression and low lake levels and/or competetive exclusion by blue-green algae, may account for the absence of diatoms between 4000 and 4200 cm. A planktonic flora occurs from 4200 to 4300 cm. This is dominated by Melosira granulata and its varieties valida and angustissima (fig. 11.3). The flora suggests possibly deeper water and a fresh lake.

A regression is indicated by the benthonic diatoms between 4300 and 4350 cm. These are dominated by Epithemia zebra var. saxonica, E. sorex and Rhopalodia vermicularis. These diatoms suggest fresh, shallow, reedy areas at the section site. A very similar flora again occurs between 4450 and 4500 cm, otherwise the remainder of the section (and Member 14) consists of non-diatomaceous sediments.

11(iii) The diatom stratigraphy of the composite sections 4 and 5

11(iii)a Introduction to the location and stratigraphy of sections 4 and 5

Two sections (numbered 4 and 5), to the east of the type section, have also provided a good diatom record, and will be discussed in this part of the chapter. Their locations are shown in figure 10.3, while their lithologies are given in figure 10.5. The diatom stratigraphy of these sections is illustrated in figure 11.4.

Members 1 to 10, and the basal part of Member 11, are well exposed in sections 4 and 5. Unlike the type section, Members 3 and 4 can be clearly identified, but Members 5 to 8 remain difficult to separate. The two sections are used to form a single diagram in figure 11.4.

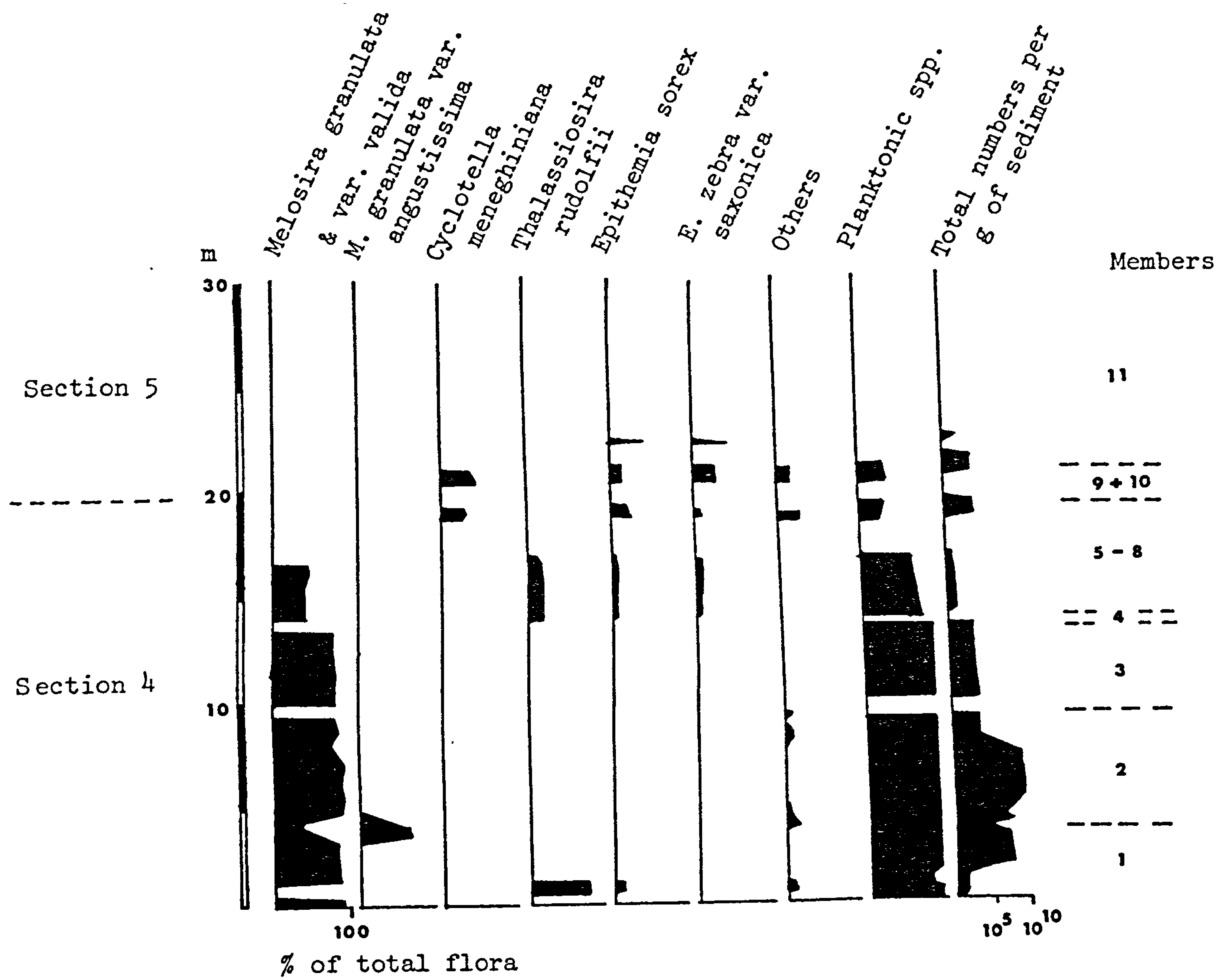
11(iii)b The diatom stratigraphy of Members 1 to 3

These Members are heavily dominated by planktonic diatoms, wich account for 100 % of the flora through much of the sequence.

The lower 50 cm of this composite section are dominated by Melosira granulata var. valida, but the flora only occurs in low numbers (10 to 100 valves/g of sediment). Between 50 and 100 cm, Thalassiosira rudolfii dominates, in similarly low numbers. These two assemblages are difficult to interpret accurately because of the low numbers involved. However, they probably represent initially fresh water, that became more alkaline.

A major transgression is indicated at 100 cm, by an increase in diatom numbers, and by the development of a flora dominated by Melosira granulata var. valida. This

Fig. 11.4 The diatom stratigraphy of sections 4 and 5 of the Olorgesailie Formation



diatom suggests fresh, deep water, that was nutrient rich, and of high dissolved silica content. It continues up to 950 cm as the sole dominant, except between 300 and 450 cm, where Melosira granulata var. angustissima becomes common. This may suggest an increase in blue-green algae, with which it is often associated in modern lakes.

Diatoms are absent between 950 and 1000 cm, which corresponds to a tuffaceous unit. This may represent an ash-fall into the lake, sufficiently rapid not to allow diatoms to accumulate. Above the tuff, and through the remainder of Member 3, there is a return to a Melosira granulata var. valida dominated flora.

11(iii)c The diatoms of Members 4 to 11

These units either lack diatoms or contain diatoms that suggest higher alkalinities than those of the lower Members.

Member 4 is devoid of diatoms, and consists of coarse pumice gravels. It probably represents a lake regression, and fluvially transported volcanic debris. This level occurs between 1350 and 1400 cm in the section (fig. 11.4).

From 1400 to 1650 cm, the flora is dominated by Melosira granulata and its variety valida, Thalassiosira rudolfii and several Epithemia spp.. Modern floras of this type are mainly found in shallow, moderately alkaline water, with a few macrophytes.

Diatoms disappear between 1650 and 1850 cm, apart from a few fragmentary individuals. A lake regression is probable with a very shallow sheet of water covering this area, or more likely complete emergence.

From 1850 to 1900 cm, and between 2000 and 2100 cm, the flora is dominated by varying percentages of Cyclotella meneghiniana, Epithemia zebra var. saxonica, E. sorex and Rhopalodia gibberula. These suggest shallow, reed-rich areas of an alkaline (though less than about 50 meq/l) lake, which was probably rich in nutients. Diatoms are absent between 1900 and 2000 cm, which reflects an influx of fluvially deposited pumice.

A few broken diatoms occur between 2100 and 2200 cm. From 2200 to 2250 cm Epithemia zebra var. saxonica and E. sorex predominate. While occurring in low numbers (10^2 to 10^3 valves/g of sediment), their presence does suggest abundant reeds, and possibly a marshy area.

Diatoms occur in very low numbers through the remainder of the composite section 4/5 (Member 11). These are not shown in figure 11.4. They are often broken and are dominated by benthonic species, belonging to the genera Rhopalodia, Epithemia, Surirella and Cymatopleura. These diatoms suggest shallow, reedy areas, probably close to a shoreline.

11(iv) The palaeogeography and palaeoecology of the mid-Pleistocene Lake Olorgesailie

11(iv)a The major ecological aspects of ancient Lake Olorgesailie

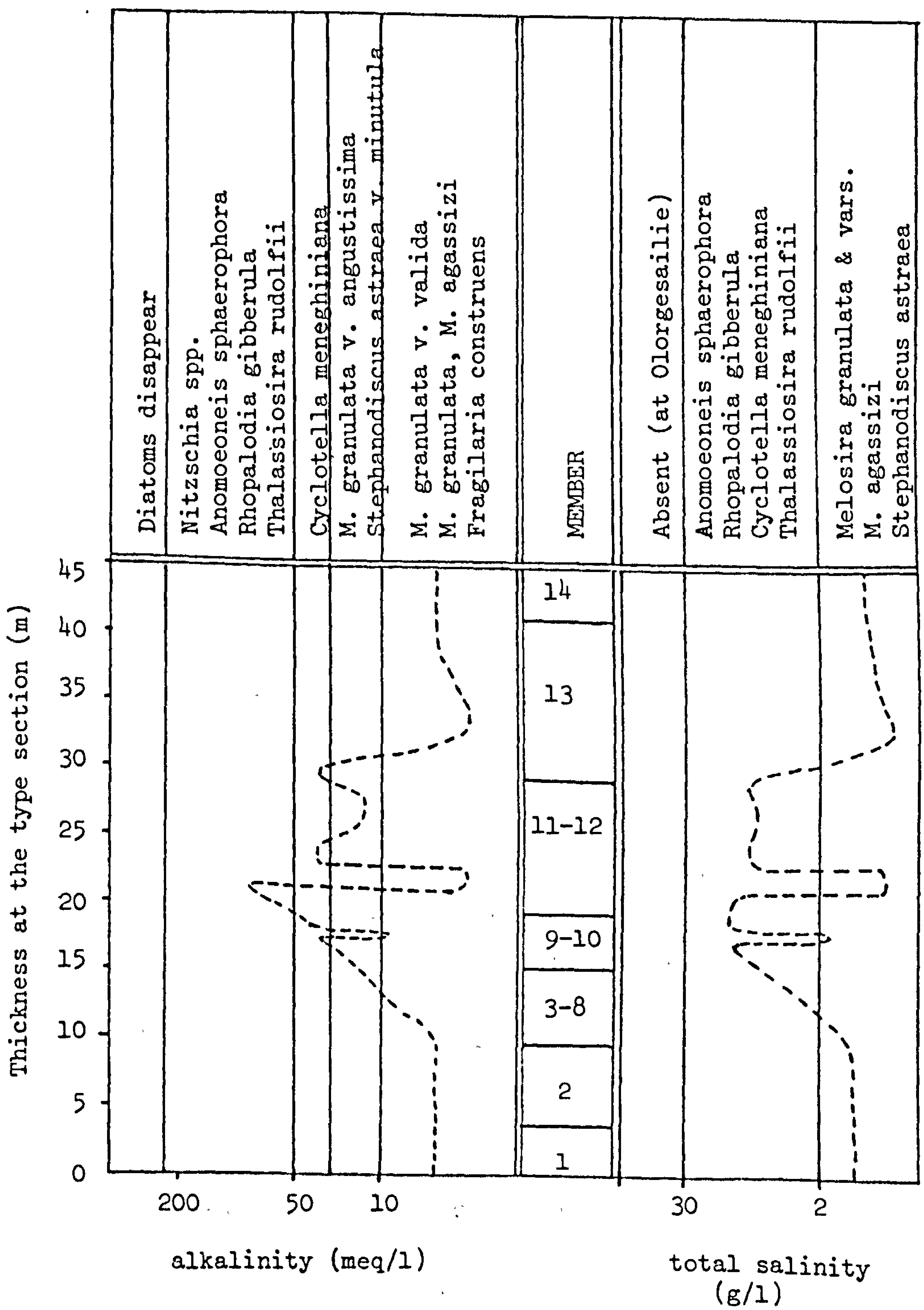
Several major fluctuations of salinity and alkalinity (as indicated by diatoms) of the palaeolake are shown in figure 11.5. Two major phases of high alkalinity (over 10 meq/l), and high salinity (over 2 g/l), can be recognised. The highest probable alkalinities were of the order of 80 to 90 meq/l. This is consistent with a lack of saline minerals in the Olorgesailie Formation. Three major stages in the evolution of the palaeolake can be identified from an inspection of figure 11.5.

(i) An early phase, during which the alkalinity was mainly less than 10 meq/l, and when salinity was less than 2 g/l. This chemically fresh lake was deep at the type section, during all of Member 2 times, and probably stood at a relatively stable surface level. This situation is most likely to have been brought about by an outlet in the Koora Graben.

(ii) A second phase, during which the alkalinity fluctuated between about 5 and 90 meq/l, and with total salinity varying from less than 2 g/l to about 20 or 25 g/l (fig. 11.5). Such wide changes suggest a lake that stood below its overflow, and which had limited or no subsurface drainage. Under these conditions a lake is very sensitive to changes in the evaporation/precipitation balance. Concentration of saline and alkaline water develops during periods of high evaporation and low precipitation, with the lake becoming more dilute during phases of higher rainfall.

(iii) During the third major phase, the water was of predominantly fresh character (with short-lived exceptions, not shown in figure 11.5). However, the diatoms and facies

Fig. 11.5 The alkalinity and salinity fluctuations of Palaeolake Olorgesailie



distributions suggest shallower water, over the outcrop area, than existed during phase (i). If this were simply due to a smaller water body, a higher alkalinity might be expected. The fresh conditions, with comparatively shallower water, may be explained in one or a combination of three ways.

a) Infilling had taken place (with no subsidence), raising the lake floor closer to the outlet height.
b) Subsurface seepage had been established, perhaps by contemporary faulting.
c) The outlet height was lower than it was during phase (i). This may have been due to either erosion or more probably tectonic movements, such as faulting and/or tilting (fig. 11.6).

The diatom data suggests that lake levels were fluctuating during phase (iii). This may support a seepage mechanism, unless tectonic forces were changing the outlet height at a sufficient rate.

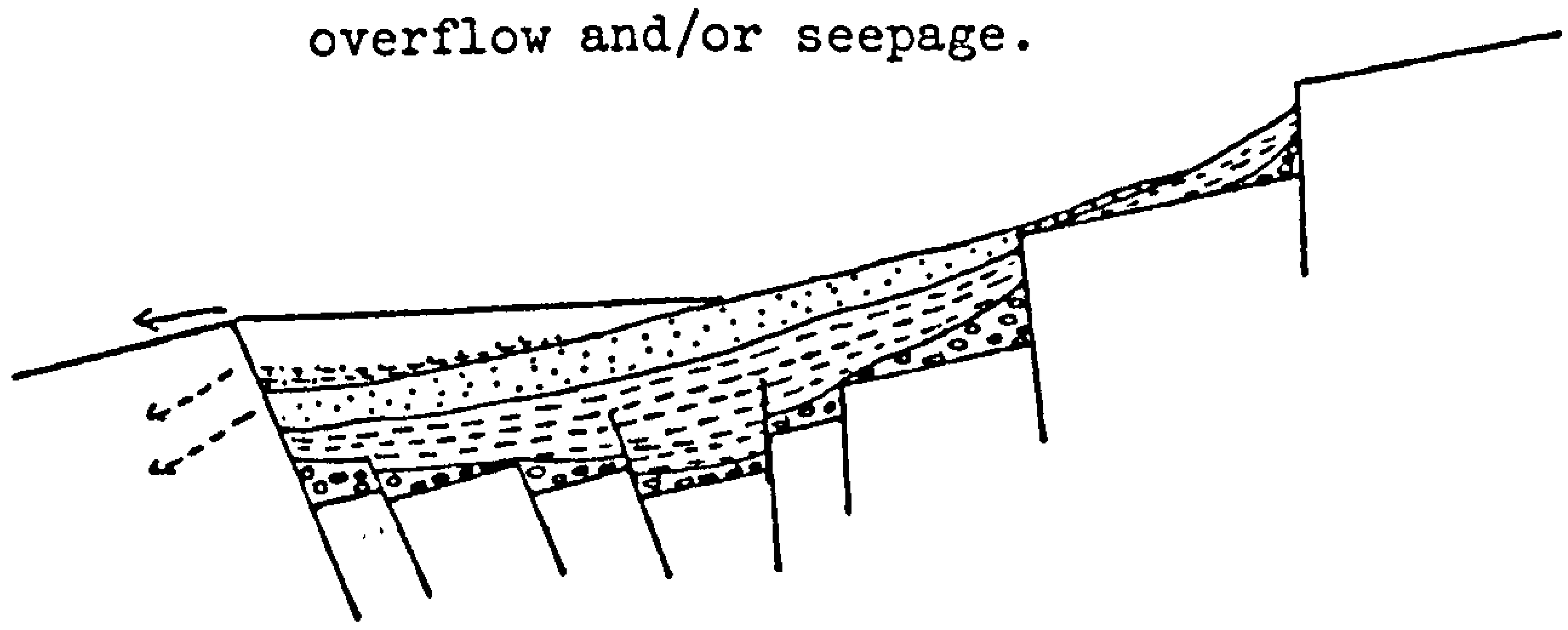
From the foregoing discussion, it seems probable that the many lake level fluctuations occurred due to a combination of climatic and tectonic processes.

Several other, ecologically important, factors appear to have remained more constant during deposition, than did alkalinity or salinity. The common occurrence of <u>Melosira</u> suggests that dissolved silica was often high (over 10 mg/l). This would be consistent with an active volcanic region. It may be that the abundance of diatoms in the Olorgesailie Formation is related to this silica availability.

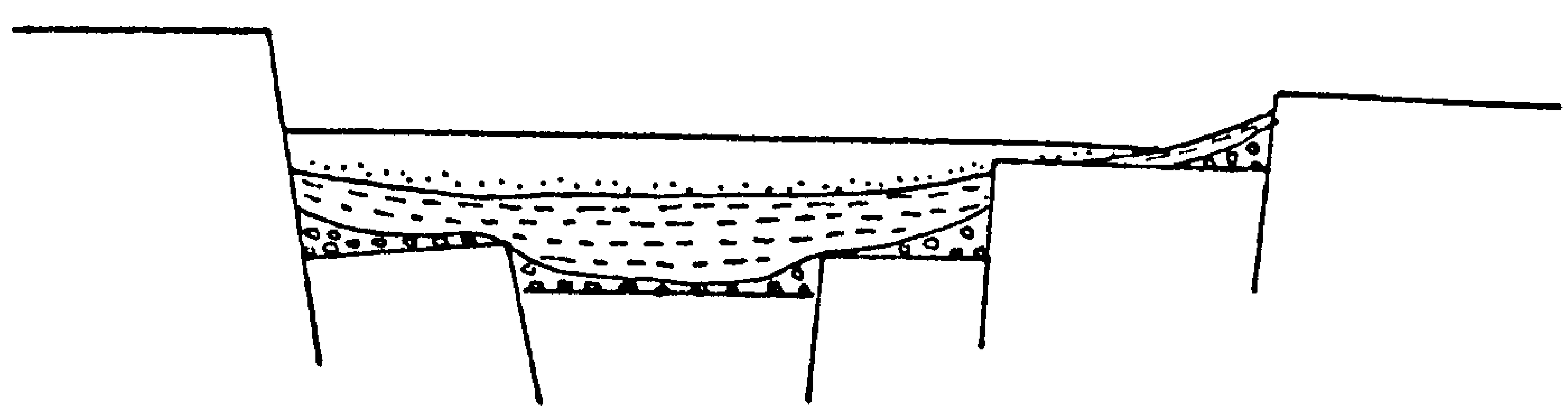
The presence of many species restricted to the modern tropics, or endemic to Africa, suggest that the lake water was warm. This may also relate to the high nutrient levels, suggested by the diatom floras. The abundance of epiphytes probably reflects a lake that was often fringed by numerous

Fig. 11.6 Suggested evolution of the Olorgesailie basin

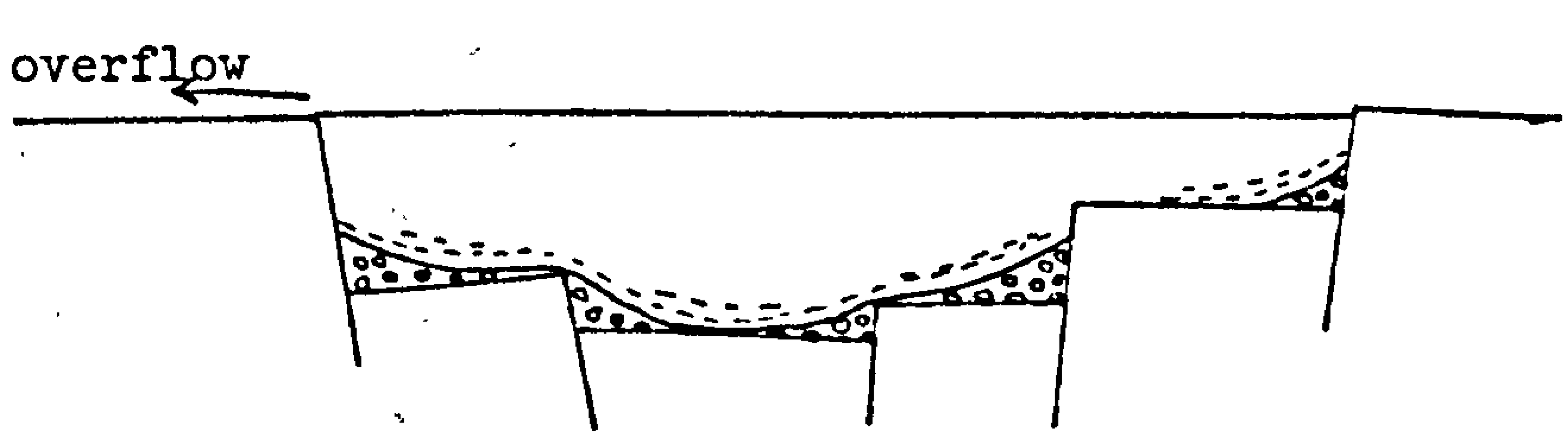
Phase 3 Fresh to slightly alkaline lakes, faulting and tilting to the south west; sediment infilling & overflow and/or seepage.



Phase 2 Alkaline and fresh water lakes, periodic loss of outlet. Sedimentary infilling plus contemporary faulting (& tilting ?)



Phase 1 Fresh water lake, sedimentary infilling.



phase 1 sediments
phase 2 sediments
phase 3 sediments
early sandy conglomeratic infill

littoral reeds and marshes.

Diatom fragments are common at many levels, and reach great abundance in several horizons. This may reflect reworking of marginal sediment, during low lake levels, and /or turbulent littoral environments.

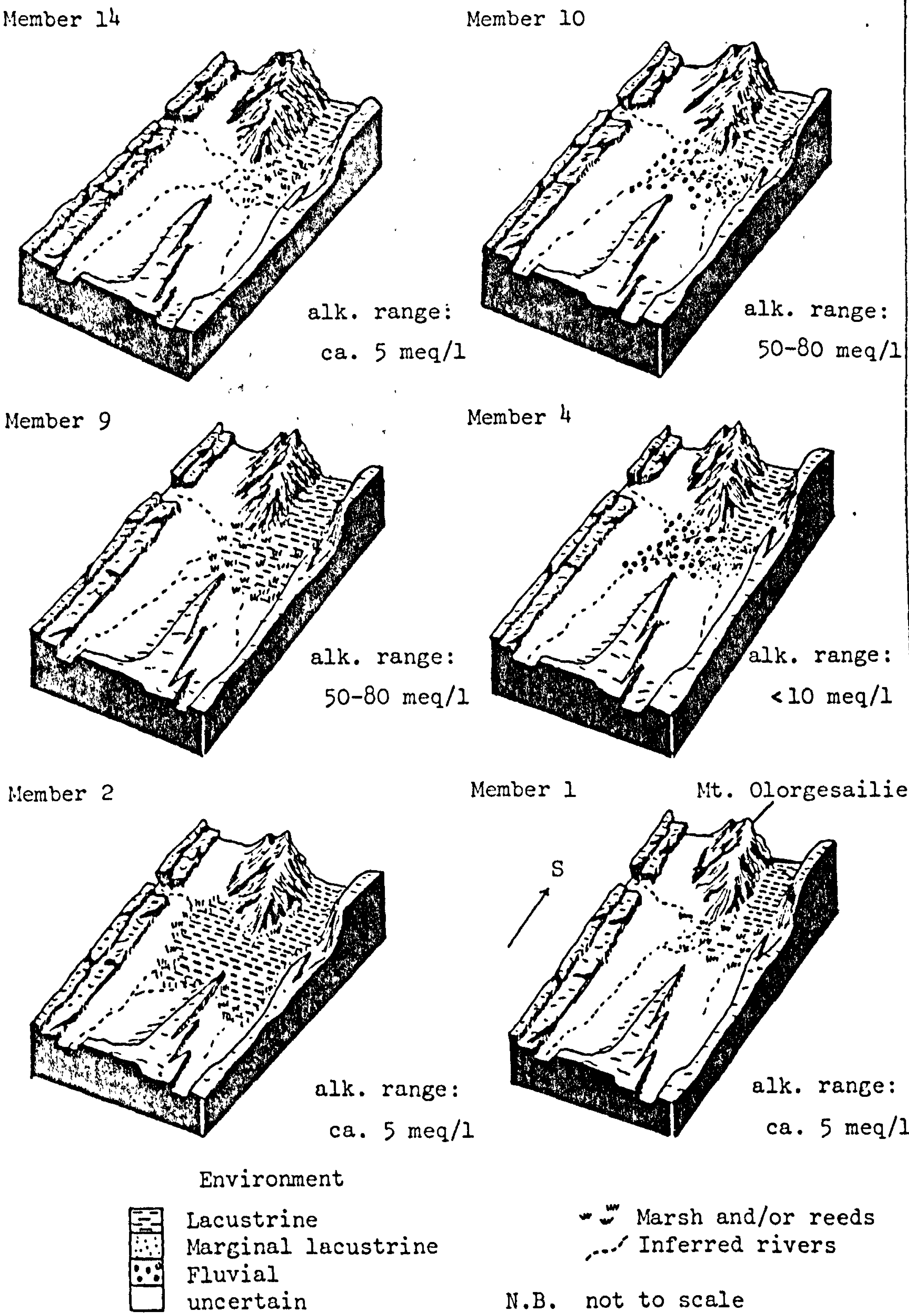
11(iv)b Summary of the palaeogeography of the Olorgesailie Formation

Figure 11.7 shows a series of block diagrams that illustrate the probable palaeogeography of the Olorgesailie basin at several key stages.

During Member 1 times, the ancient lake was confined mainly to the Koora Graben. Although the lake was mostly fresh (suggesting an outlet mechanism), it periodically, and locally became more alkaline (up to about 50 meq/l). The lake expanded and reached its maximum extent during the laying down of Member 2 (fig. 11.7). Contraction occurred during Member 3 times, and eventually the fluvial pumiceous units of Member 4 were formed. The palaeolake continued to expand and contract during the deposition of Members 5 to 8, with mostly shallow waters, of varying alkalinity, prevailing. Occasionally parts of the present Legemunge and Oltepesi Plains would become emergent. By Member 9 times the lake was alkaline, shallow, and contained numerous macrophytes (fig. 11.7). A second major input of pumice occurred during the formation of Member 10. The palaeolake attained its maximum alkalinity soon after. During Member 11 times, the Legemunge and Oltepesi Plains were often emergent or covered with shallow, reed-rich alkaline water. Shallow depths continued to prevail during the deposition of Members 13 and 14 (fig. 11.7), but alkalinity declined, suggesting an outlet mechanism.

Figure 11.8 shows a simplified palaeogeography of the southern Kenya Rift, during the middle Pleistocene. North

Fig. 11.7 The palaeogeography of the mid-Pleistocene Lake Olorgesailie at key stages in its evolution



to south drainage predominated (Isaac, 1978). Longonot volcano was probably active, and may have been the source of the pumice units, and many of the ash horizons, in the Olorgesailie Formation. Baker and Mitchell (1976) have indicated that diatomites, at Munyu wa Gicheru, may be of middle Pleistocene age. If so, they imply a small lake between Olorgesailie and Longonot, at the same time as Olorgesailie Formation deposition. It is not known if this would have interrupted southerly drainage from Longonot.

The Olorgesailie palaeolake may have overflowed, or may have been drained by subsurface seepage (or both). Any water leaving this lake would have eventually reached the Magadi basin. Eugster* (1980) has noted the probability that a very large 'Lake Oloronga' linked the Magadi and Natron basins at this time (fig. 11.8).

Ancient Lake Olorgesailie eventually ceased to exist due to a combination of faulting and regional southerly tilting (Isaac, 1978). Today, no lake occurs at Olorgesailie, and the region can be classified as semi-arid.

Fig. 11.8 Schematic representation of modern and middle Pleistocene lakes and drainage in the southern Kenya Rift

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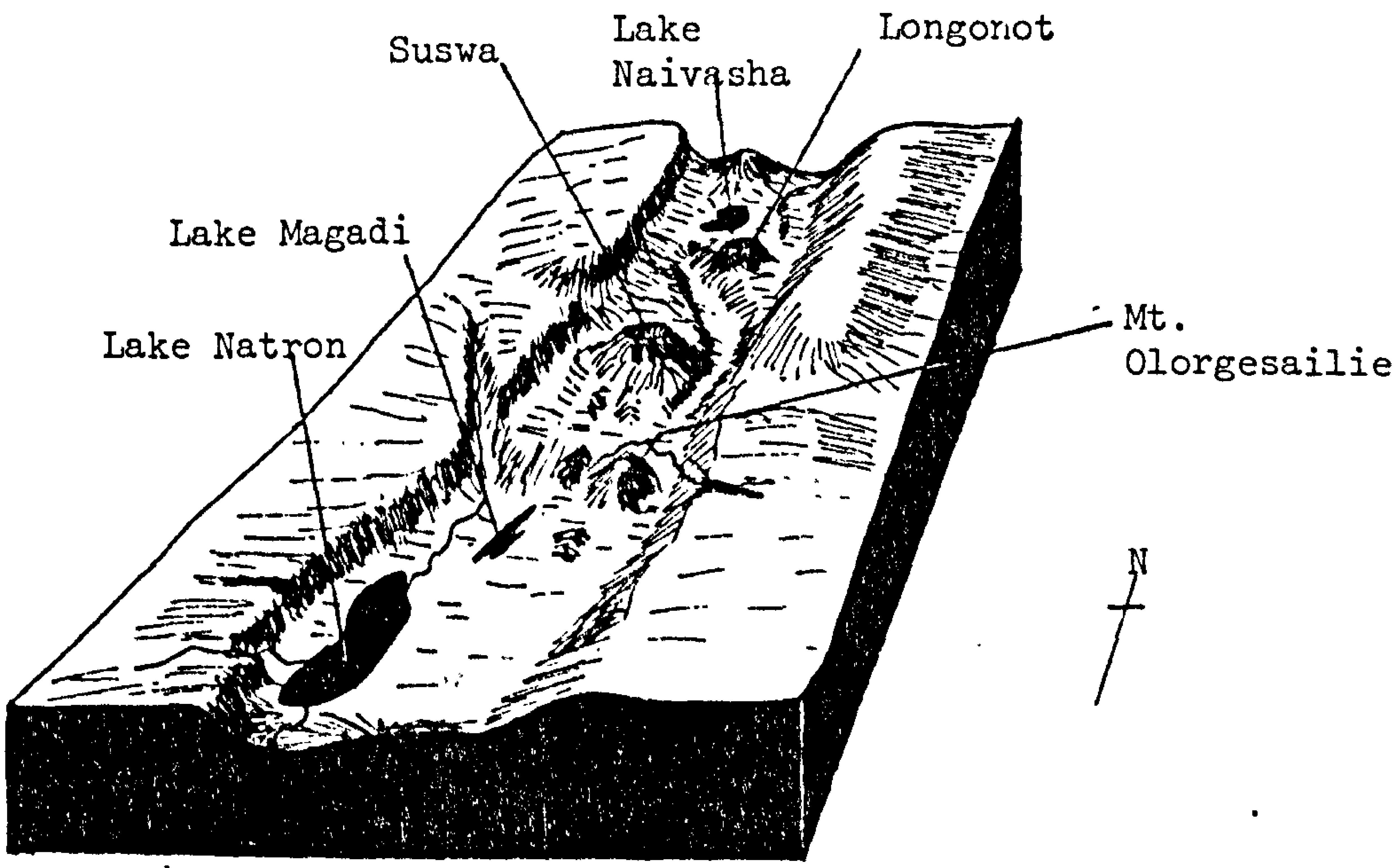
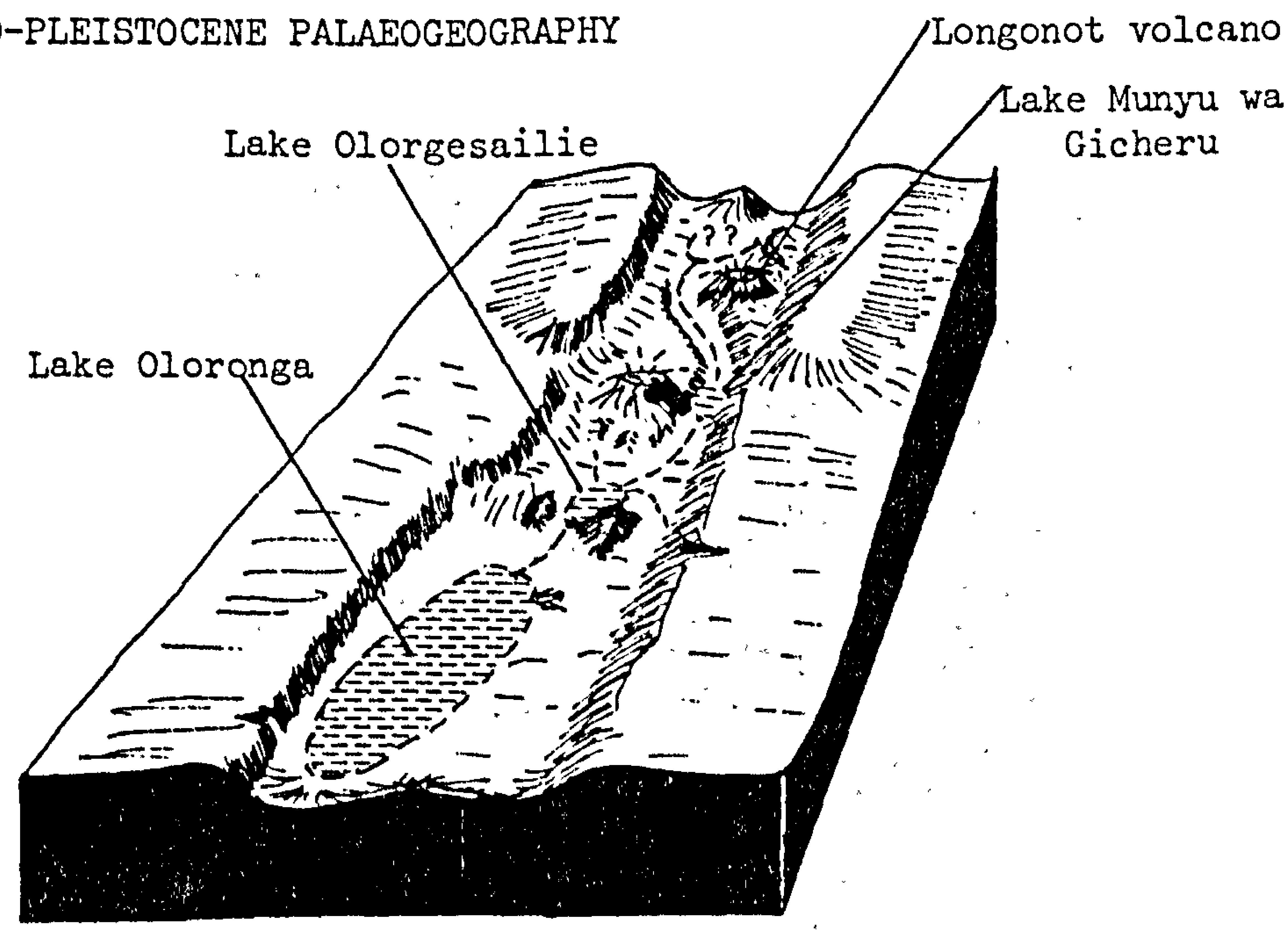


MID-PLEISTOCENE PALAEOGEOGRAPHY



N.B. boundaries of palaeolakes are approximate only.

CHAPTER 12

DISCUSSION AND CONCLUSIONS

12(i) Lacustrine sedimentation in the Kenya Rift

12(i)a Basin formation and lake typology

Today, the Kenya Rift is characterised by a series of lakes that lie at the centre of basins of internal drainage. These basins are the result of interactions between faulting, subsidence, tilting and volcanism, and have formed, existed and finally been destroyed many times during the last 15 my. Several basins appear to have continued for long periods. Such is the case at Lake Turkana, where sediments have been forming since the Pliocene. Other basins have been shorter-lived. Perhaps typical of these was the Olorgesailie basin, which developed and ceased to exist during the middle Pleistocene.

Modern and ancient lakes of the Kenya Rift can be placed into four broad groupings, based on their pattern of sedimentation. These 'lake types' are:

- (i) The clastic lake
- (ii) The biogenic lake
- (iii) The perennial saline lake
- (iv) The ephemeral saline lake

Examples of each lake type (all taken from this study, except Lake Magadi) are shown in figure 12.1, together with their main facies distributions. Figure 12.2 places the major Kenya Rift lakes, both modern and ancient, into this classification. One notable feature is that many of the lakes have shifted from one type to another at different stages in their evolutions.

Fig. 12.1 Rift Valley lakes and their sediments

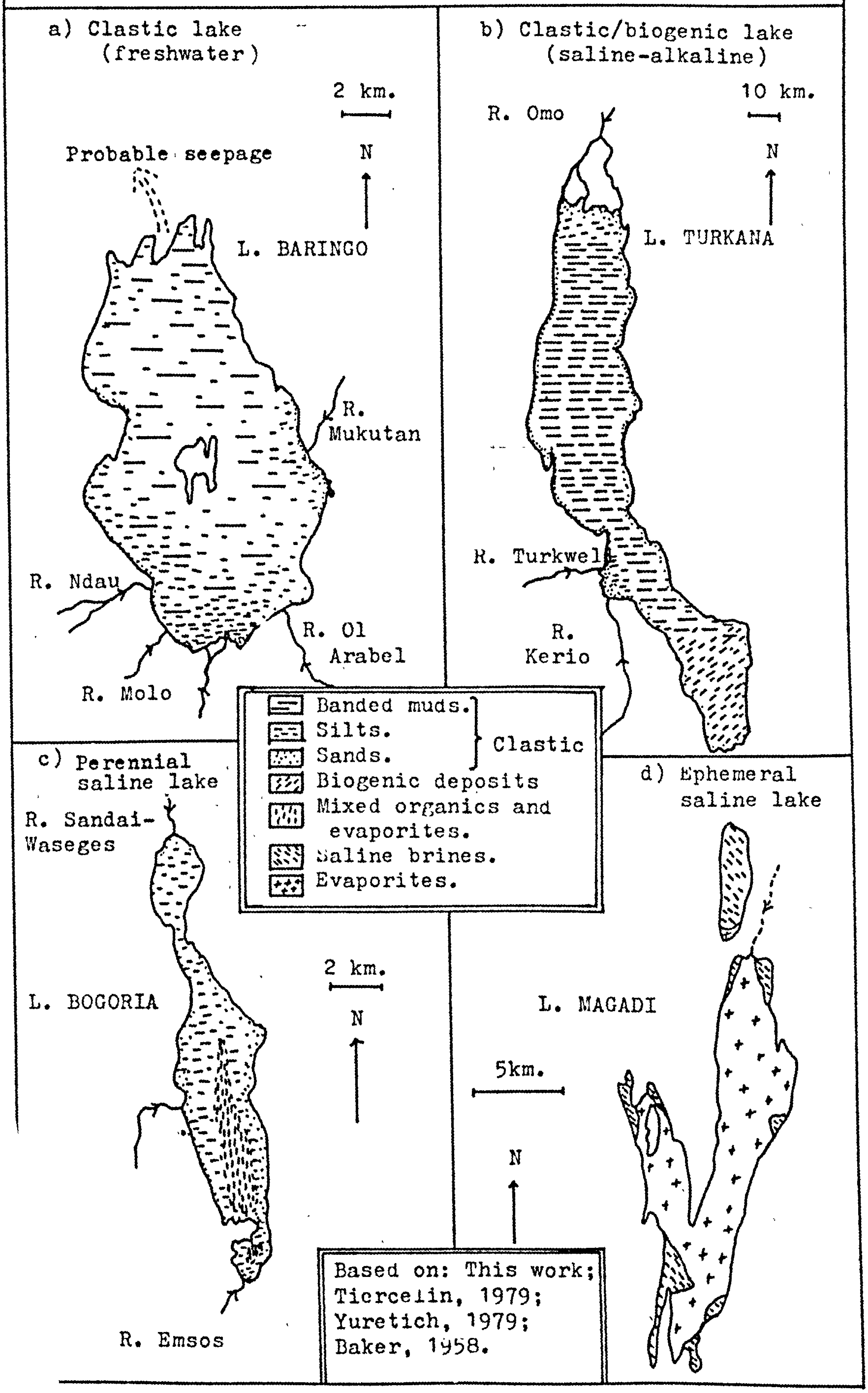


Fig.12.2 Kenyan Rift Valley lake classification and associated sediments and phytoplankton.

Lake type	Dominant minerals	Dominant plankton	Ref.
Contemporary			
Clastic:			
Baringo	Feldspar, clays	Cyanophyceae, diatoms	This work
Naivasha	Pyroclastics, feldspar, clays	Diatoms, desmids botryococcus, blue green algae	Richardson 1966.
Turkana (N. basin)	Quartz, feldspar, clays, heavy mins.	Chlorophyceae	This work
Biogenic:			
Turkana (S. basin)	Diatom silica, ostracod calcite.	Ostracods, diatom chlorophyceae	Yuretich, 1979
Perennial saline lake:			
Bogoria	Feldspar, clays evaporites	Cyanophyceae.	Tiercelin 1979, This work
Elmenteita	Pyroclastics, feldspar, clays, evaporites.	Cyanophyceae	Hecky & Kilham 1973 Rich, 1932
Nakuru	Pyroclastics, feldspar, clays, evaporites.	Cyanophyceae	Hecky & Kilham 1973 Rich, 1932
Ephemeral saline lake:			
Magadi	Evaporites (trona) minor clay.	Cyanophyceae	Baker 1958 This work.
Alablab	Evaporites	Cyanophyceae	Dodson 1963

Classification of Rift Valley Palaeolakes.
(Several lakes reappear in different classes due to varying conditions during the period considered)

Holocene
Clastic: Turkana, Baringo, Bogoria (?), 'Suguta'(Suguta Beds), Nakuru/Elmenteita, Naivasha, Magadi (?).
Perennial saline lake: Magadi (?)

Pleistocene
Clastic: Turkana, 'Suguta', 'Kapthurin' (Kapthurin F.), Nakuru/Elmenteita/Naivasha, 'Olorgesailie' (Olorgesailie F.)
Biogenic: 'Suguta', Nakuru/Elmenteita/Naivasha, 'Olorgesailie'.

Pliocene
Clastic: Turkana, 'Chemeron'(Chemeron F.), 'Lukeino'(Lukeino F)
Biogenic: 'Chemeron','Lukeino'

Miocene
Clastic: Waril and Kabarsero lakes (Ngorora F.).
Ephemeral saline: Lake Kapkiamu (Ngorora F)

12(i)b Sedimentation in the clastic lake

This lake type is dominated by inputs of detrital minerals from mainly perennial rivers and streams. The lake waters are usually fresh and exclude the development of evaporites. Biotic elements form only a small percentage of the sediment body, due largely to rapid sedimentation rates.

An idealised facies pattern for such a lake is shown in figure 12.3. Shoreline sands and gravels pass progressively into finer deposits towards the lake centre. However, where wave action is limited (eg. small lakes), or only fine grained sediments are available, silts and clays may reach the shoreline. In cross section, the deposits often show interfingering relationships, due mainly to successive lake expansion and contraction (fig. 12.3).

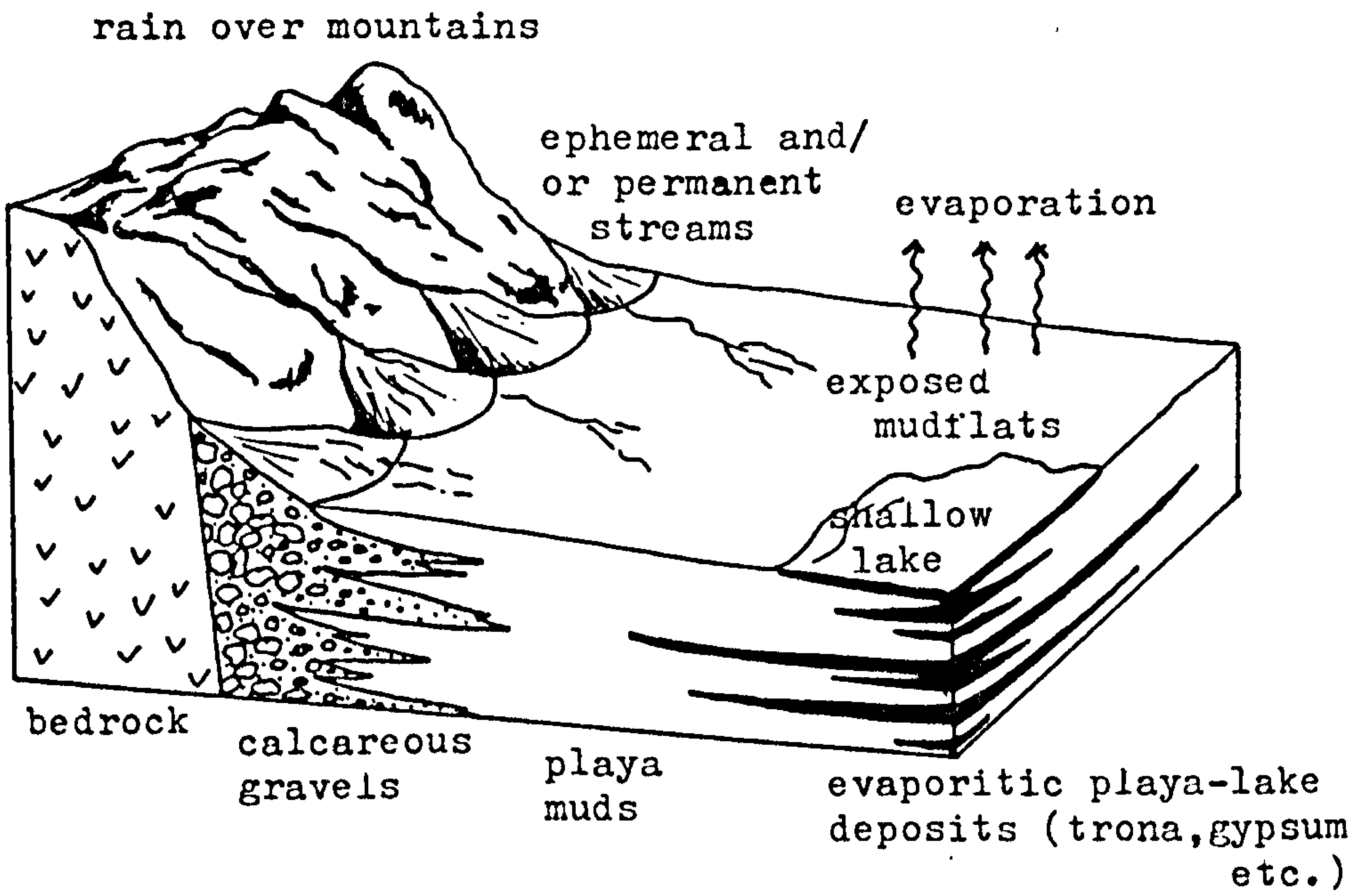
Smectites are the dominant clays in the Kenya Rift lakes. Montmorillonite has been observed in the present day Lakes Baringo and Turkana during this study, and is similarly common in ancient lacustrine sequences such as the Miocene Lukeino and Ngorora Formations of the Baringo district.

Silts and sands consist mainly of feldspars and volcanic glass, with or without lithic fragments and ferromagnesian minerals. Detrital quartz is rare in most basins, due to the composition of the volcanic source rocks. Lake Turkana is somewhat exceptional in this respect, since it contains quartz-rich basement rocks within its drainage basin.

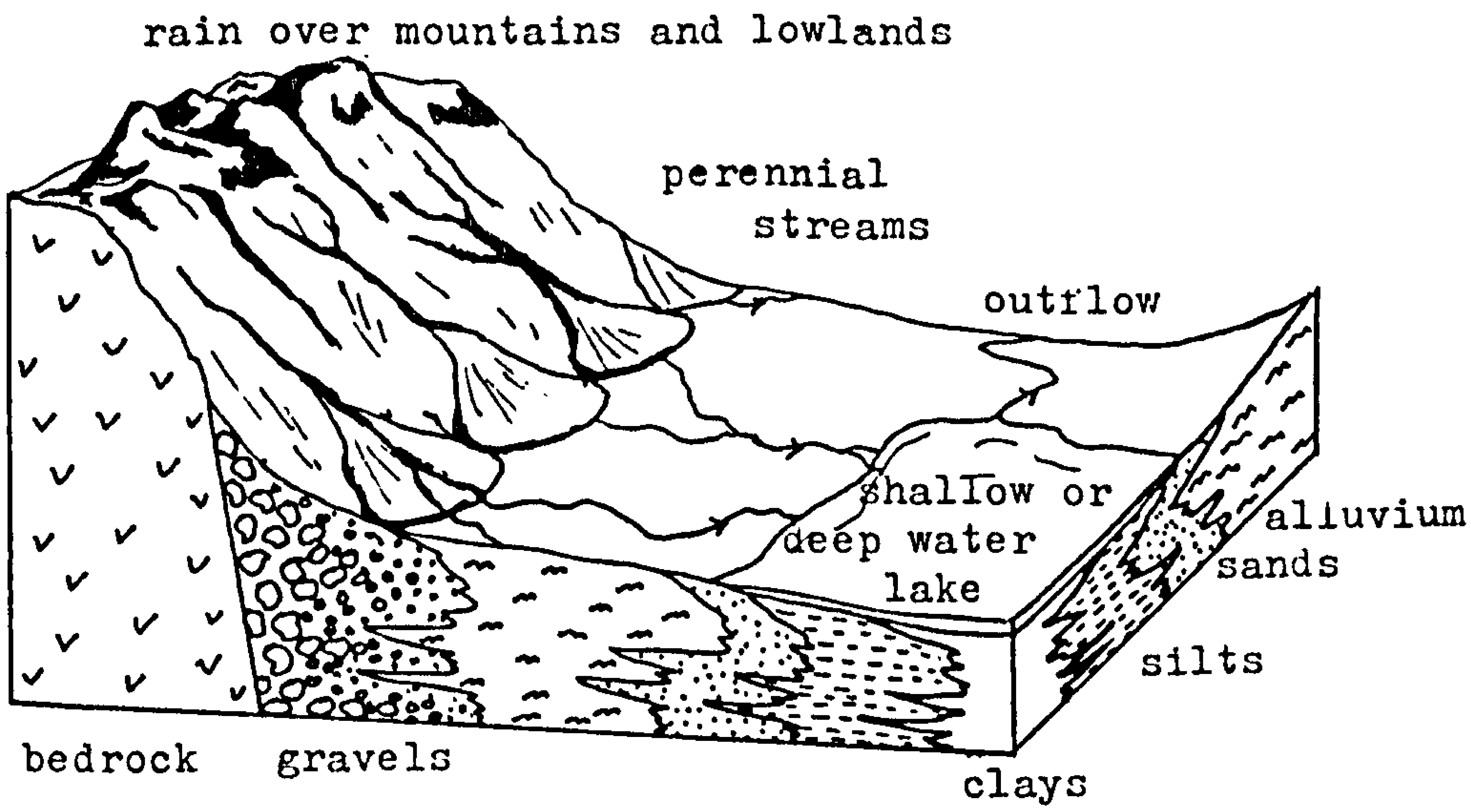
During the early Holocene, and at several stages during the Pleistocene, many rift lakes were larger than they are today. In some cases, the resulting greater 'fetch', allowed coarser deposits to be sorted into littoral zones. This probably occurred at Lake Nakuru (central Rift Valley), where sandy deposits have been left above the modern lake, which today has muddy or silty shorelines. Lake expansion, dilution and increased sediment supply resulted in many lakes

Fig. 12.3 Schematic block diagrams of depositional environments in the Gregory Rift Valley.

a). The playa lake complex



b). The freshwater permanent lake complex



Playa lakes are often surrounded by carbonate mudflats (exposed) which give way to alluvial fans. In contrast permanent fresh water lakes tend to be dominated by clastic deposition. Typically lake clays in the basin center give way to silts and then marginal sands. Alluvium then passes into alluvial fans at the basin wall.

of the clastic type forming during the early Holocene.

12(i)c <u>Sedimentation in biogenic lakes</u>

Deposits of this lake type are dominated by faunal and/ or floral debris. In Kenya, three groups have been important sediment formers. These are ostracods, diatoms and molluscs. Concentrations develop where ecological conditions were optimal during life, and where sedimentation rates of detrital minerals were low.

Sequences dominated by molluscs are usually of local extent. One example, recorded in this work, is that of <u>Etheria</u> shell concentrations (up to 3 m thick and tens of metres across) at East Turkana (p. 164).

Examples of extensive biogenic deposition are rare today. However, the southern basin of Lake Turkana does provide such a situation. There, ostracods predominate in the sediments (Yuretich, 1979), with diatoms also present.

Almost pure diatomites are recorded from the deposits of several palaeolakes. Perhaps the most famous of these, are the diatomites at Kariandusii (near Lake Elmenteita), which represents a much expanded Pleistocene lake. Less well known diatomites occur in the Lukeino and Chemeron Formations of the Baringo district. Often these are dominated by the planktonic species of the genus <u>Melosira</u>.

Outside the modern Kenya Rift, large concentrations of diatoms are often found in very fine grained profundal sediments of large non-calcareous lakes, where they are undiluted by detrital grains or limestone precipitates (eg. Lake Tanganyika; Degens et. al., 1971). However, highly diatomaceous deposits may also form under shallow waters, where there is little sediment input to the lake. This is probably the case with several diatomites in the Olorgesailie Formation.

The rate of sedimentation of diatomites or diatomaceous deposits will vary in relation to the productivity of the environment in which the diatoms lived, and in relation to competition from other organisms, as well as the rate of clastic input. Several estimates are indicated below.

LOCALITY	SOURCE	SEDIMENTATION RATE
Lake Turkana (silts with diatoms)	This work	1 m / 250-300 yrs.
Lake Naivasha (silts with diatoms)	Richardson, 1966	1 m / 325-466 yrs.
Lake Manyara (diatomaceous silts)	Holdship, 1976	1 m / 540 yrs.
Valle del' Inferno (Italy)(diatomites)	Bonnadonna, 1965	1 m / 952 yrs.
North Wisconsin (diatomite)	Conger, 1942	1 m / 3280 yrs.

It is clear that the modern and ancient lakes of the Kenya Rift have periodically developed near perfect conditions for diatom growth, and to a lesser extent the growth of molluscs and ostracods.

12(i)d Sedimentation in perennial saline lakes

For a perennial saline lake to form, outflow must be restricted or stopped, evaporation must be high and inflow must be sufficient to maintain a standing body of water. Such lakes are usually shallow (less than 10 m), although deeper ones are recorded outside Kenya (eg. Dead Sea). Water input is derived from both permanent and ephemeral rivers, while hot spring activity may be important in concentrating ions.

Evaporative concentration eventually results in the formation of surface brines and saline minerals, which sink to the bottom, below less dense and less concentrated inflow water. A continuous repetition of this sequence is typical of these lakes. Tiercelin (1979) has recorded the occurrence of evaporites along the median axis of Lake Bogoria (fig. 12.1), which have resulted from this type of process. The lake deposits are often associated with organic debris. Lakes of this type may have littoral zones that are dominated by clastic sediments. Trona ($NaHCO_3.Na_2CO_3.2H_2O$) is often the most common evaporite in Kenya.

12(i)e Sedimentation in ephemeral saline lakes

Ephemeral saline lakes occur in regions of low rainfall, and are subject to periodic dessication. Water input may be from infrequent storms or springs. During wet seasons, thin layers of silt and clay may form, while during 'drying out', evaporites develop. An idealised facies distribution in such a lake is shown in figure 12.3.

The particular saline minerals formed will depend on the brine involved and its evolution. In the Kenya Rift, the waters are dominated by Na, HCO_3 and CO_3. The best known ephemeral saline lake in Kenya is Lake Magadi (fig. 12.1), which has deposited up to 40 m of trona (Baker, 1958). The bedrocks in its catchment are mainly volcanic. Hardie et. al. (1978) have pointed out that the resulting dilute inflow, upon which evaporative concentration acts, is of a Ca-Na-HCO_3 type, and suggest the following simplified brine evolution.

undersaturated inflow $HCO_3 \gg Ca + Mg$ $(Ca \gg Mg)$ $\longrightarrow$ low Mg calcite precipitated $\longrightarrow$ HCO_3 rich, Ca poor water $\longrightarrow$ Na-CO_3-SO_4-Cl brine

Today, major ephemeral saline lakes are rare in the Kenya Rift. They are found at Lake Magadi and in the Suguta

Valley (Lake Alablab), but appear to have been absent during the wetter, early Holocene (fig. 12.2).

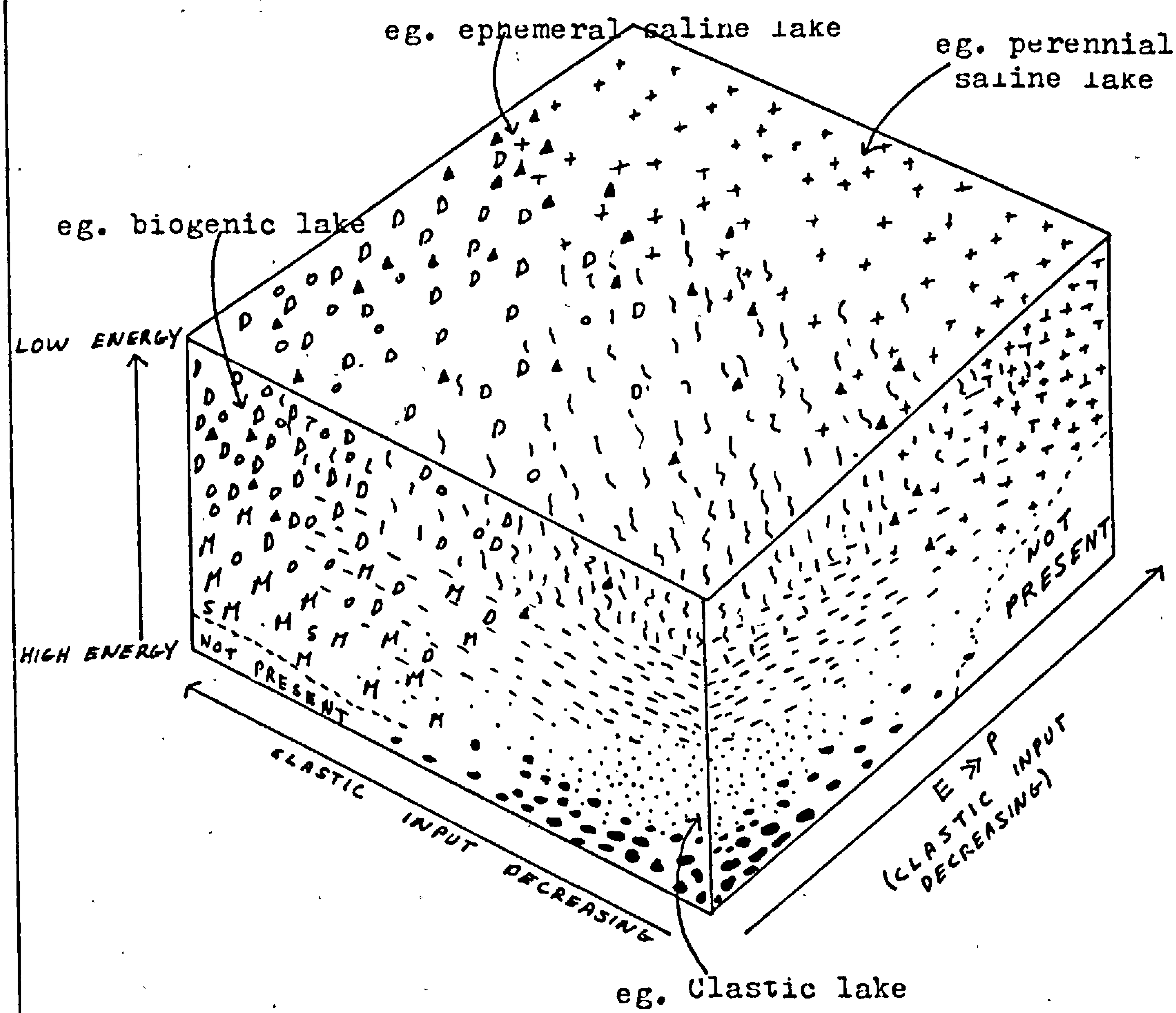
12(i)f Summary of the major influences on lacustrine sedimentation

It has already been pointed out, that in the Kenya Rift, lacustrine basins are usually initiated by tectonism and/or volcanism, and that climate is important in the further development of the lake. When considering the pattern of sedimentation, it is useful to consider three factors, although these are in turn influenced by source rock lithologies, wind speeds, water depths and so on. These factors are:

(i) The evaporation/precipitation balance
(ii) The rate of detrital input
(iii) The energy of the environment

Figure 12.4 shows the broad relationships between these three influences and sedimentation. As evaporation increases, evaporites tend to be promoted. As precipitation increases, biogenic or clastic deposits tend to be favoured. Which of the two actually develops depends on the rate of detrital input. High energy environments are usually associated with coarse deposits (or mollusc dominated biogenic sediments), while lower energies favour the formation of clays and silts (or diatom dominated biogenic units).

Fig.12.4 The relationship between certain environmental parameters (energy, clastic input and the evaporation/precipitation balance) and sedimentation



Authigenic minerals & evaporite deposits

Clays

Silts

Sands

Coarse sands and gravels

▲ Organic debris (algal)

D Diatoms

O Ostracods

M Molluscs

S Stromatolites

E Evaporation

P Precipitation

12(ii) The relationships between sediment types and diatoms

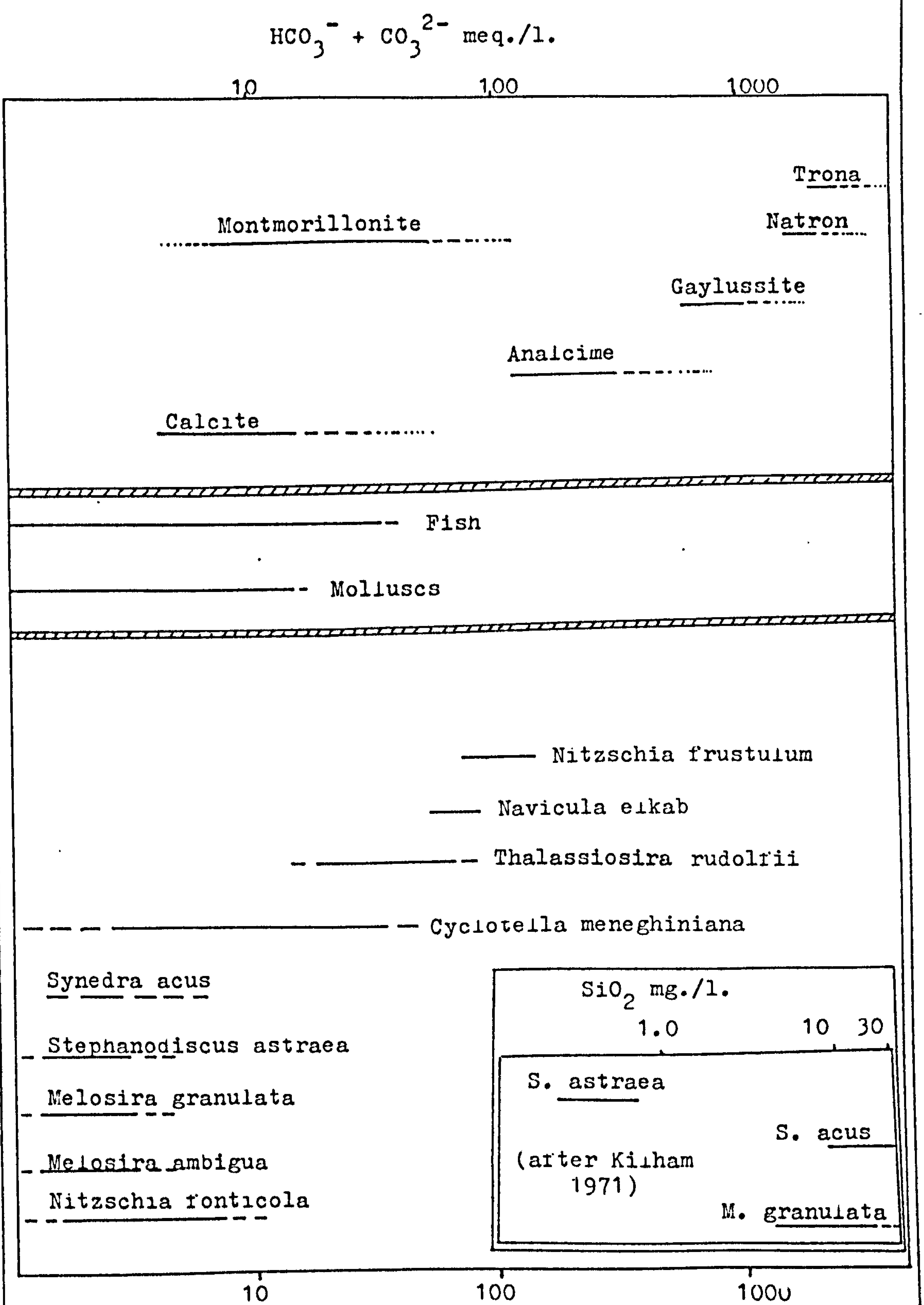
12(ii)a The links between lithology and diatom content, and their causes

Planktonic (free floating) diatoms tend to predominate over benthonic (bottom living) species in the deeper parts of lakes. Commonly, these regions are distal to sediment supply, and as a result planktonic forms tend to be associated with finer grained deposits. This broad relation holds true in the Galana Boi Formation (East Turkana), where the percentage of planktonic diatoms tends to increase as grain size decreases. Benthonic species are more common in the fine and medium sands, while diatoms disappear in the coarse sands (which formed along high energy shorelines).

Diatoms may also show relationships that are not dependent on grain size. Most diatoms disappear above alkalinities of about 150 meq/l, although a few *Nitzschia* species may occur up to about 300 meq/l (Holdship, 1976). The general upper limit results in diatoms not being found in sediments that contain primary authigenic minerals such as gaylussite, natron and trona (fig. 12.5). Analcime formation is, in most cases, beyond the tolerance limit of diatoms, although some 'overlap' does occur with certain *Nitzschia spp.*. Montmorillonite and calcite may develop, or remain stable, between alkalinities of about 4 and 100 meq/l, in Kenya waters (Cerling, 1979). This range overlaps with that of many diatoms. As a consequence, they are often found with montmorillonite, calcareous clays, or limestones. Gasse (1975) has observed that *Stephanodiscus astraea* and *Nitzschia spp.* often occur in limestones of the Afar region of Ethiopia.

A number of diatoms, such as *Navicula elkab* and *Thalassiosira rudolfii*, live in waters beyond the tolerance

Fig.12.5 The relationship between diatoms, macrofauna and mineral formation with regard to alkalinity.



Based on Hecky & Kilham, 1973; Holdship, 1976; Richardson, 1968 and Cerling 1979.

limits of most molluscs (up to 16 meq/l; Cerling, 1979) and fish (up to 40 meq/l; Cerling, 1979). Such species are therefore often found in sediments devoid of fish or mollusc fossils.

Diatoms also bear a close relationship to dissolved silica concentrations. Often, they occur in abundance in volcanic terrains, where the silica content of waters may be high. Melosira and Synedra species usually occur where the dissolved silica exceeds about 10 mg/l (fig. 12.5, inset). Other species, such as Stephanodiscus astraea, are favoured by low levels.

Today, pure diatomites are not forming in the major Kenya Rift lakes, although fossil deposits are common. These ancient diatomites normally include only one or two species. The following floras constitute the bulk of East African diatomites.

(i) Melosira spp.
(ii) Melosira/Synedra spp.
(iii) Stephanodiscus spp.
(iv) Nitzschia spp.

In the Kenya Rift Valley, only (i) and (ii) are common, although some diatomites (of local extent) are dominated by benthonic species. Floras (iii) and (iv) have been observed in the Pleistocene diatomites of the Afar (Gasse, 1975).

Figure 12.6(a) subjectively attempts to summarise the abundance of certain diatoms in different lithologies (based on personal observations). For example, clays were mostly associated with Melosira spp., while forms such as Rhopalodia vermicularis often occur in fine sands and silts.

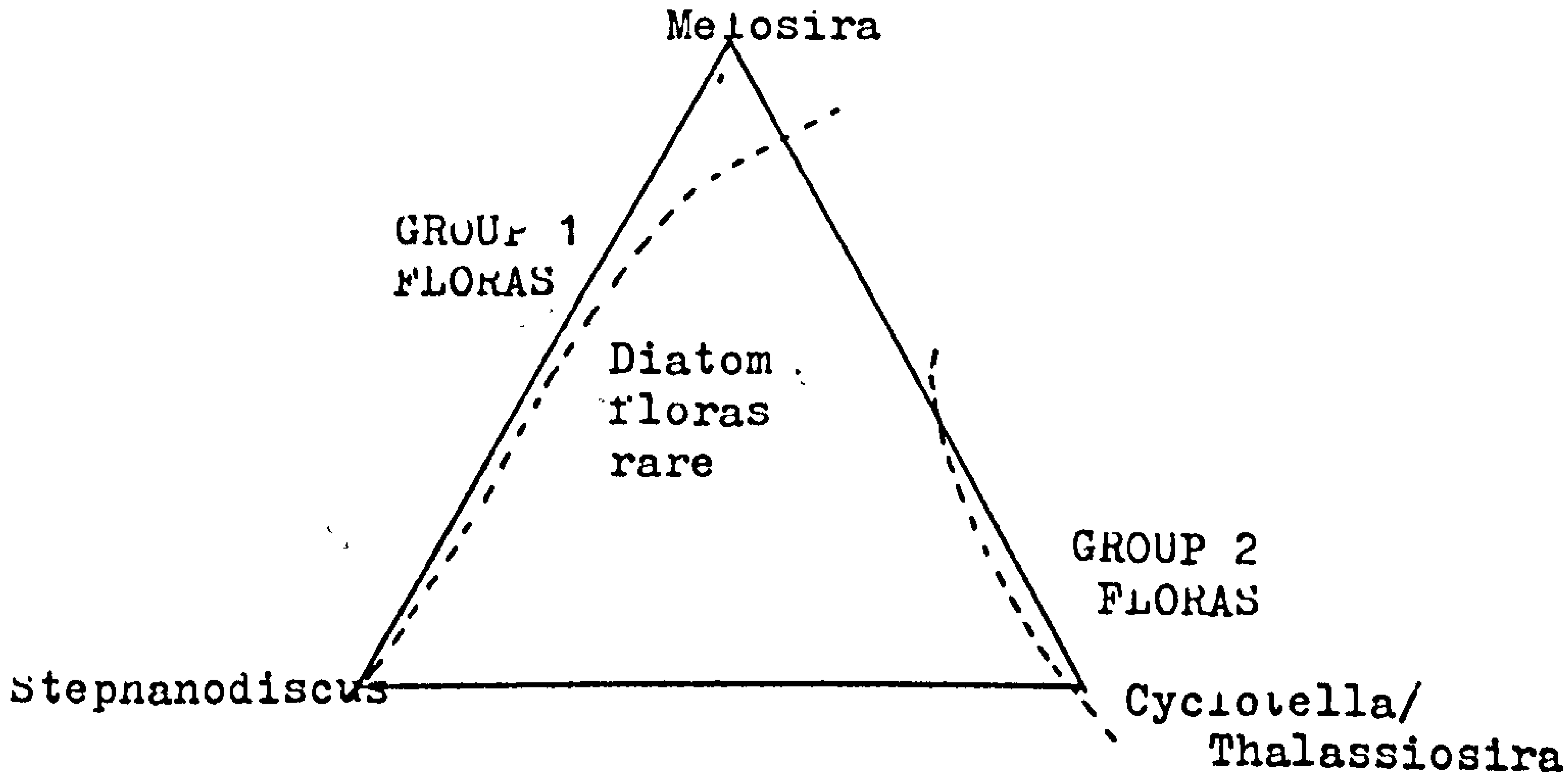
Fig. 12.6

a) Subjective frequency estimates of certain diatoms in different lithologies.

	Sand C.	Sand M.	Sand F.	Silt	Clay	Diatomite	Lmst.
Nitzschia spp.			+	++	+	+++	+
Melosira spp. (granulata & agassizi)			+	++	+++	+++	
Stephanodiscus astraea & vars			+	++	++	+++	
Cyclotella meneghiniana			+	++	++	+	+
Thalassiosira rudolfii			+	++	++	+	+
Campylodiscus clypeus			+	++	++		+
Rhopalodia vermicularis	+	+	+++	+++	+	++	
Cocconeis placentula	+	+	+++	+++	+	++	
Epithemia zebra	+	+	+++	++			

\+ present ++ common +++ abundant

b) Centric diatom triangular diagram illustrating common floral assemblages observed in the Kenya Rift Valley.



12(ii)b Floristic groupings and their relationships to lacustrine deposition

If one considers only the centric diatoms, two broad floristic groupings can be recognised, that are typical of the Kenya Rift sediments (fig. 12.6(b)). Group 1 floras consist of varying proportions of the genera *Melosira* and *Stephanodiscus*. Group 2 floras are dominated by mixtures of *Cyclotella* and *Thalassiosira*. The two floras rarely mix, probably due to their contrasting alkalinity requirements. However, some assemblages, which include *Melosira*, *Cyclotella* and *Thalassiosira* are known from the Afar (Ethiopia), and the Olorgesailie Formation of Kenya.

Group 1 floras are typically associated with fresh lakes of the clastic type (discussed earlier), in which silt and clay deposition predominates. Where detrital input is low a biogenic lake may develop. The proportion of *Melosira* to *Stephanodiscus* is probably controlled by silica (p. 385).

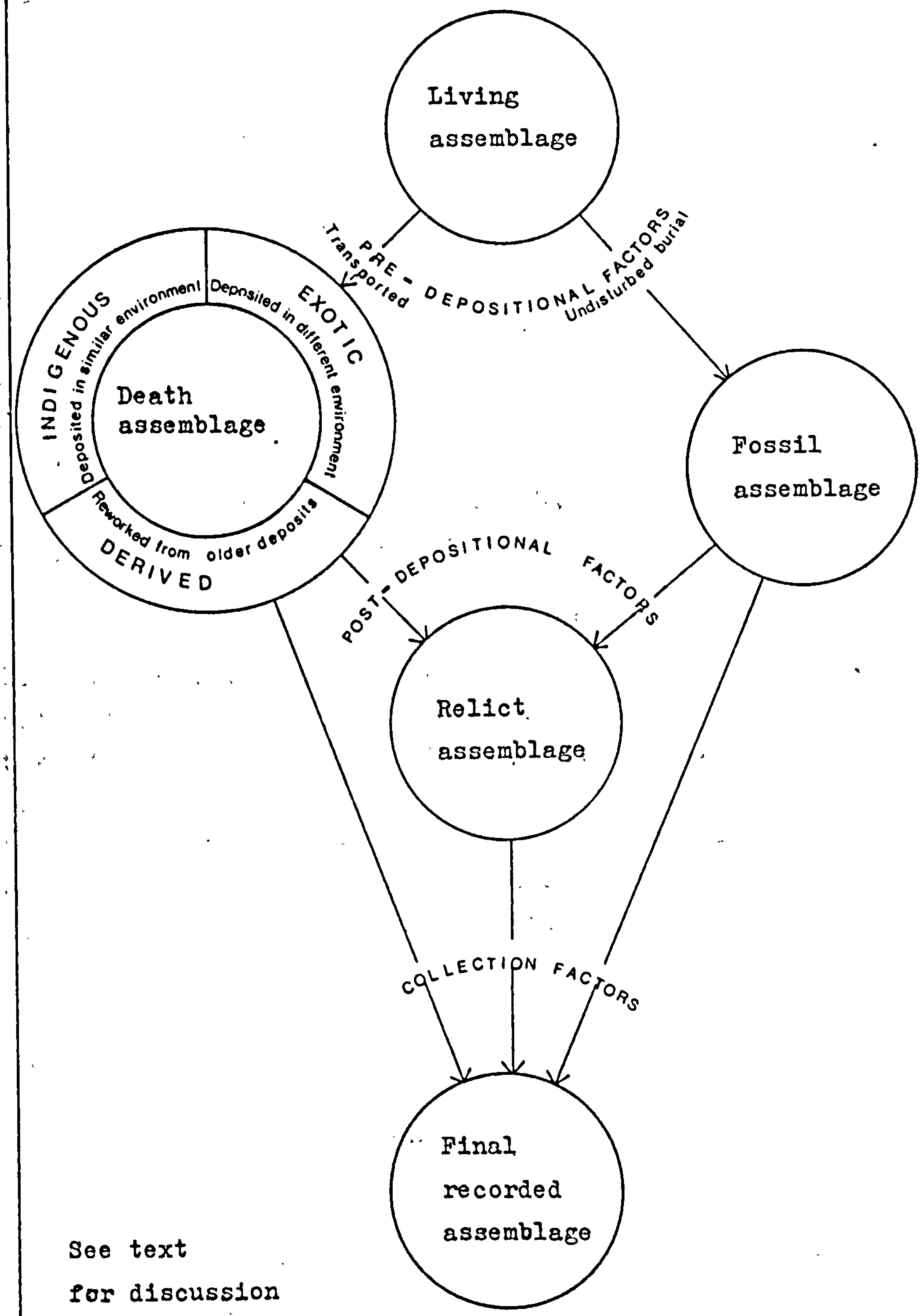
Group 2 floras are associated with higher alkalinities, which often develop during the terminal or regressive phases in a lakes evolution. Under these circumstances sands and coarser deposits advance lakewards. In extreme cases tha flora may be found in sediments interbedded with evaporite units.

12(ii)c Diatom fossilisation and the consequent difficuties in environmental interpretation

There are many processes that influence the final composition of a fossil diatom assemblage. An understanding of these is essential before interpretations can be made. Figure 12.7 indicates the main processes involved in changing a 'living assemblage' to a 'final recorded assemblage'. Three main sets of factors should be considered - pre-depositional, post-depositional and collection.

Fig. 12.7

The major stages in diatom fossilisation



See text for discussion

A. Pre-depositional factors

As a result of various mixing processes, fossil diatom assemblages may represent only the average state of a lake over several years. Where a lake has remained in the same ecological condition for long periods, this is of little importance. However, rapidly changing ecosystems may become blurred in the fossil record.

A(i) Passive mixing

This involves a simple settling of diatoms, after death, onto the lake bottom, and involves little or no breakage. Living assemblages may be easily changed by this process. For example, a planktonic flora may sink and mingle with a benthonic assemblage. The resulting flora then represents two differing habitats. East African lakes are sometimes stratified, and each layer may contain a characteristic community of its own. Upon death, these will sink and mix, producing a single combined flora.

Time may also play an important role in passive mixing. Diatom populations may vary from season to season, reflecting changing conditions. These may become mixed as they fall onto the lake floor, and disguise the seasonal changes. However, this is not inevitable. Bonnadonna (1965) has recorded seasonal changes in 'varve like' sediments. Similar periodic changes are also preserved in 'varves' from the Miocene Lukeino Formation of the Baringo district.

A(ii) Active mixing

Active mixing involves a process of movement, other than simple settling. It can take two main forms. The first type involves resuspension of the diatoms, without transportation from their original depositional sites. This may be caused by wind induced turbulence, or perhaps by a breakdown of seasonal thermal stratification. It is probably more important in the shallower parts of lakes. Diatom breakage may occur, and the relative percentages of different species will probably be altered.

The second major type of active mixing involves transportation. Diatoms may be moved from their life habitat prior to deposition. This may or may not involve damage, and size selection might operate. The effect of transportation would be to distort percentage counts and to introduce exotic species to the new area. Although difficult to detect, the transported flora would probably form only a small part of the indigenous assemblage. Diatoms can also be resuspended, or reworked, from older deposits, and then transported. Under these circumstances their is a strong chance of breakage.

Transported diatoms may be suspected from breakage, or by the occurrence of diatoms of differing ecologies in the same assemblage. In most cases, they will probably form only a small part of the indigenous flora. For these reasons, it is advisable not to include damaged, or rare, diatoms in percentage counts, although their presence should be noted. Further problems may arise from selective breakage. For example, of long slender types such as *Synedra*. In these cases, it may be necessary to make some allowances to compensate for the problem.

B. Post-depositional factors

After a flora has formed a fossil or death assemblage (fig. 12.7), it may be subjected to further alteration from one or more of three differing processes.

B(i) Biological alteration

Once deposited, diatoms may be further mixed by bioturbation. Burrowing organisms or root penetration may contribute to varying degrees. This process will tend to be concentrated in shallow, aerobic water, or in subaerial habitats, upon a lake regression. The main effect will be to further mix the diatom floras, although there may be some breakage, depending on the circumstances.

B(ii) Mechanical alteration

As sediments accumulate, compaction will increase. This may result in some diatom breakage, particularly of the more delicate or elongate forms. Some mixing may occur, but is probably minor in its effects.

B(iii) Chemical alteration

Highly alkaline groundwaters may result in the dissolution of diatoms. Thin walled species would probably be removed first, and perhaps the entire flora in extreme cases. When examining a deposit affected in this way, chemical etching of surviving species should make it clear that the process has operated.

C. Collection factors

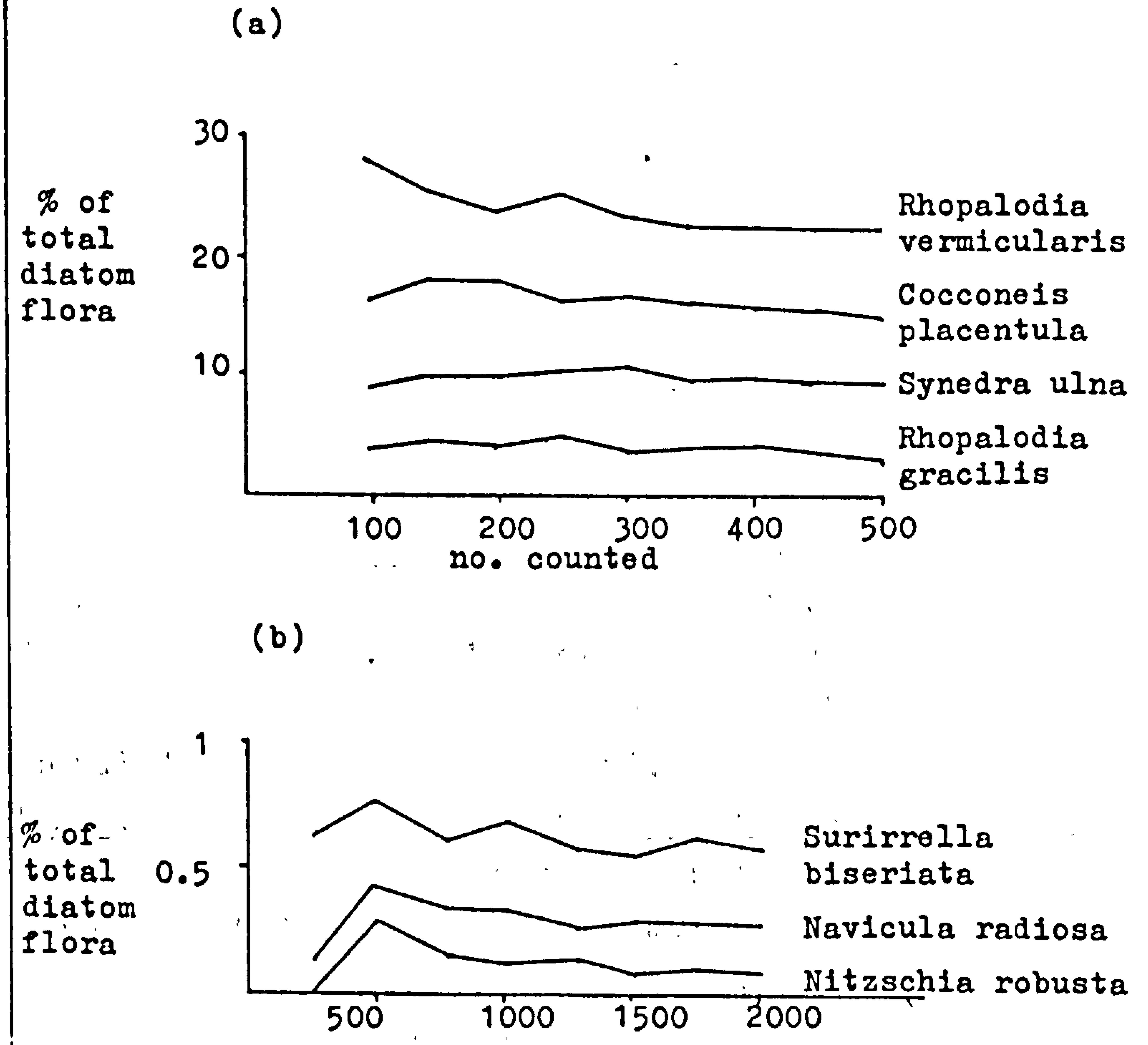
Further mixing of diatoms may occur when collecting samples. Inevitably, a certain thickness of sediment is obtained, and this represents a period over which deposition occurred, and during which the flora may have changed. If the sediment is well lithified, the problem can be minimised by taking a scraping from the surface of a sample. While this is usually possible in older units,it is more difficult in younger deposits, which are often unconsolidated. Contamination may also occur from other parts of the section being studied, and it is essential that its surface be 'cleaned' prior to sampling.

Errors may also be introduced in the laboratory. Accidental breakage and differential settling rates, during preparation for slides (p. 61), may result in a bias, if care is not taken. Inaccuracies may develop through counting too few diatoms. Figure 12.8 shows the percentages obtained for several species after different counts, based on the same slide. In order to ensure that all diatoms forming over 1 % of the flora are observed, two to three hundred individuals should be counted (fig. 12.8(a)). If accurate percentages are required for rare (less than 1 %) diatoms, it may be necessary to count 500 or more individuals (fig. 12.8(b)). A judgement is required as to the level of accuracy required.

From the foregoing discussion, it can be seen that many factors influence the final composition of a diatom flora. Consequently, interpretations should be made with care, and the realisation that the inferences are often based on an hypothetical 'average state', and rarely an instant in time.

Fig. 12.8

Variation in diatom percentages with count size



The diagram illustrates the changes in percentage of selected diatoms with increasing count size.

(a) For common diatoms, a count of between 200 and 300 is sufficient to approximate the actual percentage.

(b) For rare diatoms, a count in excess of 500 is needed to obtain a reasonable approximate of the actual percentage.

12(iii) The application of diatoms to geological research

12(iii)a Diatoms as an aid to correlation

In a study of the western U.S.A., Andrews (1971) noted that about 80 % of the species present in the middle Miocene were alive today. This figure drops to about 20 % for the late Eocene. Most East African Rift Valley sediments are younger than the middle Miocene. This suggests that diatom extinctions may be of limited value as a correlation tool in such areas.

However, there are a few possible exceptions. Stephanodiscus carconensis, a species commonly found in the lower Pleistocene, but rarely today (Gasse, 1975), has been observed in the Plio-Pleistocene Chemeron Formation of the Baringo district. It would seem that this diatom is a useful 'stratigraphic marker', where it is abundant. Melosira granulata, M. granulata-agassizi and M. agassizi are common in the Holocene deposits of the Kenya Rift. They are often difficult to distinguish and their ancestral forms appear to merge. In general, the older forms posses thicker frustules and a coarser ornamentation, which may provide a clue to the age of a deposit.

Pluvial stratigraphy (based on wet and dry periods) has been discredited for the last 15 to 20 years, because of the confusing influences of tectonism, volcanism and regional climatic variability. However, lake level fluctuations (upon which pluvial stratigraphy was largely based) may be used in local correlations for the late Quaternary, in areas where tectonism and volcanism has been minimal. Such lake level changes may be inferred from diatom studies. Comparisons made on this basis can be made in intra-basin studies, but become increasingly crude beyond the local level.

A summary of these points follows.

a) Only a few diatoms are of use in the Kenya Rift, as 'stratigraphic markers'.
b) Diatom morphology may be used in some cases as an approximate indication of age.
c) Diatoms may provide an indirect correlation method (by indicating lake levels) in late Quaternary studies.

12(iii)b Diatoms as a palaeoecological tool

The high representation of living species from the middle Miocene onwards, results in diatoms being of great value in palaeoecological studies of the Kenya Rift. Diatoms are often closely related to water depth and clarity. They can be used to infer the salinity, alkalinity, pH, nutrient status and the broad palaeotemperature of former lakes.

Diatoms usually record local environments, often with great accuracy. This contrasts with pollen studies, which are normally concerned with much wider regional variations. The short life span of diatoms, ranging from days to months, is a great advantage to this type of study. It allows changing ecosystems to be reconstructed with considerable accuracy. However, the precise 'resolution' possible depends on the degree of alteration that the living flora has been subjected to. In this thesis, they have been used to suggest environmental changes ranging from seasons (Lukeino Formation) to decades (Galana Boi Formation).

The relative percentages of planktonic and benthonic species have proved extremely useful in suggesting former lake level fluctuations. A detailed record of the Holocene expansions and contractions of Lake Turkana has been obtained in this manner. The occurrence of epiphytes can be used to suggest former reed beds (and shallow water). In some cases it may be possible to infer the proximity of a river from the presence of diatoms, such as _Pinnularia_ spp. (favoured by fresh inflow waters).

The chemical nature of a palaeolake can be inferred from its fossil flora. In the case of Lake Turkana, increasing alkalinity during the late Holocene, is indicated by a change from Melosira/Stephanodiscus assemblages to Cyclotella/Thalassiosira types. Changing alkalinity and salinity has been shown to be an important part of the evolution of ancient 'Lake Olorgesailie'. Diatoms can also be used to suggest former dissolved silica concentrations, and it would appear that these have exceeded 10 mg/l, at least periodically, in most of the palaeolakes examined.

In some instances, palaeotemperatures may be estimated. Modern warm water species (including several Nitzschia spp.) can be contrasted with cold water forms (eg. Cyclotella ocellata). When these data are combined with information from geological evidence, it may be possible to estimate former precipitation/evaporation balances.

Wherever possible diatom studies should be combined with geological investigations, in order to provide an overall synthesis of palaeoecological conditions.

In summary:

a) Diatoms are sensitive ecological indicators.
b) They allow fine scale reconstructions to be made.
c) They usually indicate local rather than regional conditions
d) They are very useful in reconstructing lake level fluctuations
e) Palaeoclimatic reconstructions can be made, especially when diatom and geological studies are combined.

12(iv) Summary of the stratigraphy and evolution of the East Turkana, Baringo-Bogoria and Olorgesailie areas

12(iv)a Comparisons and contrasts between the study areas

The three areas examined in this thesis lie in differing parts of the Kenya Rift, and show contrasting histories and sedimentation patterns. For the most part, these differences relate to variations in tectonism, volcanism, climate and catchment geology. The chronology and probable depositional environments of the units studied are shown in figure 12.9. This diagram also relates these deposits to sediments exposed in other parts of the Rift.

The contrasting natures of the basins are illustrated in cross section, in figure 12.10. Section 'A' of this diagram indicates the situation at East Turkana. This region is a somewhat ill-defined, and altitudinally low, part of the Rift, that has existed on the margins of a large lake since at least the Pliocene. The sediments reflect four major lacustrine expansions, that have occupied an 'East Turkana embayment', during this period. The Galana Boi Formation, which has received considerable attention in this work, represents the last (Holocene) of these major transgressions.

Further south, in the Baringo district, the Rift is better defined (fig. 12.10, section 'B'). This region has been subjected to more intense volcanism and tectonism than has East Turkana. This has resulted in the formation and destruction of a series of palaeolakes (distinctly separate in both space and time), rather than the continual existance of one great lake. These ancient lakes have tended to be centred further east as the Rift has developed, until by the earlier Pleistocene, lacustrine sedimentation was taking place in much the same area as today.

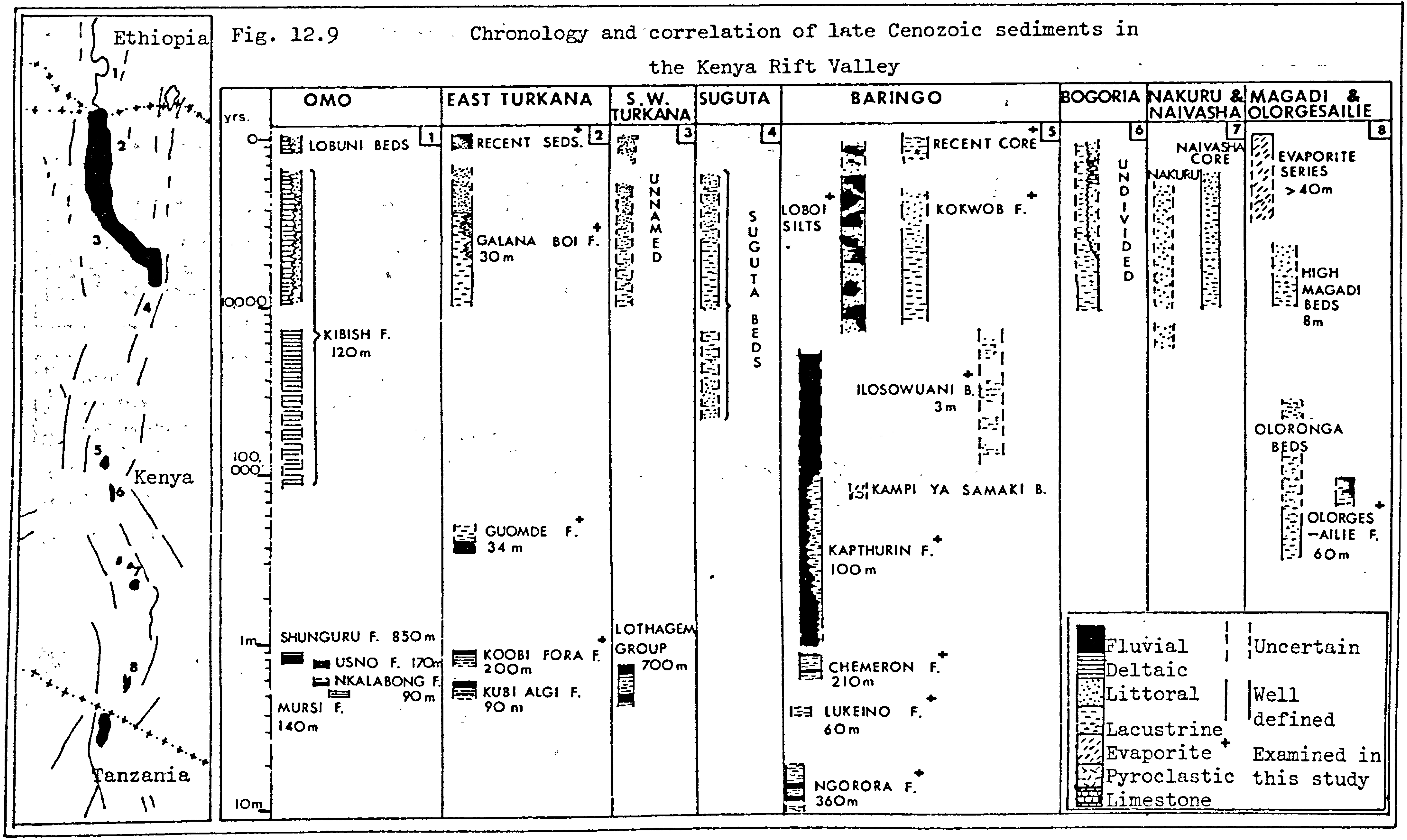
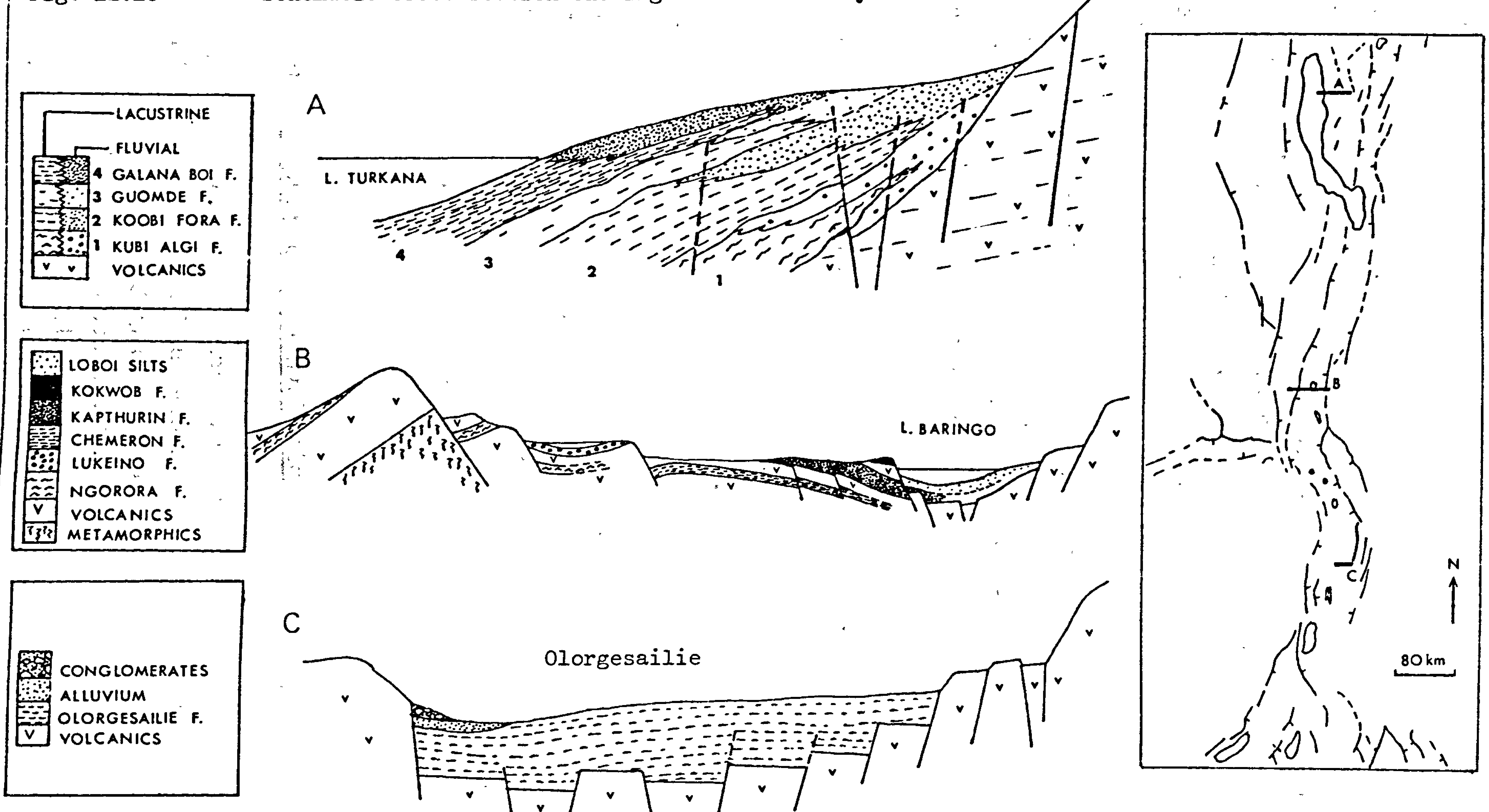


Fig. 12.9 Chronology and correlation of late Cenozoic sediments in the Kenya Rift Valley

Fig. 12.10 Schematic cross section showing the three study areas



N.B. Sections not to scale

The third area studied lies in the southern Kenya Rift, and contained a lake for a relatively short period (the middle Pleistocene). Here, the Rift is well defined and its floor consists of numerous horsts and grabens, with a north to south alignment (fig. 12.10, section 'C'). This region provides an example of a lake basin that formed in a series of interconnected grabens, and which was partly dammed to the south by the volcanics of Mt. Olorgesailie - a typical rift valley situation.

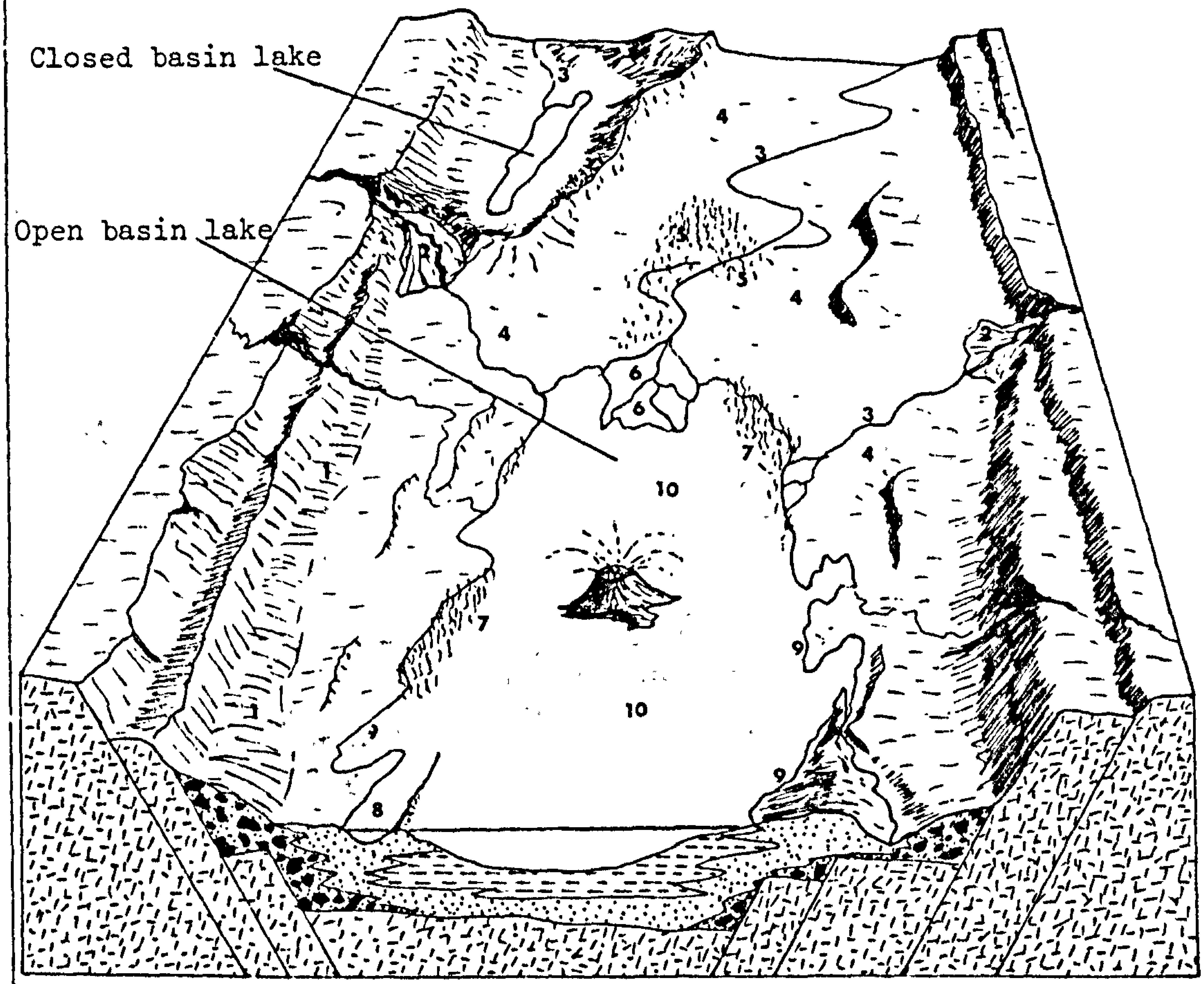
A wide range of depositional environments occur in grabens. These range from fluvial and colluvial to littoral and offshore lacustrine. The environments recorded in this work are summarised in figure 12.11, which also indicates their relative importance in the units studied.

The last of this series of summary diagrams deals with the range of chemistries of the palaeolakes investigated. This is done in a classification form, based on diatoms, and is shown in figure 12.12. The principle divisions in this classification are based on the alkalinity and salinity preferences of the diatoms found in the sediments. The diagram also indicates at what time, and in which basin, lakes of these chemical types have arisen. The classification ignores highly saline and alkaline lakes such as modern Bogoria, or the Kapthurin palaeolake, since their chemistries are beyond the tolerance limits of most diatoms

12(iv)b <u>Summary of the evolution of the East Turkana area</u>

Since the Pliocene, East Turkana has intermittently formed an embayment of an expanded Lake Turkana. The evolution of this embayment is summarised in figure 12.13. The sediments throughout this period have been dominated by quartzo-feldspathic silts and sands. These reflect outcrops of volcanics and quartz rich metamorphics within the catchment. Heavy minerals are common, as are bioclastic and

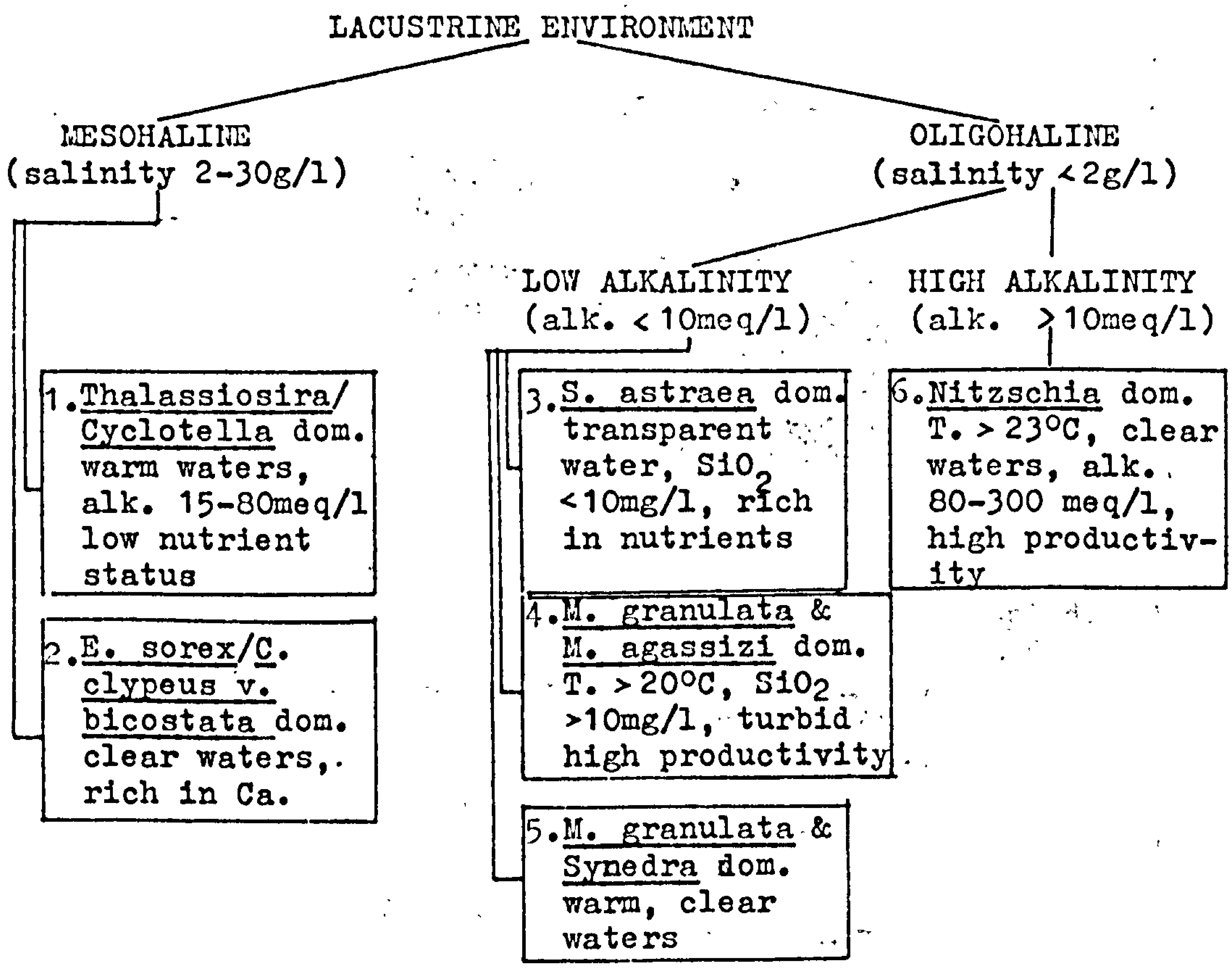
Fig. 12.11 Major depositional environments and lithologies represented by the various sedimentary units studied



SEDIMENTARY UNIT	TERRESTRIAL					DELTAIC	LACUSTRINE							
	COLLUVIAL	FLUVIAL					LITTORAL			OFFSHORE	CLASTICS	DIATOMITES	EVAPORITES	PYROCLASTICS
		FAN	CHANNEL	FLOODPLAIN	SWAMP		REED BEDS	LAGOON	BEACH					
*	1	2	3	4	5	6	7	8	9	10				
E. TURKANA GALANA BOI F.	○		○			○	◐	◐	●	●	●	○		○
GUOMDE F.	○		◐	◐			○	○	○	●	●			◐
BARINGO BOGORIA SEDS.	◐	●	◐	◐	○	●	○	○	●	●	●		●	
KOKWOB F.							●		●	○	●			
ILOSOWUANI B.	○		○							●	●			◐
KAPTHURIN F.		○	●	●						◐	●		○	◐
CHEMERON F.		○	◐	○		?				●	●	●		◐
LUKEINO F.		○	◐	○		?				●	●	●		◐
NGORORA F.		○	◐	○		?				●	●	◐		◐
OLORGESAILIE OLORGESAILIE F.	◐		●	●	◐	◐	●		◐	●	●	●		●

○ Rare ◐ Common ● Abundant *Numbers indicate location in diag.

Fig. 12.12 Ecological classification of the Rift Valley palaeolakes based on diatoms



Abbr.
E - Epithemia, C - Campylodiscus, S - Stephanodiscus, M - Melosira.

		East Turkana	Baringo	Olorgesailie
Holocene	late	1	1,4	---
	middle	3,4	---	---
	early	3,4	4	---
Pleist.	late	---	1	---
	middle	4	1(?)	1,2,4,6.
	early	4	---	---
Pliocene		---	3,4	---
Miocene		---	4,5	

--- not sampled or no sediments

Generalised distribution of the ecological classes in the sediments of East Turkana, Baringo and Olorgesailie

Fig. 12.13 Lake development during the late Cenozoic at East Turkana and in the Baringo district.

EAST TURKANA

Age	Sed. unit/basin	Facies	Diatoms	Ecology	Humidity
MODERN	Lake Turkana	Erosion, alluvium, offshore silts.	(rare) T. rudolfii Cy.men.	SiO_2 < 1 pH. 9 alk. 20-23	Semi-arid
0 — HOLOCENE	NO DATA				semi-arid
HOLOCENE 5000y. – 10000y.	GALANA BOI FORMATION	clays, silts, sands & impure diatomite	T. rudolfii &. Cy.men. appear M.granulata & S. astraea dominant (abundant)	SiO_2 1-10 pH. 7.5-8.5 alk. 5-10	Tropical humid
PLEIST. late	NO SEDIMENTS				Arid
PLEIST. middle	GUOMDE F.	silts, sands & bioclastic	M.granulata (rare)	SiO_2 ca10 pH. 7.5-8 alk.5-20	Humid
	NO SEDIMENTS				? arid ?
PLEIST. early — 2my. — Pliocene	KOOBI FORA FORMATION	Sands, silts, clay & tuffs laminated at base.	M. granulata Cy.men. (rare)	SiO_2 ca. 10 pH. 7.5-9 alk. 5-80	?humid?
Pliocene	NO DATA				????
6my. — Miocene — 12my.					

Baringo district

Age	Sed.unit/basin	Facies	Diatoms	Ecology	Humidity
MODERN	L. Baringo	clays & silts	M. granulata v.angustissima (rare)	SiO_2 15-20 pH. 8-9 alk. ca. 5	semi-arid to moist
MODERN	L. Bogoria	evaps.& silts	N.sp. (v.rare)	pH.9-10, alk.588	semi-arid
HOLOCENE	Baringo (core)	Clays & silts	T. rudolfii, M.granulata v. angustissima	SiO_2 >10 pH. 8-9 alk.5-ca.80	semi-arid
	NO DATA				?
HOLOCENE	KOKWOB FORM.	Silts & sands	M. granulata, S. astraea plus numerous littoral spp.	SiO_2 > 10 pH. 7.5-8.5 alk. ca.5	Tropical humid
	NO DATA				arid
PLEIST.	KAPTHURIN F. & ILOSOWUANI BEDS	Clays with authigenic minerals, tuff and alluvium	Absent in K.F. rare in I.B. Cy.men. T.rudolfii	pH. ca.8-9 alk.50-80	humid??? ?
	NO SEDIMENTS				NO INFERENCE POSSIBLE
	CHEMERON F. (time range uncertain)	Silts, clays diatomites and tuffs	M. granulata S.astraea (common to abundant)	SiO_2 >10 pH. ca 8 alk. 1-5	
	NO SEDIMENTS				
	LUKEINO F.	Diatomites silts & clays	M.granulata Syredra spp.	SiO_2>10 pH. 8 alk.ca.5	
	NO SEDIMENTS				
	NGORORA F.	Clays, silts & rare diatomites	M.granulata	SiO_2>10 pH. ca.8 alk. 1-5.	
	NO SEDIMENTS				

Abbreviations:
- Cy.men. - Cyclotella meneghiniana
- T. - Thalassiosira
- M. - Melosira
- S. - Stephanodiscus
- N. - Nitzschia
- evaps. - evaporites

SiO_2 in mg./l
alkalinity in meq./l
N.B. Humidity represents trends only (increases to the right)

pyroclastic sediments in several units. Four major transgressions can be recognised. The first two gave rise to the Pliocene Kubi Algi Formation and the Plio-Pleistocene Koobi Fora Formation (fig. 12.10, section 'A').

A third major transgression produced the deposits of the Guomde Formation. Diatoms are rare in this unit, and usually dominated by Melosira granulata, which is suggestive of a fresh lake. Although the age of this Formation is uncertain, it must pre-date late Pleistocene grid faults, which dislocate the entire basin. After regression, and probably during the latest Pleistocene, erosion deeply incised the landscape.

Lake Turkana again covered much of East Turkana during the early and middle Holocene, when it stood up to 80 m above modern heights. Periodic overflow to the River Nile is probable, and the lake was probably augmented by water from Lake Chew Bahir (to the north-east) and a former 'Lake Suguta' (to the south). The early Holocene alkalinity was less than 5 or 10 meq/l (today, 23 meq/l), salinities were less than 2 g/l (above this today), and dissolved silica ranged between about 1 to over 10 mg/l (today, less than 3 mg/l). The early Holocene lake was eutrophic, and of similar temperature to today. The diatom flora has shifted from one dominated by Melosira granulata-Stephanodiscus astraea-Rhopalodia vermicularis-Cocconeis placentula to a much less abundant flora dominated by Cyclotella meneghiniana-Thalassiosira rudolfii-Surirella biseriata-Anomoeoneis sphaerophora. Today, the lake abounds in blue-green algae.

Many lake level fluctuations have been recorded, from diatom assemblages and beach deposits, for the Holocene. Two phases of generally high lake levels can be recognised for the early and middle Holocene, separated by low elevations at about 7000 yr. B.P..

Tectonism may have played a role in controlling lake levels during the Pliocene and Pleistocene. However, late Quaternary changes are almost entirely due to climatic effects. Arid phases can be inferred for the late Pleistocene and late Holocene. A wetter climate than today (possibly seasonal in character) prevailed during the early and middle Holocene.

12(iv)c Summary of lacustrine sedimentation in the Baringo district

Although the sedimentary record is incomplete, lake environments have been recurrent in the Baringo and Tugen Hills areas for the last 12 my, and have, perhaps, been continuous since Kapthurin times (early-middle Pleistocene onwards)(fig. 12.13).

The sediments are diverse and include diatomites, feldspathic silts, montmorillonite clays, pyroclastics and evaporites. These reflect a wide range of conditions, that have intermittently developed.

The diatoms in most units are dominated by Melosira species, and many deposits are monospecific. Other important diatoms include Synedra spp. (Lukeino Formation), Stephanodiscus spp. (Chemeron Formation), Thalassiosira and Cyclotella (Ilosowuani Beds and core material from Lake Baringo). Inferences from diatoms and authigenic minerals suggest that the chemistries of these lakes have varied widely. Alkalinities range from less than 5 meq/l to 580 meq/l in modern Lake Bogoria. Dissolved silica has, for the most part, exceeded 10 mg/l, and the waters have generally been eutrophic. The chemical aspects of the different lakes are summarised in figure 12.13.

The older lacustrine units (Ngorora, Lukeino and Chemeron Formations) were formed in a series of quite separate tectono-volcanic basins, that have since been destroyed. The Pleistocene Kapthurin Formation was deposited on the margins of a central rift lake, whose northerly and southerly limits are as yet unclear, but which occupied much the same area as modern Lake Baringo and the Loboi Plain. The Ilosowuani Beds may represent a lacustrine sequence on the eastern side of this lake, towards the end of the Pleistocene. Late Pleistocene grid faulting lowered the axial zone, terminated Kapthurin sedimentation and resulted in the present configuration of the basin. During the latest Pleistocene/early Holocene, a regional increase in precipitation resulted in high levels for both Lakes Baringo and Bogoria. The Kokwob Formation was deposited in the former, while diatomaceous silts were laid down in the latter. Since then, lake levels have been lower, but continue to fluctuate in response to climatic variation.

In an area where extensive tectonic deformation and volcanism have been prevalent, it is difficult to evaluate the degree to which climatic changes may have been an important factor in hydrological variation. Few direct palaeoclimatic inferences can be made from pre-Holocene sediments. The late Pleistocene/early Holocene high lake levels, common to both Lakes Baringo and Bogoria, are widely reported from other East African lakes. These are generally considered to be the result of increased rainfall. Since the early Holocene, the climate has been generally drier, resulting in successively lower lake levels. That Lake Baringo has, or almost has, dried out during the later Holocene is shown by palaeosols in a core from the modern lake.

12(iv)d Sedimentation in the middle Pleistocene Lake Olorgesailie

The Olorgesailie Formation was laid down in a middle Pleistocene lake. This Formation contains the most diverse range of sediments and diatoms of any single unit studied in this thesis. This range reflects deposition on the margins of an expanding and contracting lake.

The sediments include pyroclastics (in great abundance), diatomites, quartzo-feldspathic silts, sands and conglomerates, plus montmorillonite rich clays. The diatoms are varied and consist mainly of species belonging to the genera Melosira, Thalassiosira, Cyclotella, Epithemia, Rhopalodia, Cocconeis and Campylodiscus. Their sequential development suggests at least eleven transgressive episodes of varying scale.

The alkalinity of the palaeolake varied widely, reaching a probable maximum of about 85 meq/l. However, for much of its existence it was considerably fresher (less than 10 meq/l). Dissolved silica concentrations mostly exceeded 10 mg/l, in water that was probably of comparable temperature to similarly situated lakes today. Littoral reed beds were abundant, and many areas may have been marshy. Blue-green algae may have periodically been important.

Again, due to tectonism and volcanism, climatic inferences are difficult to draw. However, it seems probable that at least some of the lake level changes were climatically induced, while rainfall may have been generally higher than today, in this modern semi-arid region.

Lacustrine sedimentation was initially made possible by graben formation, and blockage of southerly drainage by the volcanics of Mt. Olorgesailie. It was finally terminated by regional southerly tilting, which lowered the outlet height and allowed through drainage.

12(iv)e Concluding comments

Much of the work in this thesis has been concerned with Holocene deposits. These can be examined in three dimensions in many cases, due to their good exposure and unaltered state. Other parts of the thesis are concerned with older units, mostly studied in two dimensional sections. It is hoped that this work to some extent bridges the gap between these two approaches, and provides an understanding of the typical sedimentation patterns found in rift valley settings.

Diatoms form a particularly powerful tool in studying lacustrine units. They allow detailed reconstructions of water chemistry and lake ecology to be made. When combined with geological data a well rounded synthesis of the palaeoecology and palaeogeography of former sedimentary basins can be inferred.

A great diversity of sediment types are preserved in the Kenya Rift. Although these have been studied for many years, several gaps still remain in our knowledge, and large areas still require initial examination. Notable among these poorly explored regions is the Suguta Valley, to the south of Lake Turkana. Sediments to the west of this large lake have also received little formal study. Another possibly fruitful area for further research might be the Kedong basin, to the east of Suswa volcano.

Many other deposits, already examined in the field, could benefit from detailed laboratory analyses. Although pollen studies have been conducted on sediments to the north of Lake Turkana, no diatom investigations have been made. Conversely, the Holocene sediments at East Turkana would benefit from a pollen analysis.

Research in the Kenya Rift is perhaps entering a new phase. Much large scale mapping has now been completed, and attention should be shifted to more detailed and multidisciplinary work.

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APPENDIX I

List of fossil diatoms and their ecologies

On the following pages are listed diatoms observed during this work. A number of abbreviations are used and these are listed below (for definition of terms see tables 2.2 and 2.3 on pages 71 and 73 respectively).

Habitat (Hab):
p-planktonic; l-littoral; a-aerophile; c-crenophile; e-epiphyte.

pH :
al-alkaliphilic; ab-alkalibiontic; i-indifferent; ac-acidophilic. (numbers indicate pH optima).

Salinity (Sal):
o-oligohalobe; m-mesohalobe; p-polyhalobe; y-hyperhalobe; h-halophobe; e-euryhalobe.

Trophism (Tro):
o-oligotrophic; e-eutrophic; Hf-facultative nitrogen heterotrophe; h-obligatory nitrogen heterotrophe.

Current (Cur):
lp-limnophilous; lb-limnobiontic; i-indifferent; rp-rheophilous; rb-rheobiontic.

Geographic extent (Geog. ext.):
c- cosmopolitan; t-tropical; e-endemic to tropical Africa; T-temperate; A-alpine.

Sedimentary unit containing taxon (Sed. unit):
GB- Galana Boi Formation; GF-Guomde Formation; KF-Koobi Fora Formation; K-Kokwob Formation; I-Ilosowuani Beds; C-Chemeron Formation; L-Lukeino Formation; KB-Kaparaina Basalts Formation; N-Ngorora Formation; O-Olorgesailie Formation.

Taxon	Ecology					Geog ext	Sed unit
	Hab	pH	Sal	Tro	Cur		
Melosira							
M. agassizi OSTENFELD	p	al	e	-	-	t	GB,K,C,L,O.
var. malayensis HUSTEDT	p	al	e	-	-	t	GB,K,C,L,O.
M. ambigua (GR.) MULLER	p	al	o	i	-	c	GB,O.
M. distans EHRENBERG	p,l	ac	n	o	-	A	GB.
M. goetzeana MULLER	p	al	e	-	-	e	GB,O.
M. granulata (EHR.) RALFS	p	8	o	e	-	c	GB,GF,KF,K,C,L,O
var. angustissima MULLER	p	8	o	e	-	c	GB,K,C,L,O.
f. curvata HUSTEDT	p	al	o	e	-	c	GB,O.
var. valida	p	al	o,e	-	-	t	O
M. granulata-agassizi	p						GB.
M. italica (EHR.) KUTZING	p	al	o	e	-	c	O.
M. nyassensis MULLER	p	al	o	-	-	e	GB.
var. victoriae MULLER	p	-	o	-	-	e	GB.
M. praegranulata RALFS	p	-	-	-	-	-	N.
M. varians AGARDH	p,l	8.5	o	e	-	c	GB.
Stephanodiscus							
S. astraea (EHR) GRUNOW	p	al	o	e	-	c	GB,C,O.
var. intermedia FRICKE	p	al	o	e	-	c	GB,C,O.
var. minutula (KUTZ)GRUNOW	p	al	o	e	-	c	GB,K,C,O.
S. hantzschii GRUNOW	p	i	o	e	-	c	C.
var. pusilla GRUNOW	p	i	o	e	-	c	C.
S. carconensis GRUNOW	p	i	o	o	-	T	C.
Cyclotella							
C. kutzingiana THWAITES	p,l	al	o	o	-	c	O.
var. planetophora FRICKE	p,l	al	o	o	-	c	GB.
C. meneghiniana KUTZING	p,l	ab	e	Hf	-	c	GB,I,O
var. pumila GRUNOW	p,l	al	e	-	-	c	O.
C. ocellata PANTOCSEK	p,l	al	o	o	-	c	O.
Thalassiosira							
T. rudolfii BACHMANN	p	ab	o,m	-	-	e	GB,K,I.
T. lacustris GRUNOW	p	al	-	-	-	c	GB.
Terpsinoe							
T. musica EHRENBERG	a	al	o,e	e	-	t	GB.K.
Fragilaria							
F. brevistriata GRUNOW	l,p	al	o,e	o	i	c	GB,K,I,C,L,KB,O
F. construens (EHR)GRUNOW	l,p	al	o,e	o	i	c	GB,C,L,KB O.
var.binodis (EHR)GRUNOW	l,p	al	o,e	o	i	c	KB.
var. subsalina HUSTEDT	l,p	-	o,m	o	-	c	GB.
var. venter (EHR)GRUNOW	l,p	al	o,e	o	-	c	GB,KB.
F. lapponica GRUNOW	l	-	-	-	lp	c	GB,K,C,O.

Taxon	Ecology					Geog. ext.	Sed. unit
	Hab.	pH.	Sal.	Tro.	Cur.		
F. intermedia GRUNOW	1	7,8	o	-	-	c	GB.
F. pinnata EHRENBERG	1,p	7,8	o,e	o	i	c	GB,K,C
var. lancettula (SCH)HUSTEDT	1,p	7,8	o,e	o	-	c	GB.
Synedra							
S. acus KUTZING	1,e	7.5	o	-	-	c	GB,K,L.
var. angustissima GRUNOW	p	al	o	-	-	c	L.
S. affinis KUTZING	1,e	-	m	-	-	c	O.
S. dorsiventralis MULLER	1,p	al	o	-	-	t	GB,
S. rumpens KUTZING	1,e	6,8	o	-	-	c	GB,K,C.
var.familiaris (KUTZ)GRUNOW	-	-	-	-	-	c	C
var.fragilarioides GRUNOW	1,e	-	o	-	-	c	GB,K,C
S. ulna (NITSCH) EHRENBERG	1,e	7,8	o,e	e	i	c	GB,GF,KF, K,C,L,O.
var. aequalis (KUTZ)HUSTEDT	1,e	-	-	-	-	c	GB,K,C,L.
var. danica (KUTZ) GRUNOW	p	al	o	e	-	c	GB,K.
var. oxyrhyncus (KUTZ) VAN HEURCK	1,e	al	o	e	-	c	GB,K.
Cocconeis							
C. diminuta PANTOCSEK	1,e	i	o	-	i	c	GB.
C. disculus (SCH) CLEVE	1,e	i	o	-	-	t	GB.
C. pediculus EHRENBERG	1,e	al	e	-	-	c	K.
C. placentula EHRENBERG	1,e	8	o	o	i	c	GB,GF,K, C,KB,O.
var. euglypta (EHR) CLEVE	1,e	8	o	o	i	c	GB,K,O.
var. lineata (EHR) CLEVE	1,e	al	i	-	i	c	GB,K.
Achnanthes							
A. exigua GRUNOW	1,e	8	o	-	-	c	GB.
A. lanceolata (BR.)GRUNOW	1,e	7,9	o	-	rb	c	GB,K,C, KB.
Mastogloia							
M. braunii GRUNOW	1	al	m	-	-	c	K,O.
M. elliptica (AGARD) CLEVE	1	al	m	-	-	c	O.
Anomoeoneis							
A. exilis (KUTZ)CLEVE	1,c	6,7	o	o	i	c	GB.
A. sphaerophora (KUTZ)PFITZER	1	8.5	o,e	-	-	c	GB,O.
var. guntheri MULLER	1	7	m	-	-	c	O
var. polygramma KUTZING	1	-	m	-	-	c	O,I
f.rostrata MULLER	1	-	-	-	-	c	GB.
Stauroneis							
S. smithii GRUNOW	1	-	-	-	-	c	GB,K.
Diploneis							
D. elliptica (KUTZ)CLEVE	1	i	o	-	lp	c,T	GB.
D. ovalis (HILSE) CLEVE	1	i	o	-	i	c	GB,K.
var. oblongella(NAEG)CLEVE	1	al	o,e	-	-	c	GB,
D. subovalis CLEVE	1	7,8	o,e	-	-	t	GB.

Taxon	Ecology					Geog ext.	Sed. unit
	Hab.	pH.	Sal	Tro	Cur		
<u>Caloneis</u>							
C. bacilium (GRUN)CLEVE	l,c	al	o	o	rp	c	GB,O
var. fontinalis GRUNOW	l,c	-	o	-	-	c	O.
C. silicula (EHR)CLEVE	l	8.5	o	-	-	c	O.
<u>Gyrosigma</u>							
G. acuminatum (KUTZ)CLEVE	l	8	o	-	-	c	GB.
G. spenceri SMITH	l	al	o	-	-	c	GB.
var. nodifera (GRUNOW)	l	-	o	-	-	c	GB.
<u>Pleurosigma</u>							
P. salinarum GRUNOW	l	-	m	-	-	c	O
<u>Navicula</u>							
N. accomoda HUSTEDT	l	al	o	-	-	c	GB.
N. atomus (KUTZ)GRUNOW	l	6,7	o	-	-	c	GB.
N. cincta (EHR)KUTZING	l	8	o,e	-	rp	c	O.
N. confervacea KUTZING	l	8.4	o	-	-	c	O.
N. cryptocephala KUTZING	l	8	o,e	e	i	c	GB,K,C, L.
var.intermedia GRUNOW	l	al	o,e	e	-	c	GB.
var. veneta (KUTZ)GRUNOW	l	al	m	-	-	c	O
N. damasi HUSTEDT	l	7.3	o	-	-	e	GB.
N. elkab MULLER	l	8.5	m	-	-	e	GB.
N. exiguiformis HUSTEDT	l	al	o	-	-	c	GB.
N. gastrum EHRENBERG	l	al	o	-	-	c	GB,K,O,C.
N. grimmei KRASSKE	l,c	al	o,e	-	-	c	I.
N. halophila (GRUN)CLEVE	l	8	o,m	-	-	c	GB,K.
N. hungarica GRUNOW	-	al	o	-	rp	c	C.
N. menisculus SCHUMAN	l	al	o	-	-	c	GB.
N. minima GRUNOW	l	7,8	o	-	-	c	GB,C
var. atomoides (GRUN)CLEVE	l	i	o	-	-	c	GB.
N. muralis GRUNOW	a	8	o	-	-	-	O.
N. mutica KUTZING	l,c	8	o,m	-	i	c	O.
N. perrotetti GRUNOW	l	8.3	o,e	-	-	t	O.
N. placentula EHRENBERG	l	8	o	-	-	c	GB.
N. pupula KUTZING	l,c	8	o,e	-	i	c	GB,C,I,O
var. rectangularis GRUNOW	l,c	8	o,e	-	i	c	GB,C.
var. capitata HUSTEDT	l,c	8	o,e	-	i	c	GB,C.
var. elliptica HUSTEDT	l,c	8	o,e	-	i	c	GB.
var. rostrata HUSTEDT	l,c	8	o,e	-	i	c	GB.
N. radiosa KUTZING	l	7	o	-	i	c	GB,K
N. rhyncocephala KUTZING	l	7.5	o,e	-	i	c	GB
N. schoenfeldii HUSTEDT	l	al	o,m	-	-	c	GB,O
N. seminuloides HUSTEDT	l	7,8	o	-	-	c	GB.
N. seminulum GRUNOW	l	8.4	o	Hf	i	c	GB.
N. scutelloides SMITH	l	al	o	-	-	c,T	GB.
N. simplex KRASSKE	l	al	o	-	-	c	O
N. tenera HUSTEDT	l	-	o	-	-	c	O
N. thienemanii HUSTEDT	l,a	-	o,m	-	-	t	I
N. viridula KUTZING	l	al	o	-	-	c	GB.

Taxon	Ecology					Geog. ext.	Sed. unit
	Hab.	pH.	Sal.	Tro.	Cur.		
Gomphonema							
G. acuminatum var. turris (EHR.)CLEVE	l,e	al	o	-	lp	c	GB,O
G. clevei FRICKE	l,e	al	o	-	-	t	O.
G. constrictum EHRENBERG	l,e	8	o	o	i	c	O.
G. dubravicense PANTOSCEK	l,e	-	o	-	-	c	GB.
G. gracile EHRENBERG	l,e	7.3	o	o	i	c	GB.
G. abbreviatum KUTZING	l,e	al	i	-	-	c	K.
G. inticatum KUTZING	l,e	7.5	o	-	lp	c	GB
var. pumilum GRUNOW	l,e	7.2	o	-	i	c	GB,O,K
G. lanceolatum EHRENBERG	l,e	8	o	-	i	c	GB.
G. olivaceum (LG.)KUTZING	l,e	8	o	-	-	c	GB,O
G. parvulum (KUTZ)GRUNOW	l,e	al	o	Hf	lp	c	GB.
G. subtile EHRENBERG	l,e	7	o	-	-	c	GB.
Gomphocymbella							
G. brunii (FRICKE)MULLER	l,e	al	-	-	-	-	GB.
Amphora							
A. coffaeformis AGARDH	l,c	8	m	-	-	c	O
A. exigua GREGORY	l,e	-	m	-	-	c	O
A. ovalis KUTZING	l,e	8	o	-	i	c	GB,K,C.
var. libyca EHRENBERG	l,e	al	o	-	i	c	GB,K.
var. pediculus KUTZING	l,c	8	o,e	-	i	c	GB,O.
A.perpusilla GRUNOW	l,e	al	o,m	-	-	c	GB.
A. veneta KUTZING	l,e	8.5	o,e	-	-	c	O.
Cymbella							
C. affinis KUTZING	l,e	7,8	o	-	i	c	GB.
C. tumida (BR) CLEVE	l,e	al	o	-	-	c	GB.
C. turgida (GRUN)CLEVE	l,e	7.3	o	-	lp	c	GB,O
C. ventricosa KUTZING	l,e	7.8	o	o	i	c	GB,K,C, KB,O.
Nitzschia							
N. acuta (HANTSCH	l	-	o	-	-	c	GB.
N. aequalis HUSTEDT	p	8.5	o	e	-	e	GB.
N. amphibia GRUNOW	l	8.5	o,e	Hf	i	c	GB,K,O
var. pelagica HUSTEDT	p	al	o	-	-	c	GB,K,O
N. bacata HUSTEDT	p	al	o	e	-	t	K.
N. epiphytica MULLER	l,p	al	o	-	-	e	O
N. fonticola GRUNOW	l,p	al	o,e	h	i	c	GB.
N. frustulum (KUTZ)GRUNOW	l,p	8	e,m	h	-	c	GB,K,L,O
var. minutula GRUNOW	l,c	al	e,m	Hf	-	c	GB.
var. perminuta GRUNOW	l,c	al	e,m	Hf	-	c	GB.
var. perpusilla GRUNOW	l,c	al	e,m	Hf	-	c	GB.
var. subsalina HUSTEDT	l,c	-	-	-	-	c	GB,K.
N. obtusa SMITH	l	-	m	-	-	c	O.
N. ovalis ARNOTT	l	-	m	h	-	c	O.
N.palea (KUTZ) SMITH	l	al	o	h	-	c	GB.
var. tenmirostris GRUNOW	l	al	o	-	-	t	GB.
N. paleacea GRUNOW	l	8	o	-	-	c	GB.

Taxon	Ecology					Geog ext.	Sed. unit
	Hab	pH	Sal	Tro.	Cur.		
N. parvula LEWIS	1	-	m	-	-	c	GB.
N.punctata (SM) GRUNOW	1	al	m	-	-	c	GB.
N. recta HANTZSCH	1	al	o	-	rp	c	GB.
N. robusta HUSTEDT	1	9	o,e	-	-	e	O.
N. sigma (KUTZ) SMITH	1	al	m,e	-	-	c	GB.
N. spiculum HUSTEDT	p	8	o	h?	-	e	GB.
N. thermalis GRUNOW	1	al	o	e	-	c	GB.
N. tropica HUSTEDT	p	8	o	-	-	e	O.
N. tryblionella HANTZSCH	1	al	o,m	-	-	c	GB.
N. vitrea GRUNOW	1	-	m	-	-	c	GB.
Epithemia							
E. argus KUTZING	1	8	o,e	-	-	c	GB,C,I,GF, O.
E. mulleri FRICKE	1	al	o	-	lp	c	K.
E. sorex KUTZING	1	8	o,e	-	-	c	GB,K,O.
var. gracilis HUSTEDT	1	al	-	-	-	c	O.
E. turgida (EHR) KUTZING	1	8	o	-	-	c	O.
E. zebra (EHR) KUTZING	1	al	o	o	-	c	GB,O
var. porcellus (KUTZ)GRUNOW	1	al	o	o	-	c	GB.
var. saxonica (KUTZ)GRUNOW	1	al	o	-	-	c	GB,K,O
Rhopalodia							
R. gibba (KUTZ) MULLER	1	al	o	o	i	c	GB.
var. ventricosa (KUTZ)MULL.	1	al	o	o	-	c	GB.
R. gibberula EHR. MULLER	1	al	e,m	o	-	c	O,C,K
var. baltica (MULLER)	1	al	e,m	o	-	c	O.
var. debyi (PANT)MULLER	1	al	e,m	o	-	c	O.
var. protracta (GRUN)MULLER	1	al	e,m	o	-	c	I.
var. rupestris SMITH	1	al	e,m	o	-	c	I,K
var. sphaerula MULLER	1	al	e,m	o	-	c	I,K
var. vanheurcki MULLER	1	al	e,m	o	-	c	I.
R. gracilis MULLER	1	al	-	-	-	-	GB.
R. ventricosa MULLER	1	al	o	-	-	-	GB.
R. hirundiformis MULLER	1,p	-	o	-	-	e	GB.
R. musculus (KUTZ)MULLER	1	al	m,p	-	-	c	O.
R. rhopola (EHR) MULLER	1	al	o	-	-	e	GB.
R. parallela (GRUN) MULLER	1	al	o	-	-	c	GB.
R. vermicularis MULLER	1	al	o	-	-	e	GB,GF,KF, L,C,O.
var. perlonga	1	al	o	-	-	e	GB.
Cymatopleura							
C. solea (BR) SMITH	1	al	o	-	-	c,T	GB,O.
var. laticeps MULLER	1	al	o	-	-	c	GB,
var. rugosa MULLER	1	al	o	-	-	c	O.
Surirella							
S. biseriata BREBISSON	p,1	al	o	-	-	c	GB,O.
var. lanceolata RICH	p,1	al	o	-	-	c	GB.
S. engleri MULLER	p	al	o	-	-	e	GB.
f. angustior MULLER	p	al	o	-	-	e	GB.

Taxon	Ecology					Geog ext.	Sed. unit
	Hab	pH	Sal	Tro	Cur		
S. engleri f. recta MULLER	p	al	o	-	-	e	GB.
S. fulleborni MULLER	p	al	o	-	-	e	GB.
var. elliptica MULLER	p	al	o	-	-	e	GB.
S. constricta var. africana MULLER	p	al	o	-	-	e	GB.
S. linearis var. elliptica MULLER	l	i	o	-	-	c	GB,K.
S. ovata KUTZING	l	al	m	-	-	c	I.
S. ovalis BREBISSON	l	8.5	m	-	-	c	I,O
var. apiculata MULLER	l	-	m	-	-	c	O.
S. linearis var elliptica MULLER	l	i	o	-	-	c	GB.
var. constricta (EHR)GRUNOW	l	i	o	-	-	c	GB.
S. robusta EHRENBERG	l	-	o	-	-	c	GB,O.
<u>Campylodiscus</u>							
C. clypeus EHRENBERG	l	al	m	-	-	c	O.
var. bicostata (SM)HUSTEDT	l	al	m	-	-	c	O.

APPENDIX II

Descriptions of some common diatoms from the Quaternary sediments of the Kenya Rift

CENTRICAE

MELOSIRA Agardh

M. granulata (Ehr.)Ralfs.

Pl. A.III-1, ph. 1-3

Valves cylindrical, forming chains. Diameter 8-15 µ; valve height 12-17 µ. Areolae coarse, in longitudinal rows (striae), ca. 8-12/10 µ; 7-10 areolae/10 µ along pervalvar axis. Heteromorphic spines encircling valvar disc. Very polymorphic species.

M. granulata var. angustissima Muller

Valves cylindrical. Similar to nominate species, except length: width ratio much greater. Diameter 4-6 µ; valve height 18-25 µ.

M. granulata var. valida Hustedt

Valves cylindrical. Similar to nominate species, except very coarse ornamentation. Diameter 9-15 µ; valve height 13-19 µ; striae 7-9/10 µ. Areolae quadrangular; well developed sulcus.

M. agassizi Ostenfeld

Pl. A.III-1, ph. 14, 18
Pl. A.III-7, ph. 6

Similar to Melosira granulata, but with finer ornamentation, and smaller height:width ratio (less than 1). Diameter 12-35 µ; valve height 10-18 µ; 12-13 striae/10 µ; 14-16 areolae/10 µ. Areolae round or elongate perpendicular to the pervalvar axis. Spiral processes common.

M. nyassensis var. victoriae Muller

Pl. A.III-1, ph. 7

Cylindrical valve. Diameter 12-18 u; valve height 20-28 u; 7-8 striae/10 µ; 5 or 6 areolae/10 µ. Areolae elongate parallel to pervalvar axis, and split by a median plate. Col well developed (up to 5 µ in height). Sulcus weak and frustule thin.

CYCLOTELLA Kutzing

C. meneghiniana Kutzing

Pl. A.III-7, ph. 12, 13

Valve discoid with linear tangential undulations. Diameter 10-35 µ; striae 6-10/10 µ, radial and restricted to the margins.

STEPHANODISCUS Ehrenberg

S. astraea (Ehr.)Grunow

Pl. A.III-2, ph. 5, 6

Valve discoid with concentric undulations. Diameter 20-45 µ. Valvar disc with hyaline ribs in outer quarter (terminated by spines). 6-8 radial striae/10 µ; 2 or 3 rows of areolae at the end of the radial striae. About 12 areolae/10 µ. Central area consists of disordered areolae.

S. astraea var. minutula (Kutz.) Ehrenberg

Pl. A.III-2, ph. 3, 4, 7, 8
Pl. A.III-7, ph. 10, 11

Frustule more delicate than nominate species. Diameter 6-28 µ. Radial hyaline ribs longer (a third of the diameter) than in S. astraea, otherwise similar.

PENNATAE

FRAGILARIA Lyngbye

F. construens (Ehr.)Grunow

Pl. A.III-3, ph. 2, 5, 7
Pl. A.III-8, ph. 2

Rectangular in girdle view, cruciform in valvar view. Length 6-18 µ; width 5-10 µ. Transapical striae 14-17/10 µ, slightly radial. Pseudoraphe narrow, slightly lanceolate.

SYNEDRA Ehrenberg

S. ulna (Nitzsch.)Ehrenberg

Pl. A.III-3, ph. 10, 11

Valve linear, very gradually tapering to subrostrate apices. Pseudoraphe very narrow. Striae about 10/10 µ, parallel. Length 60 -350 µ; width 5-8 µ. Many varieties exist.

COCCONEIS Ehrenberg

C. placentula Ehrenberg

Pl. A.III-3, ph. 13

Pl. A.III-8, ph. 1

Elliptical in valvar view. Length 10-60 μ; width 7-35 μ.

Raphe valve:- radially punctate. Transapical striae 20/10 μ. Hyaline ring interrupts striae. Raphe straight. Axial area narrow, rounded at centre.

Rapheless valve:- Transapical striae distinctly punctate, 22/10 μ, radial. Pseudoraphe narrow, linear

ANOMOEONEIS Pfitzer

A. sphaerophora (Kutz.)Pfitzer

Pl. A.III-4, ph. 1
Pl. A.III-9, ph. 4

Valve elliptic-lanceolate, with rostrate apices. Axial area narrow, broadening at centre, with lateral hyaline areas interrupting the striae. Striae 15-17/10 μ, slightly radiate, composed of irregularly spaced punctae. Length 40-65 μ; width 12-18 μ.

NAVICULA Bory

N. gastrum Ehrenberg

Pl. A.III-4, ph. 6,15
Pl. A.III-8, ph. 16,17

Valve broadly elliptic, with short rostrate apices. Length 25-40 μ; width 12-17 μ. Axial area narrow, linear (rectangular at centre). Raphe straight. Transapical striae strongly radial, alternately short and long in the middle, 8-10/10 μ.

N. pupula Kutzing

Pl. A.III-4, ph. 4

Valve linear-lanceolate. Rounded broad apices. Length 20-43 μ;

width 7-11 µ. Raphe straight. Axial area narrow. Transapical striae radial, 22-25/10 µ. Terminal nodules transversely wwdened.

N. radiosa Kutzing

Pl. A.III-4, ph. 13

Valve lanceolate with sharply rounded apices. Ill-defined central area. Striae radial at centre, slightly convergent at apices, 10-12/10 µ. Length 35-85 µ; wwdth 8-17 µ

N. scutelloides Smith

Pl. A.III-4, ph. 11
Pl. A.III-8, ph. 18

Valve broadly elliptic. 10-30 µ long, 8-20 µ wide, punctae distinct, about 10/10 µ. Striae radial, about 10/10 µ. Raphe straight, axial area narrow.

EPITHEMIA Brebisson

E. zebra var. saxonica (Kutz.)Grunow

Pl. A.III-5, ph. 6
Pl. A.III-8, ph. 6-10

Dorsal margin strongly convex, ventral margin straight or slightly concave. Slightly rostrate apices. Length 17-55 µ; width 8-10 µ. Costae 2-4/10 µ, radial. Areola rows 12-14/10 µ. 4-8 areola rows between costae.

E. sorex Kutzing

Pl. A.III-8, ph. 5

Dorsal margin highly convex and ventral margin concave. Rounded apices. Length 18-43 µ; width 8-14 µ. Raphe bent strongly towards the dorsal margin. Costae 5-7/10 µ, radial. Areola rows 12-14/10 µ. 2-3 areola rows between costae.

RHOPALODIA Muller

R. gibberula (Ehr.)Muller

Pl. A.III-5, ph. 2

Valves in girdle view, long and elliptical with rounded apices. Dorsal side highly convex, ventral margin straight or concave. Areolae distinct between costae. Length 35-54 µ; width 19-23 µ, costae 3-4/10 µ; 2-8 rows of areolae between costae.

R. vermicularis Muller

Pl. A.III-5, ph. 5
Pl. A.III-8, ph. 11

Margins straight, wedge shaped in girdle view. Length 140-250 µ; maximum width of girdle face 32-38 µ.

APPENDIX III

Diatom photographs

The diatoms in each of the lists below refer to plates on the following pages. The magnifications given include the effects of photographic enlargement.

Plate A.III-1 Optical microscope photographs (Centricae)

1 - Melosira granulata (3500), Chemeron F. (Plio-Pleistocene)
2 - M. granulata (3000), Chemeron F. (Plio-Pleistocene)
3 - M. granulata (3300), Galana Boi F. (Holocene)
4 - M. granulata var angustissima f. curvata (4350) Kokwob F. (Holocene)
5 - M. granulata var angustissima f. curvata (5200) Galana Boi F. (Holocene)
6 - M. goetzeana (3850), Olorgesailie F. (middle Pleistocene)
7 - M. nyassensis var victoriae (850), Galana Boi F. (Holocene)
8 - M. granulata (3500), Chemeron F. (Plio-Pleistocene)
9 - M. granulata (3500), Galana Boi F. (Holocene)
10- M. granulata (3500), Chemeron F. (Plio-Pleistocene)
11- M. granulata (3200), Kokwob F. (Holocene)
12- M. granulata (3350), Kokwob F. (Holocene)
13- M. granulata-agassizi (3950), Galana Boi F. (Holocene)
14- M. agassizi (4000), Galana Boi F. (Holocene)
15- M. agassizi var malayensis (3000), Chemeron F. (Plio-Pleistocene)
16- M. agassizi var malayensis (3000), Chemeron F. (Plio-Pleistocene)
17- M. granulata-agassizi (3500), Galana Boi F. (Holocene)
18- M. agassizi (3800), Galana Boi F. (Holocene)
19- M. granulata-agassizi (3900), Galana Boi F. (Holocene)
20- M. agassizi var malayensis (3500), Chemeron F. (Plio-Pleist.)
21-23 - M. goetzeana (3200), Olorgesailie F. (middle Pleistocene)
24- M. distans (?) (4200), Ilosowuani Beds (late Pleistocene)

PLATE A.III-1

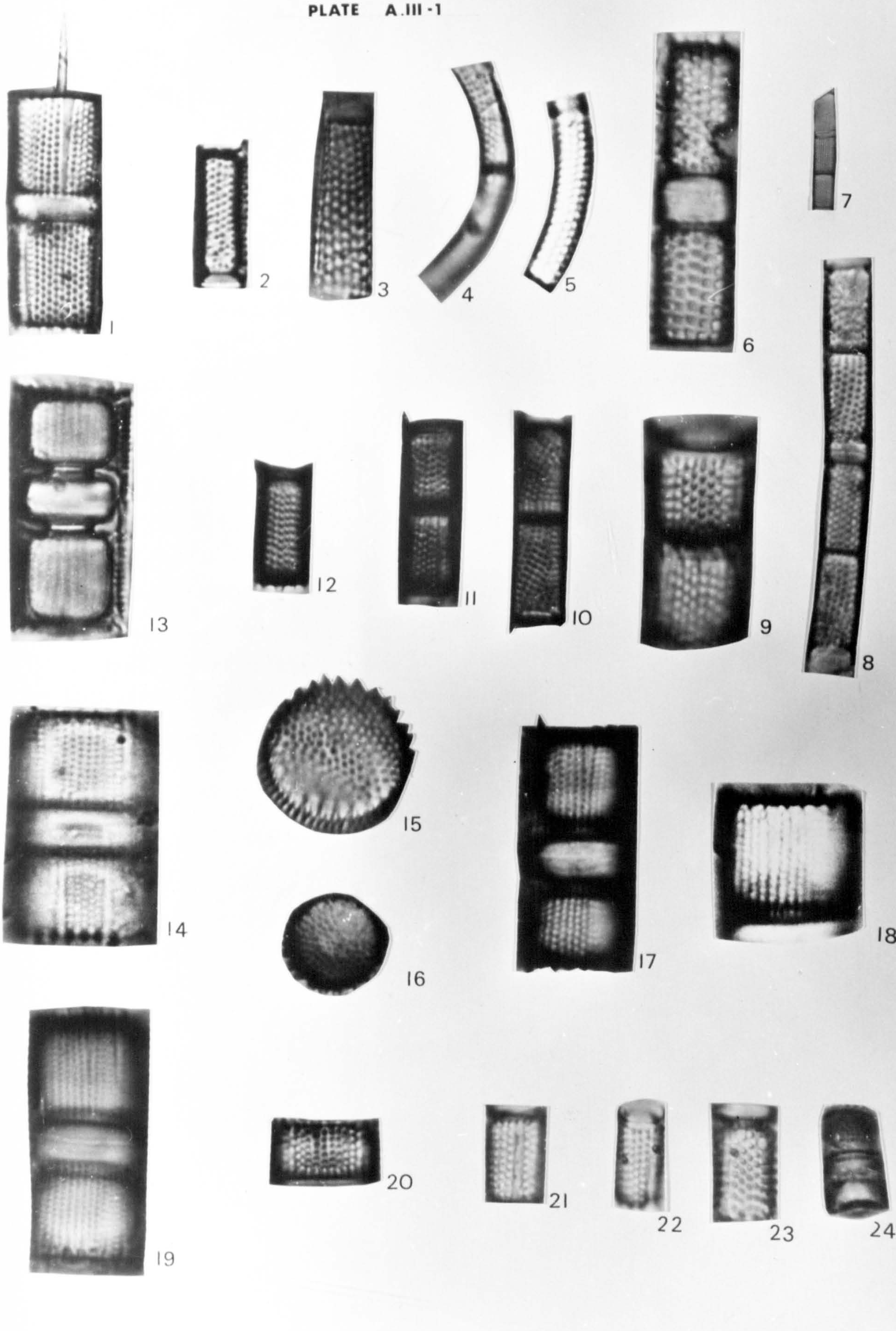


Plate A.III-2 Optical microscope photographs (Centricae)

1 - Thalassiosira rudolfii (3300), Galana Boi Formation (Holocene)
2 - Thalassiosira rudolfii (3300), Galana Boi Formation (Holocene)
3 - Stephanodiscus astraea var minutula (3800), Galana Boi Formation (Holocene)
4 - S. astraea var. minutula (3900), Chemeron Formation (Plio-Pleistocene)
5 - S. astraea (3500), Galana Boi Formation (Holocene)
6 - S. astraea (3500), Galana Boi Formation (Holocene)
7 - S. astraea var minutula (3700), Galana Boi Formation (Holocene)
8 - S. astraea var. minutula (3800), Galana Boi Formation (Holocene)
9 - Thalassiosira rudolfii (2900), Olorgesailie Formation (Holocene)

PLATE A.III-2

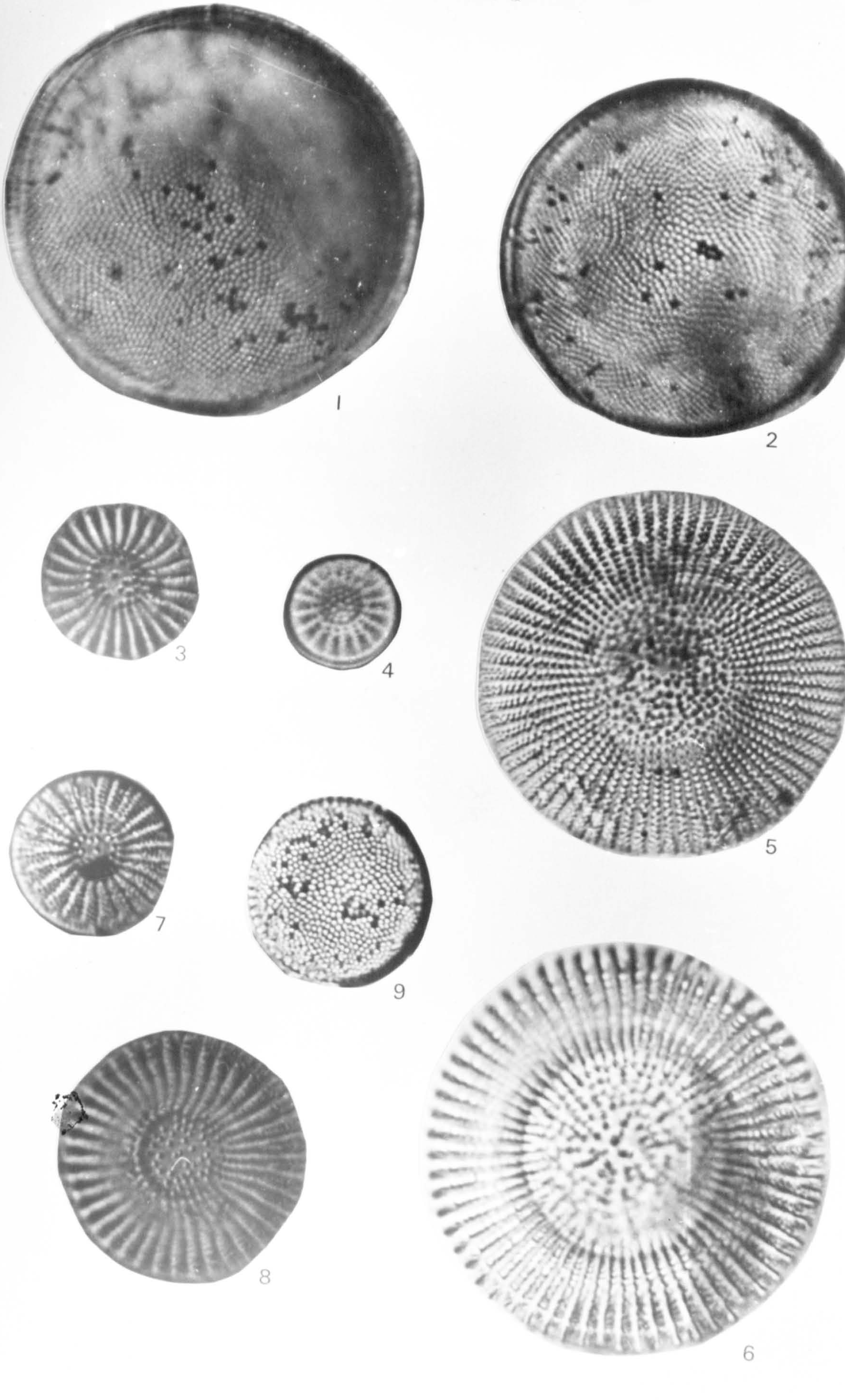


Plate A.III-3 Optical microscope photographs (Pennatae)

1 - Fragilaria construens var triundulata (3200), Galana Boi F. (Holocene)
2 - F. construens (3800), Galana Boi F. (Holocene)
3 - F. lapponica (3500), Galana Boi F. (Holocene)
4 - F. lapponica (3500), Galana Boi F. (Holocene)
5 - F. construens (3200), Galana Boi F. (Holocene)
6 - F. construens var subsalina (3350), Galana Boi F. (Holocene)
7 - F. construens (2900), Kaparaina Basalta F. (upper Miocene)
8 - F. pinnata (3250), Galana Boi F. (Holocene)
9 - Tetracyclus lacustris var emarginatus (750), Galana Boi F. (Holocene)
10- Synedra ulna (1400), Kokwob F. (Holocene)
11- S. ulna (1400), Kokwob F. (Holocene)
12- Achnanthes sp. (3200), Ilosowuani Beds (late Pleistocene)
13- Cocconeis placentula (2600), Galana Boi F. (Holocene)
14- C. placentula var euglypta (4850), Kokwob F. (Holocene)
15- Diploneis subovalis (3000), Galana Boi F. (Holocene)
16- D. subovalis (3000), Galana Boi F. (Holocene)
17- Terpsinoe musica (4200) Galana Boi F. (Holocene)
18- T. musica (4200), Galana Boi F. (Holocene)

PLATE A.III-3

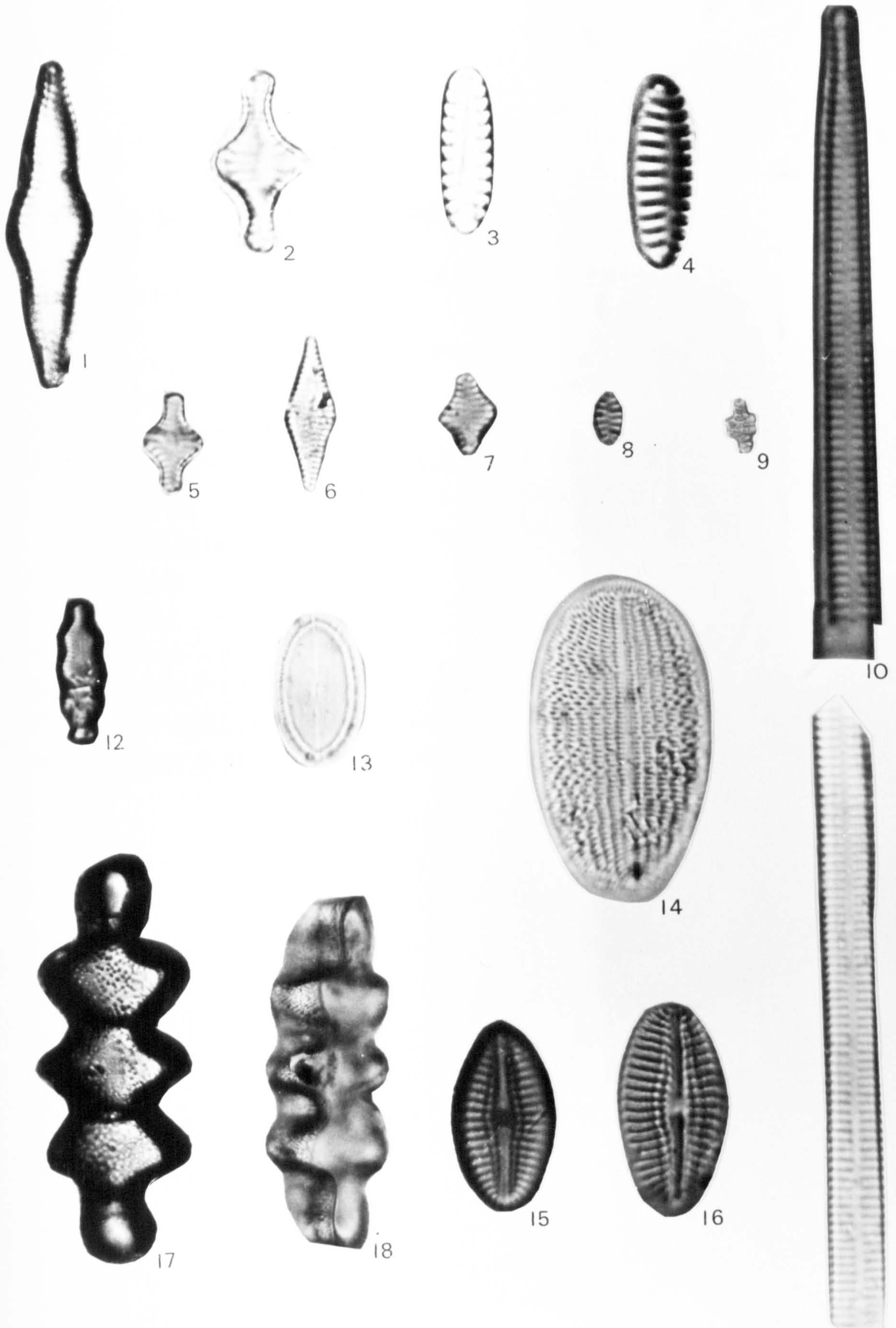


Plate A.III-4 <u>Optical microscope photographs (Pennatae)</u>

1 - *Anomoeoneis sphaerophora var sculpta* (3300), Ilosowuani Beds (late Pleistocene)
2 - *Navicula halophila* (3000), Galana Boi F. (Holocene)
3 - *N. halophila* (3000), Galana Boi F. (Holocene)
4 - *N. pupula var capitata* (3200), Galana Boi F. (Holocene)
5 - *N. pupula var rectangularis* (3200), Galana Boi F. (Holocene)
6 - *N. gastrum* (3550), Galana Boi F. (Holocene)
7-9 - *Navicula sp.* 2/23 (3900), Galana Boi F. (Holocene)
10- *N. halophila* (?) (1500), Galana Boi F. (Holocene)
11- *N. scutelloides* (3200), Galana Boi F. (Holocene)
12- *Navicula sp.* 1/20 (3000), Galana Boi F. (Holocene)
13- *N. radiosa* (2600), Galana Boi F. (Holocene)
14- *N. radiosa* (2450), Galana Boi F. (Holocene)
15- *N. gastrum* (1500), Galana Boi F. (Holocene)
16- *Caloneis bacillum* (1650), Galana Boi F. (Holocene)
17- *Mastogloia braunii* (2300), Kokwob F. (Holocene)

PLATE A.III-4

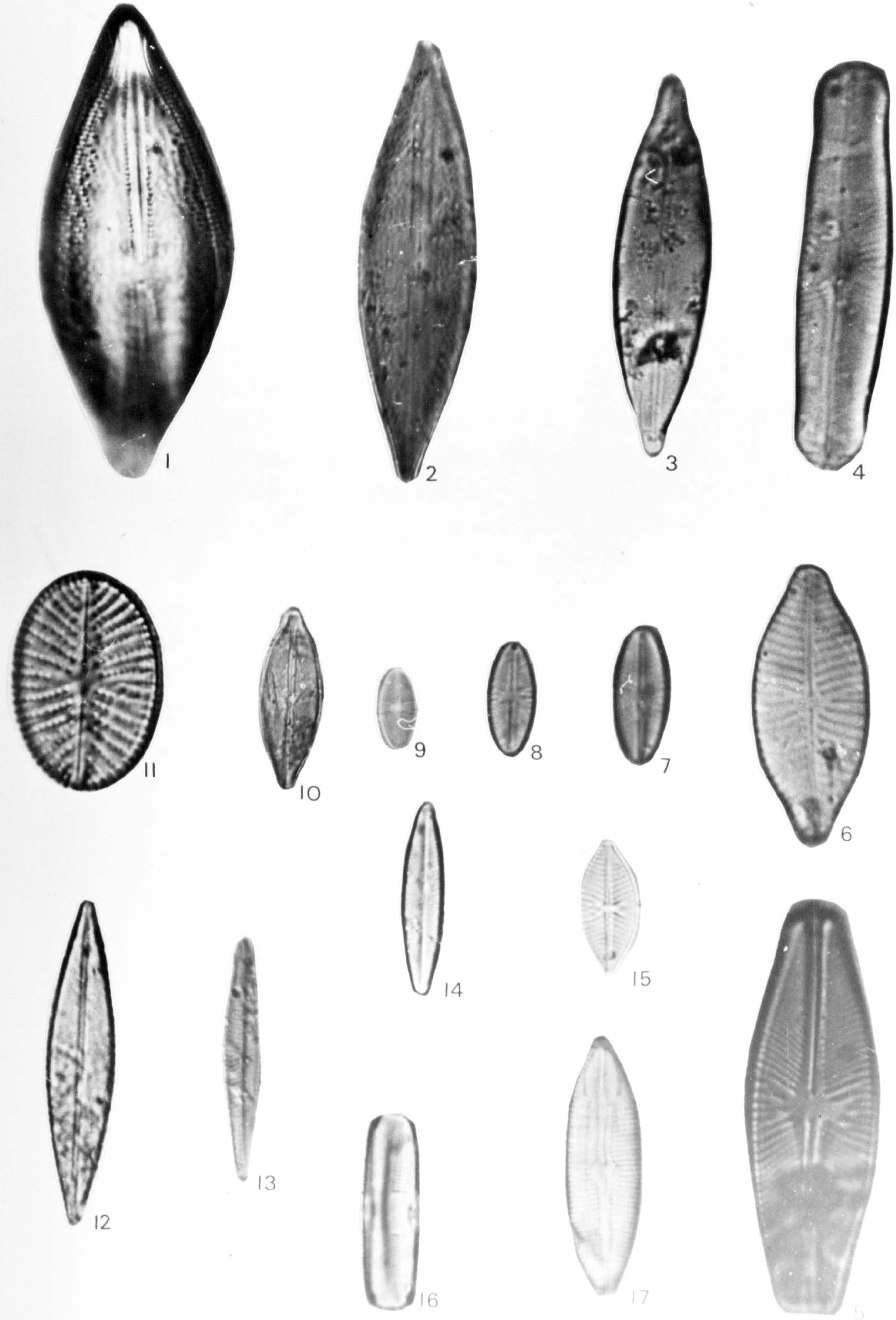


Plate A.III-5 Optical microscope photographs (Pennatae)

1 - Rhopalodia gibberula var sphaerula (3950), Ilosowuani Beds (late Pleistocene)
2 - R. gibberula (1650), Kokwob F. (Holocene)?
3 - R. gibberula (950), Kokwob F. (Holocene)
4 - R. vermicularis var perlonga (950), Galana Boi F. (Holocene)
5 - R. vermicularis (1200), Galana Boi F. (Holocene)
6 - Epithemia zebra var saxonica (2400), Galana Boi F. (Holocene)
7 - E. zebra var. saxonica (2400), Galana Boi F. (Holocene)
8 - E. sorex (2400), Olorgesailie F. (middle Pleistocene)
9 - Cymbella turgida (2000), Galana Boi F. (Holocene)
10- C. turgida (2000), Galana Boi F. (Holocene)
11- Amphora ovalis var libyca (2650), Galana Boi F. (Holocene)
12- Gomphocymbella brunii (2200), Galana Boi F. (Holocene)
13- Amphora ovalis var libyca (3100), Galana Boi F. (Holocene)
14- Nitzschia amphibia (4050), Galana Boi F. (Holocene)
15- N. amphibia (3700), Galana Boi F. (Holocene)
16- N. amphibia (3800), Galana Boi F. (Holocene)
17- N. palea (3800), Galana Boi F. (Holocene)
18- N. palea (3800), Galana Boi F. (Holocene)

PLATE A.III-5

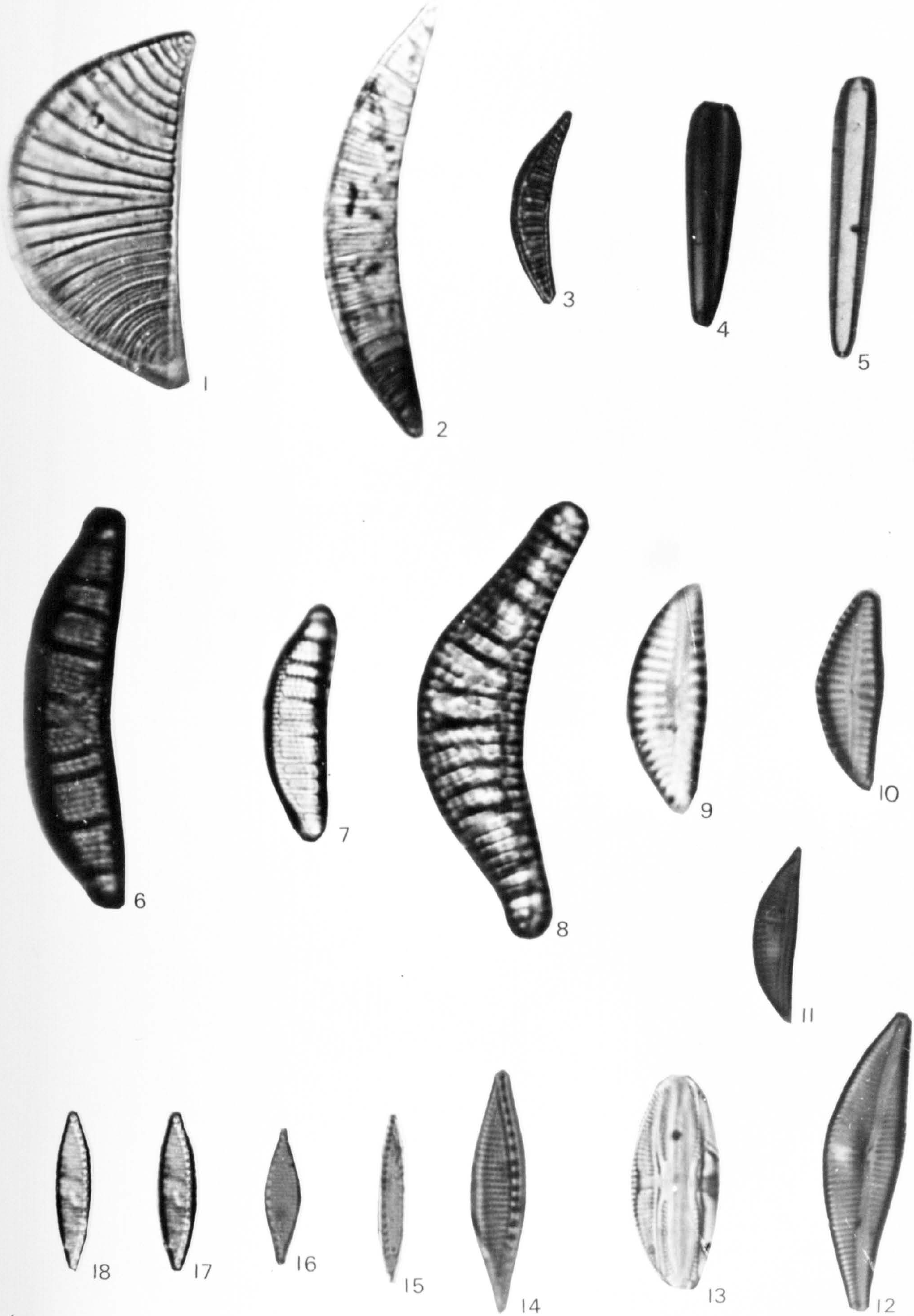


Plate A.III-6 Optical microscope photographs (Pennatae)

1 - Surirella ovalis var apiculata (1600), Ilosowuani Beds (late Pleistocene)

2 - S. biseriata (1600), Galana Boi F. (Holocene)

3 - S. ovalis (1000), Olorgesailie F. (middle Pleistocene)

4 - S. linearis (950), Galana Boi F. (Holocene)

5 - S. linearis (950), Galana Boi F. (Holocene)

6 - Cymatopleura solea (1600), Olorgesailie F. (middle Pleistocene)

7 - C. solea (1600), Olorgesailie F. (middle Pleistocene)

PLATE A.III-6

Plate A.III-7 Scanning electron microscope photographs (Centricae)

1 - Melosira & Stephanodiscus assemblage from the Chemeron F. (Plio-Pleistocene) (1000)

2 - Melosira and Stephanodiscus assemblage from the Chemeron F. (Plio-Pleistocene) (1800)

3 - Melosira granulata var curvata (2000) Ngorora F. (upper Miocene)

4 - M. granulata (2500), Galana Boi F. (Holocene)

5 - M. granulata (2500), Galana Boi F. (Holocene)

6 - M. agassizi (2500), Galana Boi F. (Holocene)

7 - Stephanodiscus astraea var minutula (4200), Galana Boi F. (Holocene

8 - S. astraea (external view)(840), Galana Boi F. (Holocene)

9 - S. astraea (internal view)(1500), Galana Boi F. (Holocene)

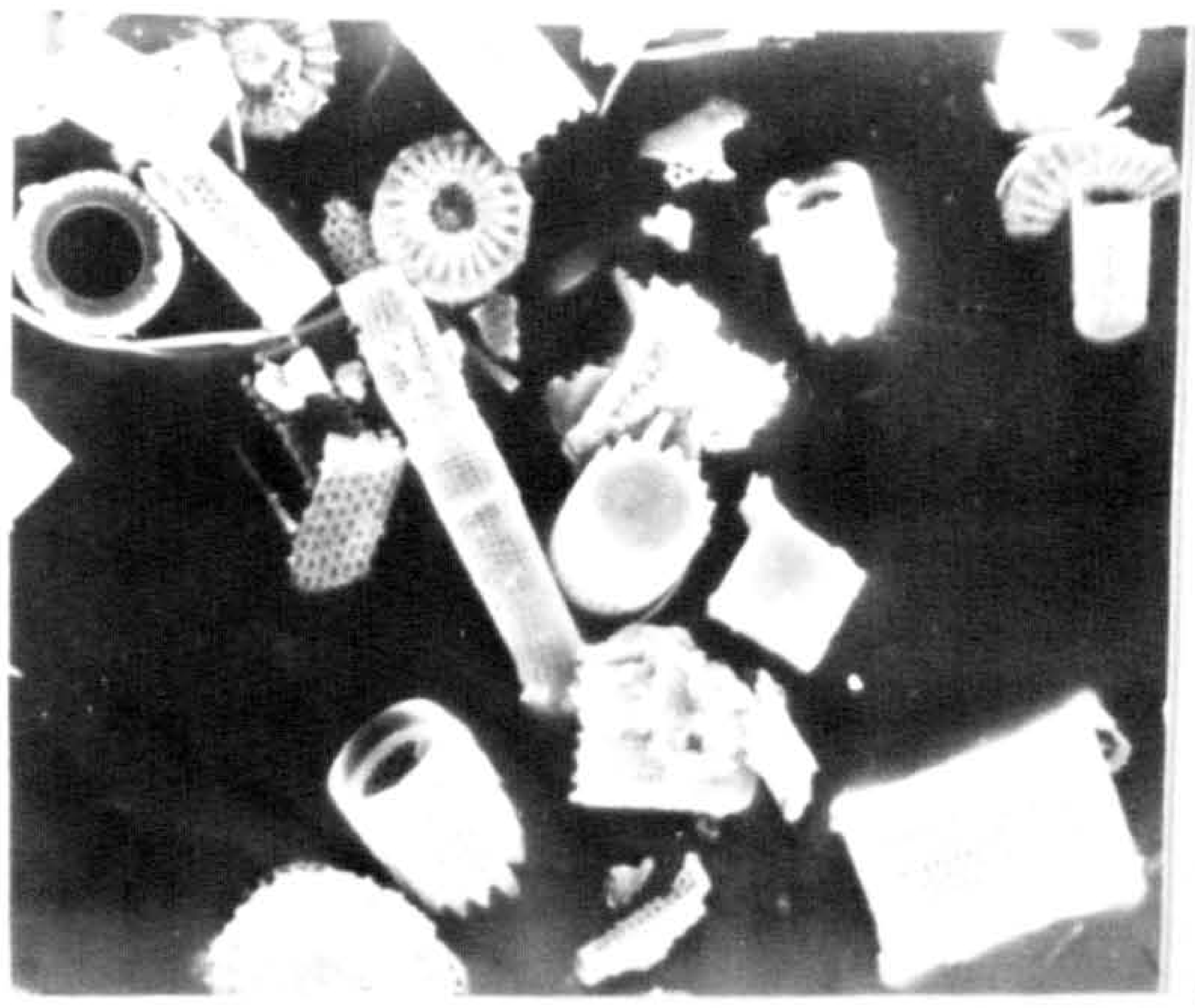
10- S. astraea var minutula (external view)(3800), Galana Boi F. (Holocene)

11- S. astraea var minutula (internal view)(4100), Galana Boi F. (Holocene)

12- Cyclotella meneghiniana (external view)(1500), Ilosowuani Beds (late Pleistocene)

13- C. meneghiniana (internal view)(1200), Ilosowuani Beds, (late Pleistocene)

PLATE A.III-7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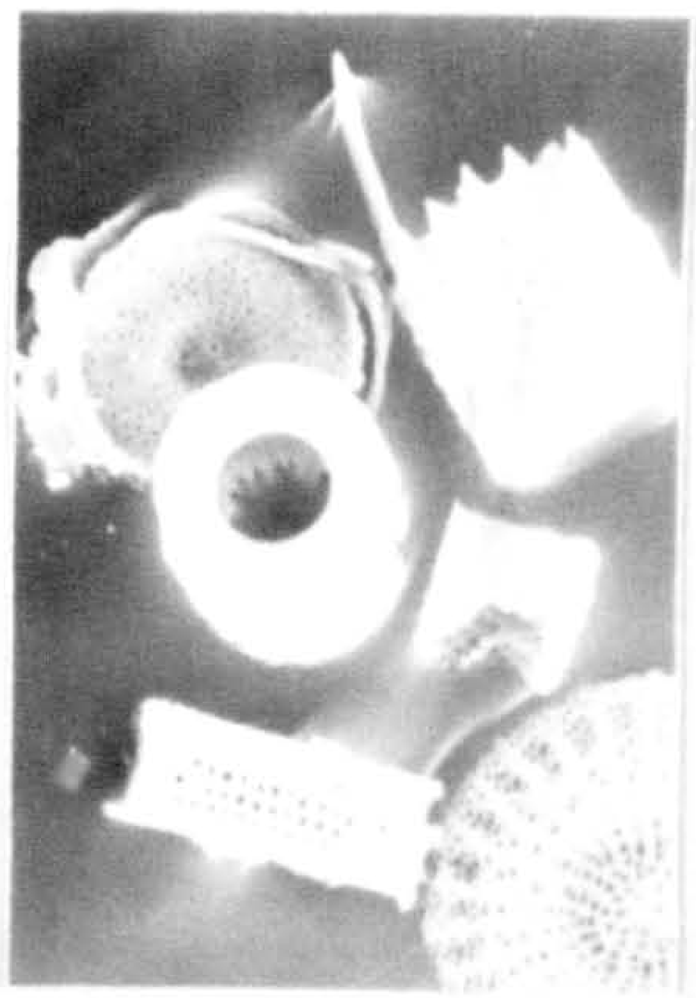
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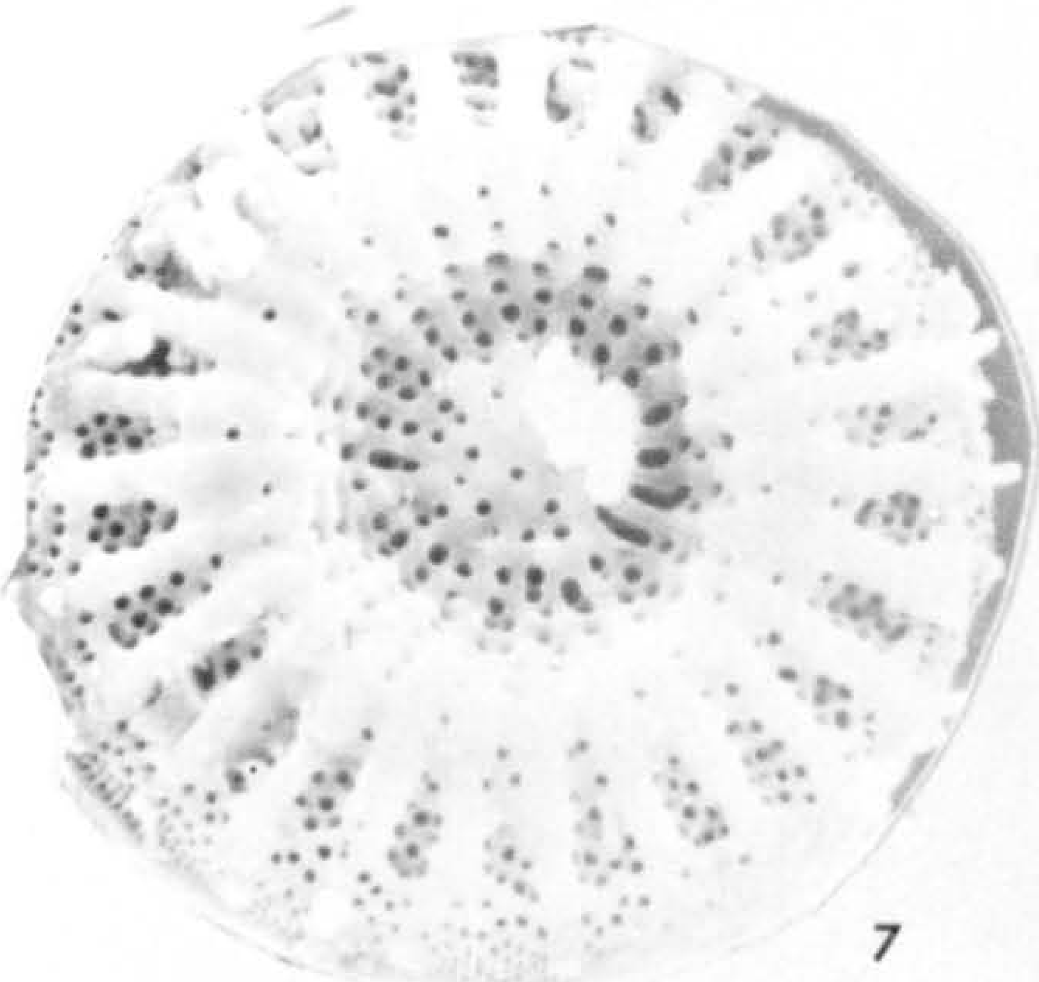
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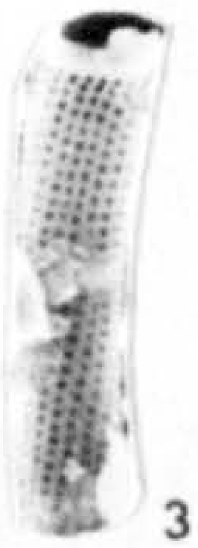
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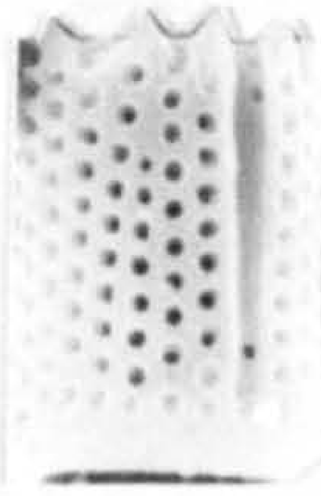
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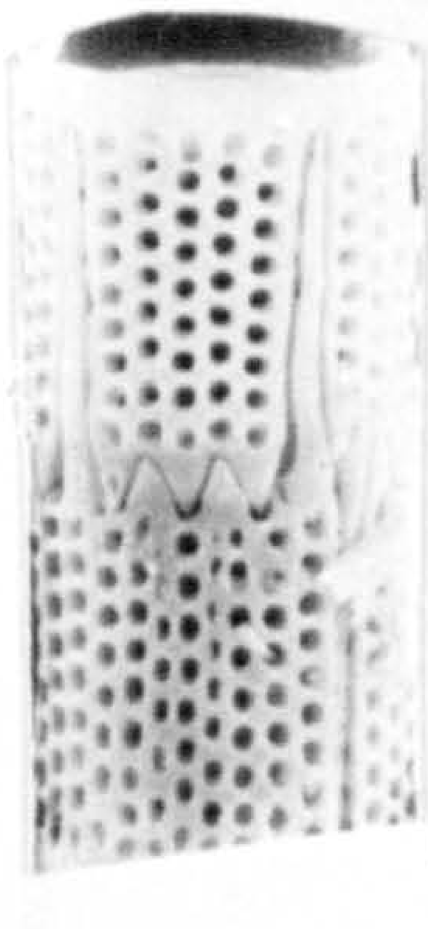
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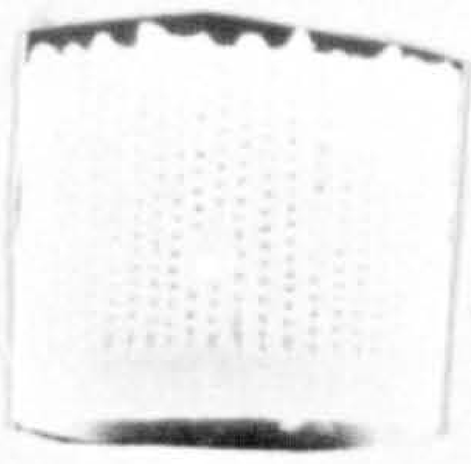
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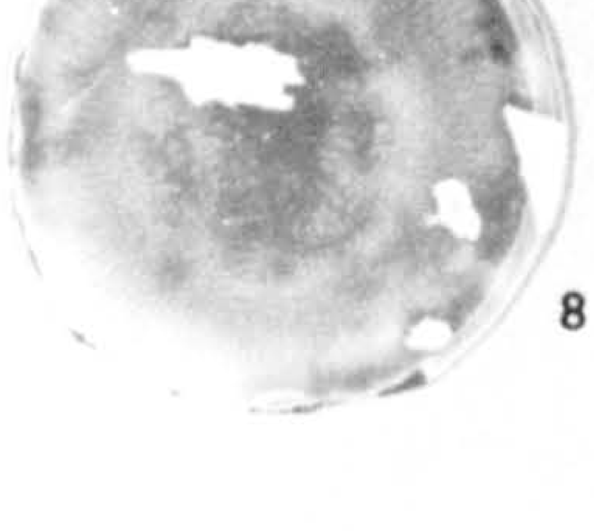
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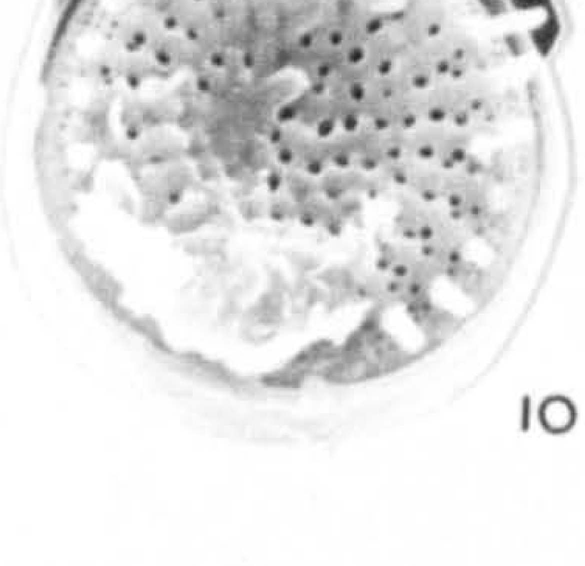
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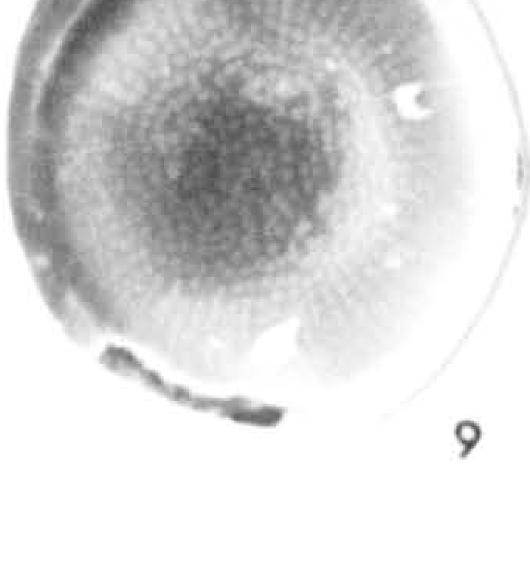
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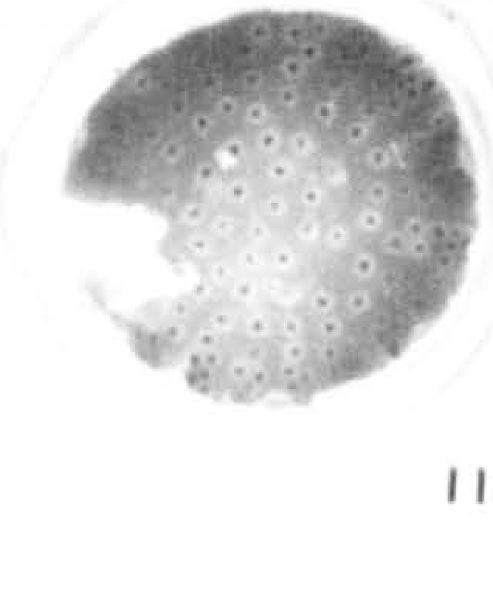
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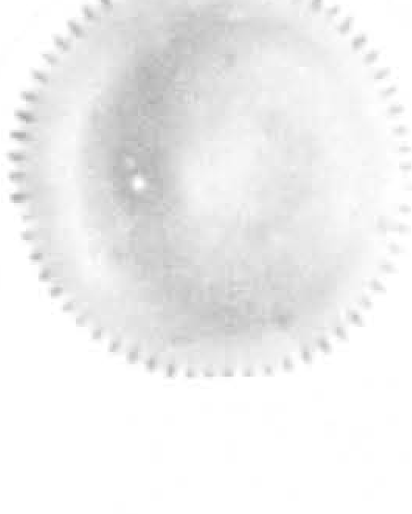

Plate A.III-8 Scanning electron microscope photographs (Pennatae)

1 - Cocconeis placentula (1500), Kokwob F. (Holocene)
2 - Fragilaria construens (2800), Galana Boi F. (Holocene)
3 - F. lapponica (3000), Galana Boi F. (Holocene)
4 - Epithemia zebra (2400), Galana Boi F. (Holocene)
5 - E. sorex (1100), Galana Boi F. (Holocene)
6 - E. zebra var saxonica (1000), Galana Boi F. (Holocene)
7 - E. zebra var saxonica (1100), Galana Boi F. (Holocene)
8 - E. zebra var saxonica (900), Galana Boi F. (Holocene)
9 - E. zebra var saxonica (8900), close up of central area, Galana Boi F. (Holocene)
10- E. zebra var saxonica (8900), internal view showing transverse costae and raphe system, Galana Boi F. (Holocene)
11- Rhopalodia vermicularis (500), Olorgesailie F. (middle Pleist.)
12- R. gibberula var debyi (1400), Galana Boi F. (Holocene)
13- R. gibberula (1600), Olorgesailie F. (middle Pleistocene)
14- a) Cymbella turgida (2200), Galana Boi F. (Holocene)
b) C. turgida (1800), Galana Boi F. (Holocene)
15- Campylodiscus clypeus var bicostata (550), Olorgesailie F. (middle Pleistocene)
16- Navicula gastrum (1500), Galana Boi F. (Holocene)
17- N. gastrum (1900), Galana Boi F. (Holocene)
18- N. scutelloides (2100), Galana Boi F. (Holocene)
19- Surirella ovalis(700), internal view, Olorgesailie F. (middle Pleistocene)
20- S. ovalis (600), external view, Ilosowuani Beds, (late Pleistocene)
21- Navicula sp. 2/10 (1200), Galana Boi F. (Holocene)
22- N. gastrum (1200), Galana Boi F. (Holocene)
23- Navicula sp. 2/23 (4300), Galana Boi F. (Holocene)
24- Nitzschia punctata (2400), Galana Boi F. (Holocene)
25- Nitzschia sp. 1/18 (4200), Galana Boi F. (Holocene)
26- Nitzschia sp. 1/24 (4200), Galana Boi F. (Holocene)

PLATE A.III-8

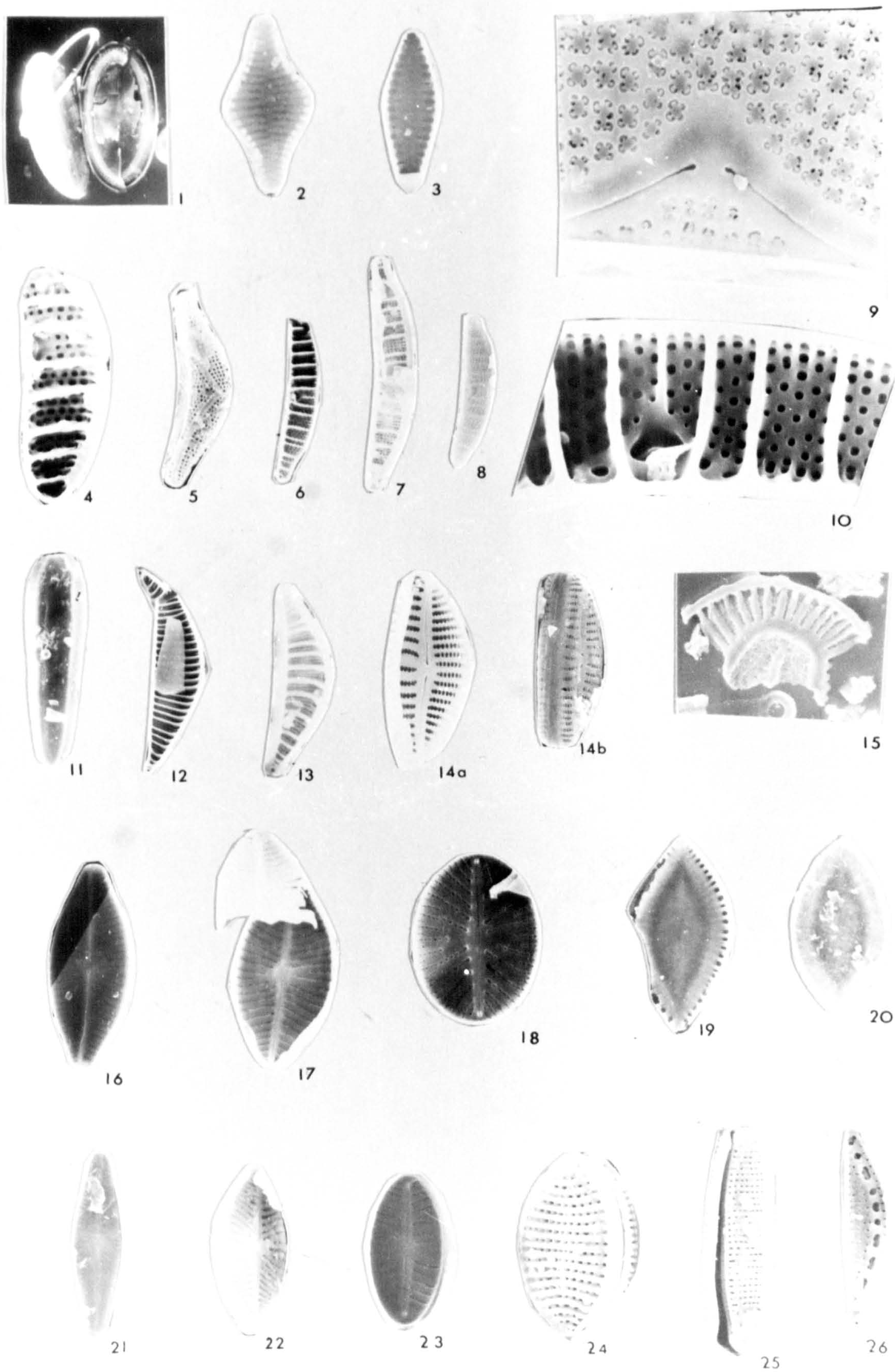

Plate A.III-9 Diatom casts in a siliceous precipitate from Lake Bogoria

1-3 Melosira 'casts' in a siliceous deposit. Note the well developed spiral processes (internal). Finely ornamented species with 20 pores/10 u, arranged in double rows. 14 pore-rows/10 u. Photo 1 resembles Melosira granulata var muzzanensis (Holocene)

4 - Anomoeoneis sphaerophora var sculpta, Lake Bogoria (Holocene)

5 - Epithemia zebra var saxonica (internal view), Lake Bogoria, (Holocene)

PLATE A.III-9

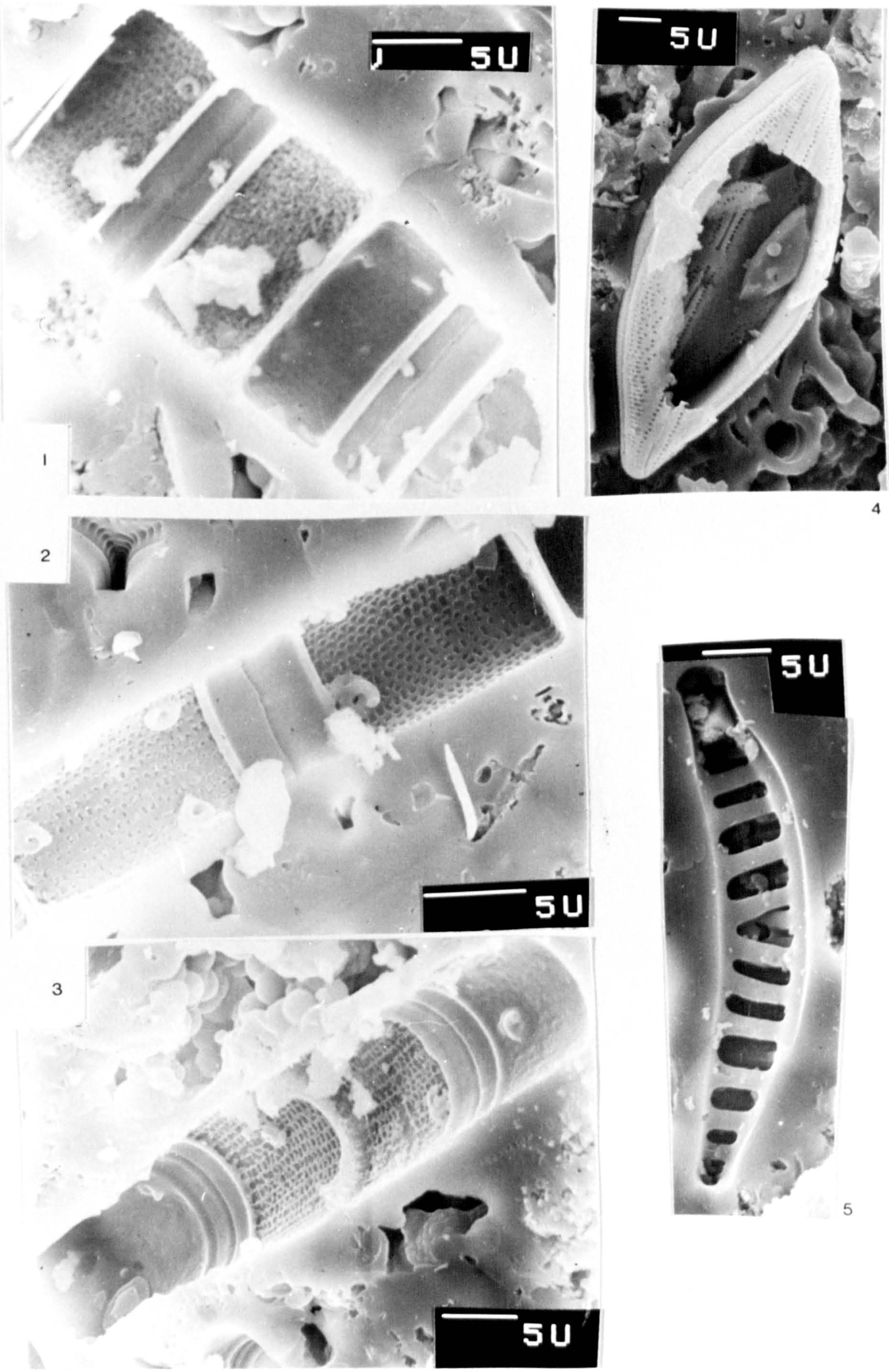

Plate A.III-10 Centric diatom morphology

1-3 Melosira granulata.

V - valvar disc
M - mantle
CM - criblee membrane
A - areola
T - marginal teeth
S - marginal spine
St - suture
Su - sulcus
C - col

4 - Stephanodiscus astraea var minutula

S - marginal spine (note pore-canals below spines)
R - radial hyaline ribs
CB - connecting bands (part of the 'girdle')

PLATE A.III-10