CHAPTER THREE

LAKE BASIN FORM AND PROCESS

3.1 MORPHOMETRY AND BATHYMETRY

As indicated on Plate 1.1 and Fig. 1.2, there are essentially four lakes in the system. Lake III is almost totally colonised by sedges, while Dry Lake could be classified as a swamp. The other lakes have margins of aquatic vegetation which will be described in Section 3.5 below.

Because of the availability of topographic maps contoured at intervals of 25 ft (8.3 m) and 10 ft (3.3 m), the lake shorelines were not mapped in the field. However, bathymetric maps of Lakes I, II and IV were constructed from data collected from echo sounding traverses, and are shown on Fig. 3.1.

Table 3.1 contains morphometric data for each of the lakes. It must be noted here that both large scale (in the order of at least several metres) and small scale (a few centimeters) changes of lake level have occurred both this year and in the past, and, where possible, lake levels will be related to that in May, 1974, i.e. approximately 0.3 metres below the top of a ladder attached to the pier on the eastern shore of Lake II. Current year lake level fluctuations were roughly monitored to this level, but the need for a fixed datum point is obvious. The data in Table 3.1 relates to lake level as at March, 1966, when the aerial photographs from which the 1:4800 topographic map was constructed were taken.

The shoreline development (D_L) supposedly reflects the effect of littoral processes on lake form (Hutchinson, 1957), but in this situation is more likely a function of the origin of the lakes. For example, circular crater lakes have values for D_L approaching unity, while glacial lakes have very large values. The large values of D_L exhibited by Thirlmere Lakes reflect their elongate but narrow form which is a result of their location in a rock-cut valley which restricts their lateral expansion. However, the values for volume development and the mean depth/maximum depth ratio

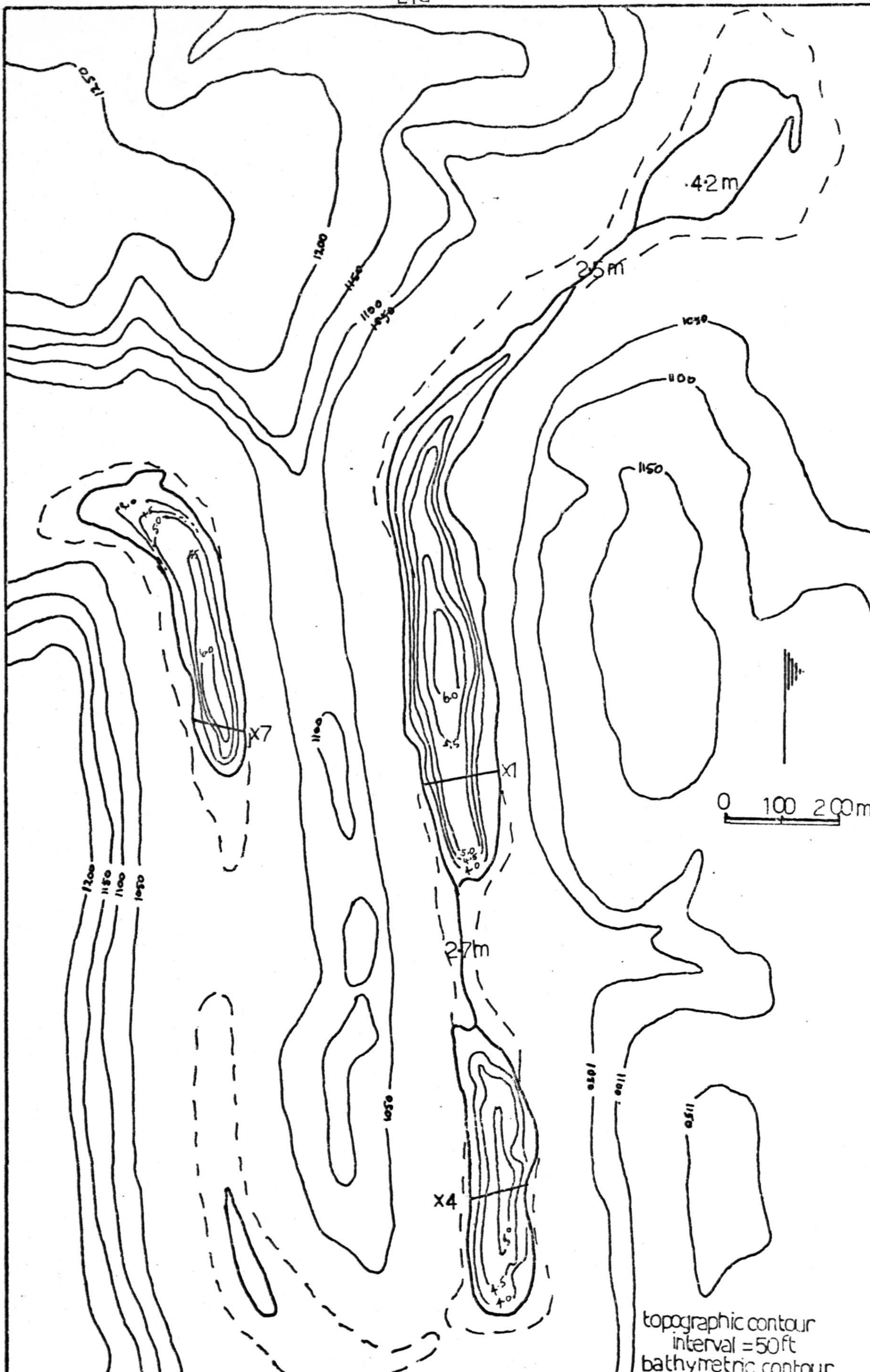

Fig. 3.1 : BATHYMETRIC MAPS OF THIRLMERE LAKES
locations of profiles shown in Fig. 3.2 are indicated

TABLE 3.1 : MORPHOMETRIC AND BATHYMETRIC DATA, THIRLMERE LAKES

Parameter	Lake I	Lake II	Lake IV
Max. length (m)	989.0	466.0	586.0
Max. effective length (m)*	811.0	466.0	485.0
Max. width (m)	158.0	110.0	125.0
Mean width (m)*	7.0	6.4	5.7
Max. depth (m)	6.6	5.2	6.7
Mean depth (m)*	2.2	1.7	3.3
Surface area (m^2)	6,922.0	2,978.0	3,347.0
Total volume (m^3)	15,228.0	5,063.0	11,045.0
Shoreline devel.*	7.6	5.7	6.3
Vol. development*	1.0	0.9	1.5
Mean depth/max depth* relationship	0.3	0.3	0.5

* Max. effective length: length of straight line connecting two remotest extremities of lake along which wind and wave action occur without land interruption.

Mean width: area divided by max. length.

Mean depth: vol. divided by surface area.

Shoreline Development: ratio of actual length of shoreline to length of circumference of circle the area of which is equal to that of lake = $\frac{s}{2\sqrt{a\pi}}$

where s = shoreline length and a = area of lake

Volume development: ratio of total vol. of lake to vol. of cone whose basal area equals surface area of lake and whose height equals max. depth of lake = $\frac{3(md)}{mxd}$ where md = mean depth and mxd = max. depth

Mean depth/max depth rel.: mean depth divided by max. depth; represents approach of lake basins to conical forms.

are typical of lakes with dominant littoral processes; shallow flat-bottomed lakes similar to Thirlmere Lakes generally have very large values for these parameters. The lack of sufficient isobaths (see Section 1.4) has probably affected their calculation.

The bathymetric maps and bottom profiles in Fig. 3.2 show that the lakes have relatively steep sides and flat bottoms, except for a bench at a depth of 4.3 - 4.7[1] metres in Lakes I and II, and 5.4 - 6.0 metres in Lake IV[2]. The feature may be related to either a low lake level shoreline or the channel of a former river course. This will be further discussed below.

The following morphometric data was also collected for other areas in the lake basin and has been noted on the bathymetric map (Fig. 3.1):

Max. depth, Lake IA	:	4.2 m
Channel depth, IA-I	:	2.5 m
Channel depth, I-II	:	2.7 m
Surface area, Lake III	:	5,182 m^2

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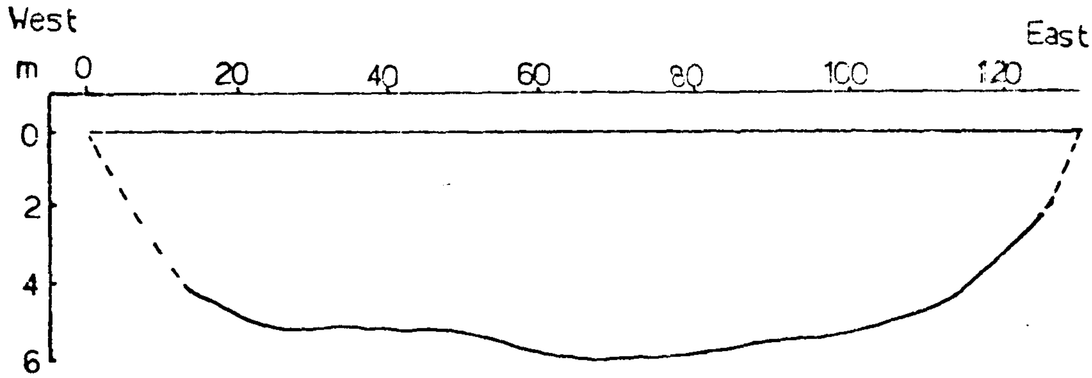
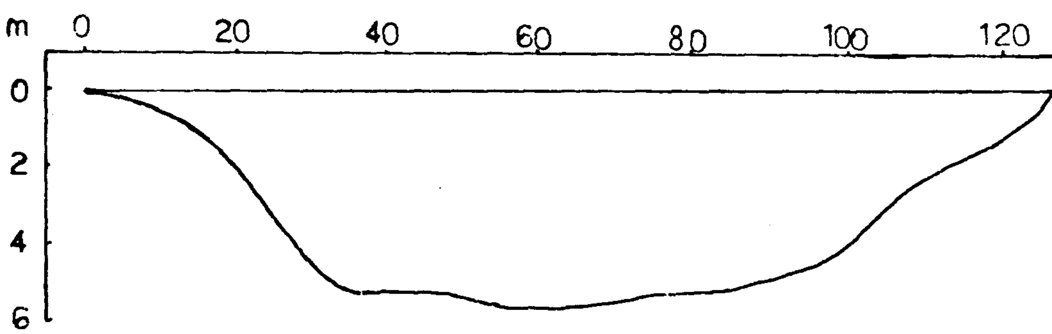
1 Lake level as at May, 1974, when sounding traverses conducted.

2 Differences in bench level between lakes probably reflects error inherent in echosounding which can be as much as 10%.



LAKE 1- X1



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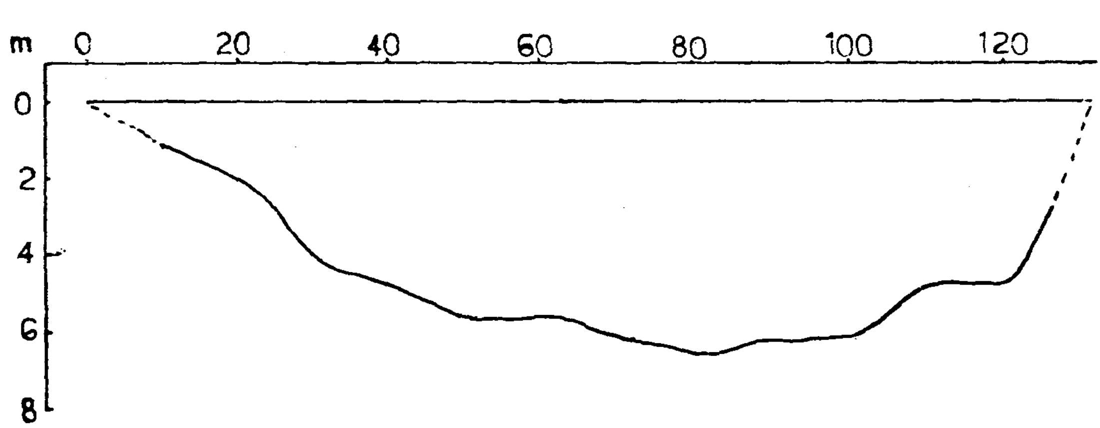

LAKE 4 - X7

Fig. 3.2 : REPRESENTATIVE BATHYMETRIC PROFILES OF THIRLMERE LAKES
locations are shown in Fig. 3.1

3.2 WATER PHYSICS AND CHEMISTRY

Some limnological data for Lake I, obtained during the winter months of 1972, was kindly made available to the writer by J. Stanisic, Univ. of Sydney, and is reproduced in Table 3.2.

TABLE 3.2 : LIMNOLOGICAL DATA FOR LAKE I

Measurement	Surface	- 3m	- 6m
Temperature (^{o}C)	14	-	13.5
pH	6.5	6.3	6.2
O_2 content (mg/L)	5.0	4.7	4.2
Ca^{++} (p.p.m.)	0.4		
Mg^{++} (p.p.m.)	11.1		
Cl^{-} (p.p.m.)	17.0		
HCO_3 (p.p.m.)	11.5		
Si O_2 (p.p.m.)	0.9		
Fe^{-} (p.p.m.)	0.41		
Fe (p.p.m.)	0.40		
Total phosphate (p.p.m.)	0.015		
Soluble phosphate (p.p.m.)	0.007		
Hardness	11.5		
Turbidity (Si O_2 Scale)	3		
Colour*	40		

Source: Stanisic, J. (1972)

* Clear = 0; Highly organic = 300

From this data, the following points can be made :

1. At the time of data collection, the lake was isothermal, i.e. of uniform temperature throughout. However, no conclusions can be drawn as to whether this is true for the rest of the year, or is merely due to winter mixing of the waters of the epilimnion and hypolimnion.

2. The decreasing dissolved oxygen content with depth may reflect the presence of H_2S as a result of decomposition or organic ooze on the lake floor. It could also indicate that the lake water does not undergo periodic "turnover" which usually results in replenishment of the hypolimnion with oxygen. If the lake was isothermal at the time of data collection because of winter turnover, then one would expect a fairly uniform dissolved oxygen content throughout.

3. The slight acidity of the water is related to the high silica content of the bedrock in the catchment area. The slightly higher pH values of the surface water may be related to decreased carbon dioxide content due to warmer temperatures and/or photosynthesis.

4. The relatively high HCO_3^- content of the water would have a buffering effect on pH fluctuations.

5. The low total phosphate content suggests that pollution of the water by agricultural fertilizers is non-existent.

Year-round data collection at many points in each of the lakes is required before more substantive conclusions can be made about the physico-chemical relationships. This is particularly important for a complete understanding of the mechanics of sedimentation within this, and other, lake systems.

3.3 SEDIMENT TYPE AND DISTRIBUTION

An extensive coring of the lakes floors could not be undertaken because of the lack of suitable equipment. However, some samples of the surface sediment were obtained in random locations with a clamshell snapper bulk sampler, and a length of steel tubing welded to the end of an auger handle and extension pipe. The cores are described in detail in Appendix B.

Within the aquatic vegetation belt of Lakes I, II and IV, the bottom sediments consist of medium sand overlying grey (Munsell N7/0) sandy clay. With increasing depth (at approximately 3 to 4 metres depth) the surface sediment consists of coarse detrital organic remains which can be classified as peat. It is composed mainly of the partly decomposed remains of stems, rhizomes[1] and roots of aquatic plants. While the peat exhibits some coherence in the cores, this is most likely due to compaction during the coring process, as it was found that in water depths of say, 3 metres (measured with a lead weight and line), the corer would penetrate a further 3 metres but would retrieve only 0.3 metres of core. Thus, the material in situ is most likely of a watery, cohesionless consistence, with the surface bound only by the rhizomes of the emergent reeds. The surface organic matter becomes finer with increasing distance from the shore, and in the centre of the lakes is so fine that it may be called "gyttja", or nekron mud, after von Post (1924, in Troels-Smith, 1955).

No attempt was made to correlate between cores because the depths of each layer were not accurately known because of possible compaction. However, at water depths of at least up to 2 metres, alternation of sand with clay and sandy clay probably reflects progressive advance and retreat of the littoral zone in response to fluctuating water levels, increasing clay content generally being indicative of deeper water where the dominant sedimentation process is settling out of the fines. Increasing sand content generally reflects greater sediment influx from subaerial erosion and deposition in relatively shallow water. This pattern of sedimentation is in keeping with the general lacustrine facies model constructed

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1 Rhizomes: underground stem, bearing buds in axils of reduced scale-like leaves; serving as a means of perennation and vegetative propagation (Abercrombie et. al., 1951).

by Twenhofel (Picard and High, 1972), and a review of the literature on lacustrine sedimentation has shown that this is nearly always the case under natural conditions.

The change from dominantly inorganic to dominantly organic sedimentation in the profundal (i.e. bottom) zone of the lakes is related to colonisation of the waters by aquatic vegetation, the remains of which are the dominant constituents of the peat. This probably occurred upon the attainment of a sufficiently shallow depth to allow colonisation, firstly by the water lily *Brasenia schreberi* which is now found at the greatest water depths of all the aquatic species, and then by the sedges. The aquatic vegetation ecology and zonation will be further discussed in Section 3.5 below. According to Deevey (1965), the grading from clay or silt to gyttja or peat is a symptom of the onset of dystrophy, whereby organic material is provided to the lakes at a faster rate than it can be decomposed, and it gradually results in the transformation of the lake into a bog or swamp. The process tends to accelerate as more organic detritus is added because fewer decomposer organisms are tolerant of the increasingly acidic conditions. The decreasing oxygen content with depth in the lakes, mentioned in Section 3.2 above is probably indicative of anaerobic conditions which have allowed organic matter to accumulate.

The lack of alternations between coarse inorganic and organic sediments within the peat layers of the cores from deeper water suggested that sediment contributed by intermittent sheetwash (see Section 2.3) does not penetrate very far from the littoral zone (i.e. that bounded by the margin of the aquatic vegetation). However, when determining organic carbon content of bottom samples from loss of dry weight on ignition, it was found (see Table 3.3) that the samples from the centre of the lake contained at least 20% inorganic matter, probably in the form of clay which continuously settles out of suspension. The lowest ignition losses were

TABLE 3.3 : LOSS OF WEIGHT ON IGNITION (600°C) OF BOTTOM SEDIMENT SAMPLES

Sample Number	Location	Loss on Ignition (%Dwt)
1	Centre, Lake IA	59.6
2	Channel, IA to I	69.6
3	LI, channel mouth	63.5
4	LI, north centre	80.9
5	LI, toe of fan	27.2
6	LI, centre	51.9
7	Channel, I to II	21.4

recorded for samples from locations near the alluvial fans; although the same transportational processes appear to be operating on both the fans and the hillslopes (see Section 2.3 above), greater net sediment influx would be expected from the former because of the greater net catchment area per unit length of shoreline, and the greater opportunity for channelled flow and hence greater sediment carrying capacity.

The presence of charcoal in the cores supports the notion of pyric influence of subaerial erosion in this area.

3.4 THE NATURE AND ORIGIN OF THE FLOATING PEAT ISLANDS

3.4.1 Morphology and Distribution: Some clues as to the nature of the organic deposits on the bottom of the lakes have been obtained from a study of mats or "islands" of peat which were observed to be floating on the surfaces of Lakes IA, I, II and IV (Plates 3.1 to 3.4). Detailed descriptions of their dimensions and the type of peat of which they are made are given in Appendix C, but the following general points may be made.

Plate 3.1 : Peat Island with Reed and Water Lily Remains Lake IV.

Plate 3.2 : Details of Reed Remains on Peat Island in Plate 3.1.
(Note rhizome on surface, centre front of photograph)

Plate 3.3 : Flat, Bare Peat Island, Lake II.

Plate 3.4 : Vegetated Peat Island, Lake IA.

The islands vary in diameter from 0.5 metres to about 5 metres, with thicknesses of not more than 1 metre. Surface appearances are variable : some bear the remains of aquatic sedges and their rhizomes (Plates 3.1 and 3.2), and roots, stems, and sometimes the whole plant, of the water lily, *Brasenia schreberi*; others have flat, bare surfaces (Plate 3.3), while still others are colonized by herbs, grasses, sedges such as *Juncus sp.*, and swamp plants such as *Polygonium strigosum* (Plate 3.4). The islands exhibit an "iceburg" effect, whereby the greater proportion of their mass (up to 95%) is below the water surface, but in spite of this they are relatively easily moved about. Their buoyancy was illustrated where a log was found protruding from the side of an island; after extraction from the peat, the log was transported to shore only with great difficulty! The three morphological types described above also exhibited different bouyancies : the former type can have up to 50% of its surface area out of the water, while those with the bare, flat surfaces are usually almost totally submerged; the vegetated islands are intermediate between these two.

The peat of which the islands are made contain decaying rhizomes (Plate 3.5) of similar size and shape to those of the reeds such as *Lepironia articulata* and *Eleochaeris sphacelata* which are currently growing in the area; these are sometimes layered within the islands. In the process of decay, the central radial tissue decomposes first, leaving a more resistant "cylinder" of epidermal and cuticular tissue. The stems and roots of the water lily, *Brasenia schreberi*, appear to constitute the bulk of the peat and its seeds are abundant throughout. Pollen and seeds of the sedge, *Eleochaeris sphacelata*, are also present (Prof. D. Walker, pers. comm.). All of the peat samples examined were composed of coarse plant remains, with interstices filled with fine sedimentary detritus; all were classified as *Turfa herbacea*, according to the classification of Troels-Smith (1955 - see Appendix C). Both visual examination and x-ray photography

Plate 3.5 : Reed Rhizomes From The Peat Islands
(Note hollow leaf bases on surface)

showed that the samples were finely laminated; maximum layer width was 5 mm.

The islands tend to congregate at the northern and southern ends of the lakes, along the line of greatest fetch of the wind, and all are found on the inside (lake-ward side) of the reed margin. An interesting phenomenon observed during the research period was that their numbers appeared to decrease throughout the year, but as they were not monitored, it is not known how many were "lost" or where they went; one can only presume that they sank!

3.4.2 Previous Literature: References to similar islands in the literature are few. Hutchinson (1957) cites several cases where the organic sediment on the bottom of lakes, for example the Ogel-see in Brandenburg and Derwentwater in the English lake district, has been bouyed up by the accumulation of gas under the sediment. However, these are not true islands as they remain attached to the substratum and subside when the gas is dissipated. The true floating islands mentioned by Hutchinson appear to be derived from floating mats extending from the lake shore. This is also the case with papyrus mats on Lake Chad, prodigiously described by Sikes (1972) in the following manner (p. 47) :

> "...Due to the constant fragmentation of clumps and rafts of floating vegetation that break away from the anchored floating islands, one frequently encounters vagrant 'mini-islands' in one's course, or as now when running before the wind, accompanying one alongside. Most of these, however, travelled more slowly than the yacht under full sail, and we quickly outstripped them..."

Floating mats in the Rawa Penang of Central Java, Indonesia, (Polak, 1951), are composed of either water hyacinth (*Eichhornia crassipes*) or grasses and sedges, and "sawahs" (paddy fields) have been laid out on them. Polak believes that wind and water motion on the surface of the Rawa Penang cause lumps of material to break off the edges of "trembling marshes" which are attached to the shore at one end and extend by overgrowth over the water. He cites two cases in Switzerland where flooding of former marshes has lead to the formation of these floating islands.

Thus it appears that a rising water level is instrumental in the formation of floating islands which have been described in the literature. However, those found at Thirlmere Lakes differ in that they are not derived from the outgrowth of vegetative material from the shore; the presence of sedge and water lily remains on their surfaces, and of a thick reed margin around the perimeter of the lakes, excludes this. They are, in fact, composed of sedimentary organic detritus which has accumulated on the lake bottoms and which is almost identical with the material retrieved by coring. The mechanisms possibly responsible for their formation are described below.

3.4.3 Formation of the Islands: It is fairly obvious from the descriptions of the islands given above that they are derived from the bottom of the lakes, where similar peat, as displayed in the cores (Appendix B), is presently accumulating. Therefore, either the mechanism involved in their formation is able to overcome the weight of the overlying water, or the water is temporarily "removed" i.e. a fall in lake level exposes the peat, mats of which break off when water level subsequently rises.

This latter hypothesis is in accord with those given in the literature (although the site of formation is not quite the same), and also with the following observations of a local landowner, Mr. W. Racklyeft : during the period from 1938 to 1940, a substantial portion of the bottom of Lake IV was exposed by a fall in lake level, and when the water began to rise again, "Lumps" of peat were observed to be floating on the surface. Thus, at least some of the islands could have been in existence for at least 30 years.

However, the different surface morphologies of the peat islands suggest that they have been floating on the surfaces of the lakes for different periods of time. This is because, firstly, some of the islands have water lily plants embedded in them which are still undecomposed. Secondly, they exhibit differing amounts of colonisation by secondary vegetation; if they had all been floating on the water surface for a similar period of time then the chances are that most, if not all, of them would be colonised in a similar manner. On one island, some of the annual herbs had dead flower stalks which would have been in bloom during the preceeding summer, i.e. almost one year ago, and the seeds would have had to have been deposited on the island at least one year before that, giving a minimum age of that particular island of 2 years. The growth shown in Plate 3.4 must represent at least a few years. Thirdly, they appear to be a favourite resting place of the wild fowl which inhabit the lakes : if the islands had been exposed to the tramplings and scratchings of the ducks and swamp hens for a similar period, then they should exhibit similar surface roughness; as stated above, this is not the case. Finally, the differing amounts of surface area above the water may be a function of differing intensities of post-flotational processes, such as periodic wetting and drying, acting on the islands, where intensity is a function of time.

It is possible that the different bouyancies, as portrayed by the different surface exposures, are a function of different initial densities because of their composition of different types of peat. Only more detailed microscopic examination of the layers within the samples could elucidate this matter; the only differences displayed thus far have been in terms of humicity (see Appendix C), and abundance and distribution of decaying reed rhizomes within the islands (some islands appeared to have more than others; in some, they were confined to the surface or immediately beneath a layer of water lily remains, while in others they were in layers through almost the whole thickness of the island). Thus, while the different bouyancies of the islands may reflect factors other than different periods of flotation, their correlation with different surface morphologies suggests that length of time of flotation and exposure to post-flotation processes is a factor. If this is the case, then island "disappearance" through sinking may occur when the island becomes fully waterlogged.

A multi-causational hypothesis therefore seems to be indicated. While some of the islands may have originated when lake levels were very much lower, others have surfaced since this time, possibly as recently as the current year. However, evidence strongly suggests that lake level fluctuation is the common denominator. Firstly, if the situation regarding the cohesionless nature of the organic deposits in the present lakes (described in Section 3.3 above) has always existed, then the network of rhizomes which appears to be binding the material must have decayed in order for the peat to be released from the bottom, and reed die-back due to a change in water depth (either up <u>or</u> down) seems to be a likely cause. Secondly, as mentioned above, some of the islands have a layer of rhizome remains overlain by water lily plants; the fact that the water lilies are largely growing in deeper water than the reeds at the present time (see Section 3.5 below) strongly suggests that a change in water depth occurred at the place of origin of those peat islands. Thirdly, it has also been mentioned that some of the islands exhibit layer upon layer of rhizome remains; as these, by definition, serve as a means of perennation they are not likely to die annually, therefore some phenomenon has caused repeated die-back of the rhizomes, and, again, a change in water depth seems to be the most likely cause. In all of these situations, decay of the rhizomes would have to proceed to a stage whereby their binding effect on the peat would be lost. At the same time, the creation of air spaces within the hollow stems and rhizomes may give added bouyancy to the material, allowing it to overcome the pressure of the overlying water. The build-up of products of decomposition, such as methane and hydrogen sulphide, may also be of assistance.

Thus, the sequence of events envisaged for the formation of the islands (illustrated in Fig. 3.3) is as follows :

1. Peat accumulation in the lakes proceeds via decay of stems and leaves of aquatic vegetation. As this is restricted to the margins of the lakes, then accumulation is more rapid here than in the centre; thus, the low level bench exhibited on the echo sound traces (see Section 3.1 above) may be composed of peat and thus is a possible source of peat islands.

2(a). Water level falls, exposing the peat; when water level rises again, islands break off at a level governed by some unknown factor; or

2(b). Water level change causes the death of the reed rhizomes which had been binding the peat; decay of the rhizomes proceeds until the bouyancy given to the peat by the accumulation of gases in the voids created by the hollow reed remains is sufficient to allow the peat to float to the surface.

3. Post-flotation processes, such as periodic wetting and drying and colonisation by secondary vegetation, proceed.

4. As the peat decays further, the air spaces become fewer and the accumulated gases dissipate, resulting in gradual submergence and ultimate sinking of the island.

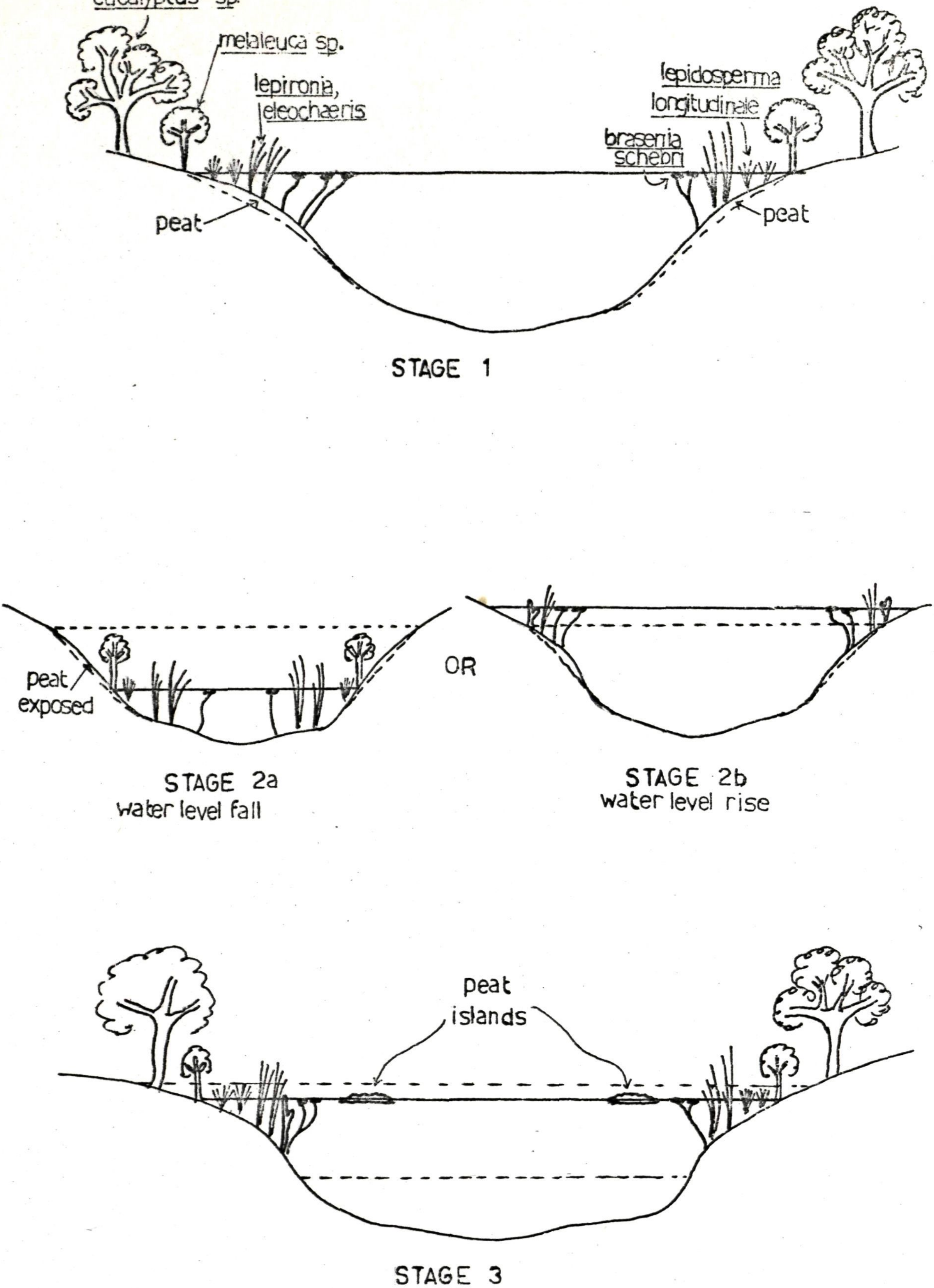


Fig. 3.3 : POSTULATED MECHANISMS FOR FORMATION OF PEAT ISLANDS (not to scale) Details are described in the text

Thus, under this system the creation, evolution and sinking of the peat islands is a cyclic process, the recurrence interval of which is governed by water level change "events". At the present time at Thirlmere Lakes, if the last water level change event was the partial drying out of the lakes from 1938 to 1940, then the islands would be appearing at a decreasing rate and disappearing at an increasing rate; it was mentioned above that the abundance of peat islands seemed to decrease during the current year, but monitoring of the islands is required to elucidate this matter.

3.4.4 Implications: The following points may be made about organic lacustrine sedimentation in lakes where peat islands exist, in light of the above discussion :

1. Contrary to stratigraphic principles, there would not be an increase in age of the sediment with depth. This is because, while the islands are floating around on the surface, organic material continues to accumulate on the bottom; when the islands sink, older material is deposited on top of younger material. As the same sediment could be contained in any number of islands through time, then, the age differences may be quite large. Thus, there would be a constant churning of the organic sediment and, where a lake survives for a long period, radiocarbon dating of its organic deposits may give misleading results.

2. If the islands tend to accumulate at either end of the longest wind fetch, as they do in Thirlmere Lakes (i.e. at the northern and southern ends), then island sinking would occur more often at these locations; given that the islands may originate from anywhere around the perimeter, then a net gain in sediment depth would occur at either end of the long axis. This would have the

effect that, firstly, infilling of the lakes would proceed more rapidly at the sites favoured for island sinking, resulting in a proceedingly less elongate form, and, secondly, rates of sedimentation calculated from only a few dates on sediment from only a few locations in a lake may be in error, whereby if samples were taken from the sites favoured for island sinking, then the rate of sedimentation would be faster here than elsewhere in the lake.

3. Whereas lake basins have been considered to be sites of continuous deposition, peat island formation may be considered to be erosional, and therefore anomalous to the classical model of lake evolution as formulated by Twenhofel (in Picard and High, 1972).

3.5 HYDROLOGY AND WATER LEVEL CHANGE

3.5.1 Introduction: The following equation, formulated by Coventry (in press) for the Lake George Basin, expresses the relationship between the size of the lake and the prevailing hydrological parameters when a situation of dynamic equilibrium exists :

$$(P\ A_L) + (R\ A_c) + GI = (E_L A_L) + GO + OF + B \qquad \text{Equation A}$$

where P = precipitation over lake basin per unit area;
R = runoff from lake catchment per unit area;
E_L = evaporation from lake per unit area;
A_L = area of lake;
A_c = area of lake catchment (= area tributary to lake);
GI = groundwater seepage into lake basin;
GO = groundwater seepage from lake basin;
OF = vol. of overflow from lake basin;
B = biological consumption of lake water.

While there are no measurements for any of the hydrologic parameters for Thirlmere Lakes, estimates of their relative magnitudes may be made. At the present time, precipitation falling directly on the lake's surface would be the biggest source of inflow. Runoff from the surrounding slopes would become equally, if not more, significant when infiltration capacity of the soil is reduced by removal of vegetation after fire; the possibly large amounts of sediment moved by sheetwash after fire, described in Section 2.3 above, testifies to the increased discharge on the slopes. Both ground water inflow and groundwater outflow are unknowns at this stage; the sandy nature of the surrounding soils and bedrock may render them more significant than is generally the case in other lake basin studies.

The volumes of both evaporation and biologic consumption are unknown; so too is the discharge through the outlet at Blue Gum Creek, but this must be the greatest means of water loss from the present lakes basin. The significance of this is that the upper limit of lake level fluctuations is governed by the weight of the outlet above the lake floor (Coventry, 1973), and the fact that the outlet is open at the present time suggests that the lakes are exhibiting their highest possible water levels. Evidence to support this claim will be given below, along with evidence for substantially lower lake levels.

3.5.2 Vegetation Evidence: Two types of vegetation community are in evidence at Thirlmere Lakes, i.e. terrestrial and aquatic or semi-aquatic.

The terrestrial vegetation may be classified as the Mixed Eucalypt Forest association of Pidgeon (1937), which is widely distributed on the sandy loam soils derived from Hawkesbury Sandstone. More recently, the C.S.I.R.O. (Leeper, 1970) has reclassified Australian vegetation according to the life form and projective foliage cover of the tallest stratum, and under this system, the terrestrial vegetation at Thirlmere Lakes would be classified as Open-forest. Within this community two associations can be distinguished (D. Benson and J. Pickard, pers. comm.). The sandstone ridges and debris slopes are dominated by *Eucalyptus piperita* (Sydney Peppermint) and *E. gummifera* (Red Bloodwood), with a shrub understorey of such species as *Banksia serrata, Telopea speciosissima* (Waratah), *Lambertia formosa* (Mountain Devil), *Pinelea linifolia* (Slender Rice Flower), and several *Acacia sp* (wattle). As well as the above species, the alluvial fans also support *Angophora floribunda* (Rough-barked Apple), *Melaleuca linariifolia* (Paperbark), and the herb *Schoenus melano stachys*, all of which favour damp, relatively fertile locations. The significance of this to a discussion of changes in lake level lies in the fact that, at the present time, the forest species on the perimeters of the lakes are becoming submerged, and in many places, a line of dead eucalypts marks the present (i.e. May, 1974) waters edge. This supports the hypothesis given above that the lakes have this year attained their highest level for some time.

Of even greater significance in the search for evidence of magnitudes of lake level change is the presence of submerged tree stumps in the growth position encountered within and beyond the reed margin (i.e. in water depths of up to 4 metres). In an attempt to determine the genus of one of these stumps and hence give an estimate of water level rise since the plant germinated, transverse sections of the stump were treated according to the method outlined in Section 1.4 above, together with sections of *Melaleuca linariifolia* and *Eucalyptus gummifera* presently growing at the water's edge. Plate 3.6c shows that the unknown (i.e. the stump) exhibits the following features :

1. Rays of one-cell thickness (i.e. uniseriate);

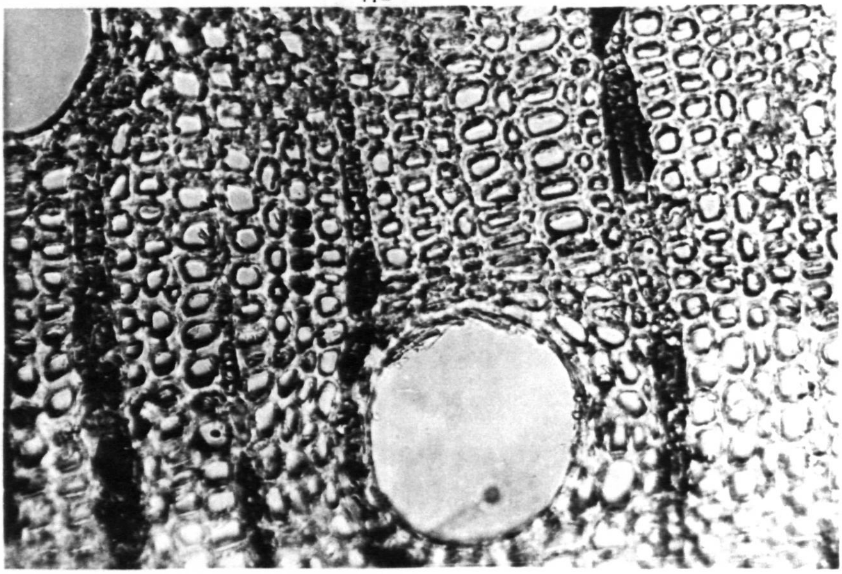
2. Large diameter vessels, many of which are blocked by amorphous, reddish coloured resin.

Plate 3.6 : PHOTOMICROGRAPHS OF TRANSVERSE SECTIONS OF PLANT STEM TISSUE

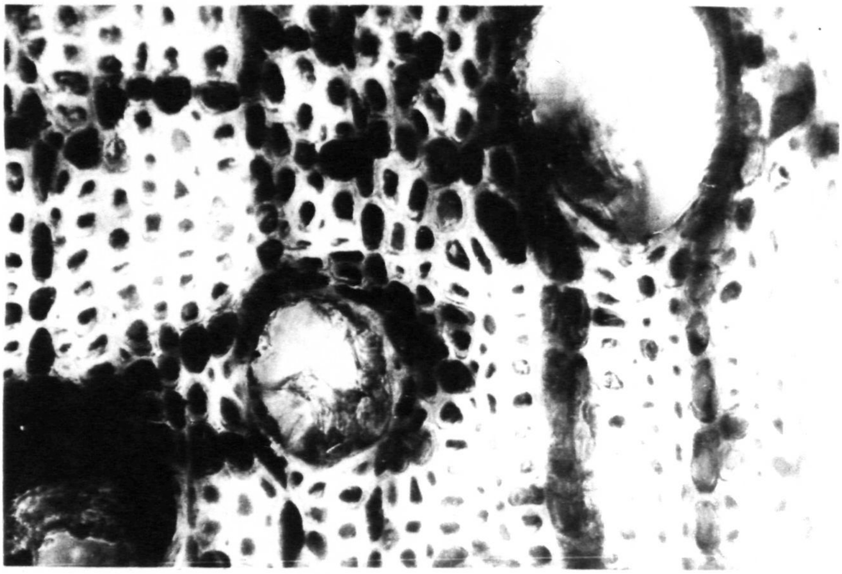
A: *Eucalyptus gummifera*
B: *Melaleuca linariifolia*
C: Stump submerged in 4 metres of water in Lake II

Magnification of negative = 100 X

A



B



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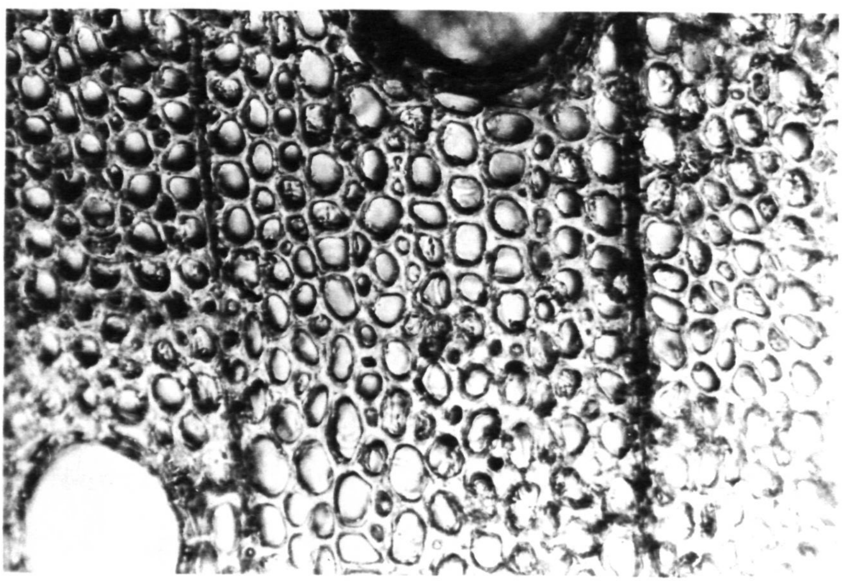

The stump itself was 2 cm in diameter, and had been attacked by insect larvae (wood borers).

Of the possible genera to which the unknown may belong (i.e. *Melaleuca sp* or *Eucalyptus sp, Acacia sp* and other open forest types), *Melaleuca sp* may be eliminated on the following grounds :

1. Treatment of *Melaleuca sp* by the method described in Section 1.4 usually allows one to see deposits (or granules) of silica in the lumen of the ray cells; however, no silica was observed in identically prepared slides of the stump.

2. *Melaleuca sp* usually has abundant tanin in the ray cells and in many cells between the rays (Plate 3.6b); the unknown (Plate 3.6c) only had tanin in the ray cells.

3. *Melaleuca sp* have relatively thick cell walls (Plate 3.6b).

Plate 3.6a shows that *Eucalyptus gummifera* has certain affinities, when viewed in transverse section, with the unknown, such as uniseriate rays, thin cell walls, and the presence of tanin in the ray cells but not in the cross-cells. However, the eucalypt has no resin in the vessels; instead, many of the vessels were observed to be blocked by tyloses, which are extensions of the cell walls of neighbouring cells which protrude through pits and occlude the lumen of the vessel. The above characteristics suggest that the unknown is definitely not *Melaleuca sp*, with the absence of silica as a strong diagnostic criterion. Equally strongly, the presence of resin in the vessels distinguishes it from *Eucalyptus sp*. The most probable diagnosis is within the genus *Acacia*, as the pattern of borer attack is typical of *Acacia sp*, the distribution of rays and vessels is consistent with *Acacia sp*., and the presence of resin in the vessels is also typical of *Acacia sp.* The significance of this is that, by eliminating the possibility that the unknown is a water-tolerant plant such as *Melaleuca sp.*, one may estimate the change of waterdepth which has occurred since the plant colonised its present position, based on the fact that open forest species, such as *Acacia sp.*, will die when exposed to open water for lengthy periods. Thus, the presence of submerged stumps of water-intolerant plants in water depths of up to 4 metres suggests that lake level has been at least 4 metres lower than the present.

The aquatic vegetation presents a similar story. Four different zones can be distinguished in all of the lakes, and the characteristic species, with their corresponding water depths are given in Table 3.4. A schematic profile (Fig. 3.4) illustrates the species change with depth of water. That changes in these zones have occurred, probably in response to changing water depth, is illustrated when aerial photographs taken in 1955, 1965 and 1972[1] are compared. The first line of evidence is that, since 1955, the width of the reed margin has increased considerably; the low total phosphate content of the water (see Table 3.2) negates the influx of fertilizers into the lakes as a cause, and it is possible that recolonisation after a die-back caused by lowering of lake level is responsible for the increase in width of the aquatic vegetation margin. The second line of evidence is contained in Fig. 3.5. Here, a map of the present vegetation zonation in Lake III is superimposed over an enlarged section of an aerial photograph of Lake III taken in 1965. It can be seen that changes in the zonation have occurred, most likely in response to a rise in water level, whereby Zone C vegetation was observed in the field to be encroaching upon areas previously occupied by Zone D species, and Zone B types (especially *Eleochaeris sphacelata*) into Zone C.

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1 N.S.W. Dept. Lands 581 Warragamba Catchment; Run 10; July, 1955; 5033, 5034, 5035
N.S.W. Dept. Lands 1414 Cumberland; Run 34 and 35;October, 1965; 5031, 5032, 5033 and 5028, 5029, 5030.
N.S.W. Dept. Lands 2018 Wollongong; Run 3; June, 1972; 5111 to 5115 incl.

TABLE 3.4 : AQUATIC VEGETATION ZONATION, WITH CORRESPONDING WATER DEPTHS

Zone	Plant Species	Approx. waterdepth[1] range (m)
A	*Brasenia schreberi*	4.0
B	*Lepironia articulata*	2.0 - 4.0
	Eleochaeris sphacelata	1.0 - 3.0
C	*Lepidosperma longitudinale*	0 - 2.0
D	*Melaleuca linariifolia*	0 - 0.3
	Lepyrodia muelleri	0 - 0.1

1 Water depths as at May, 1974; note that zone boundaries are diffuse in terms of water depth, but are clearly distinguished in the field

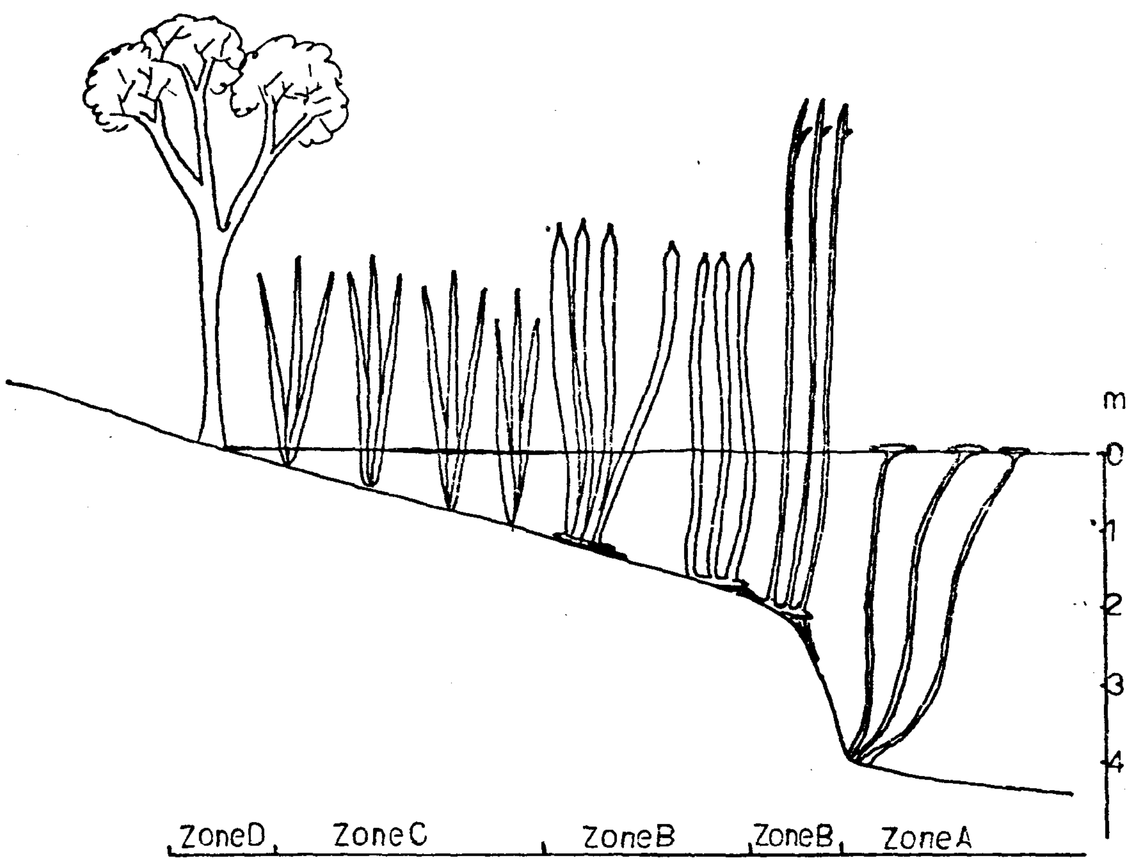
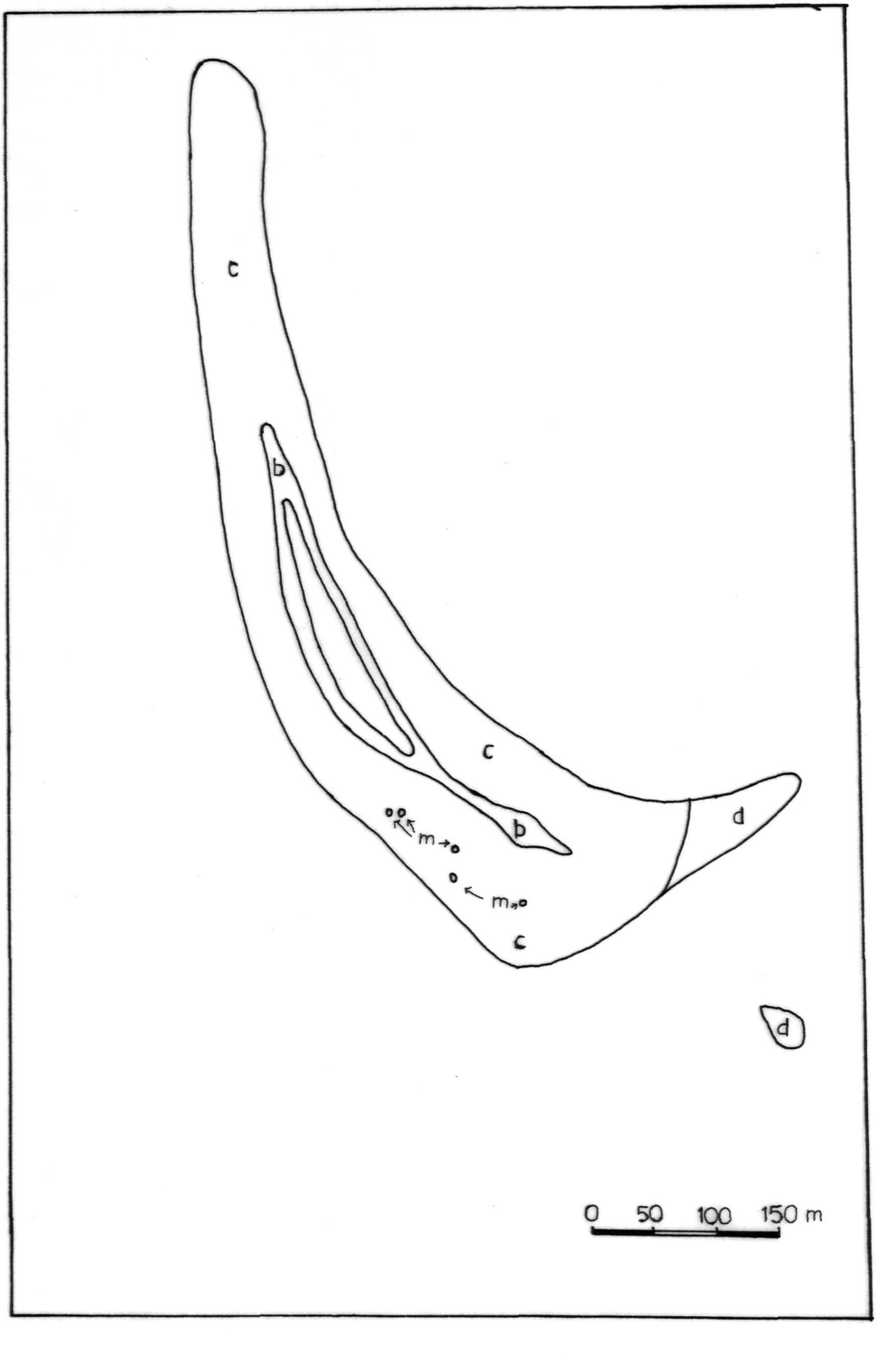


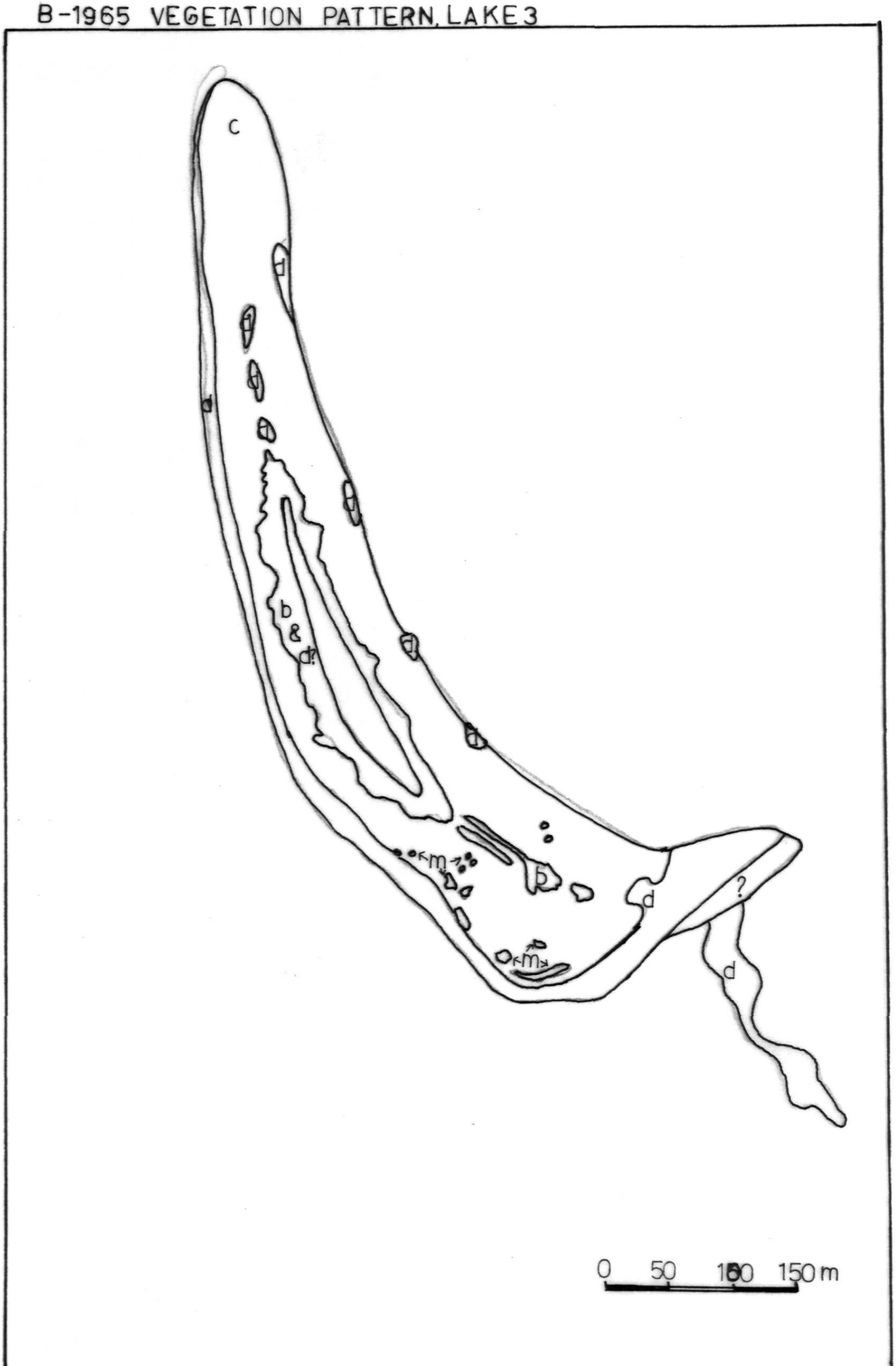
Fig. 3.4 : SCHEMATIC PROFILE OF AQUATIC VEGETATION ZONATION AT THIRLMERE LAKES

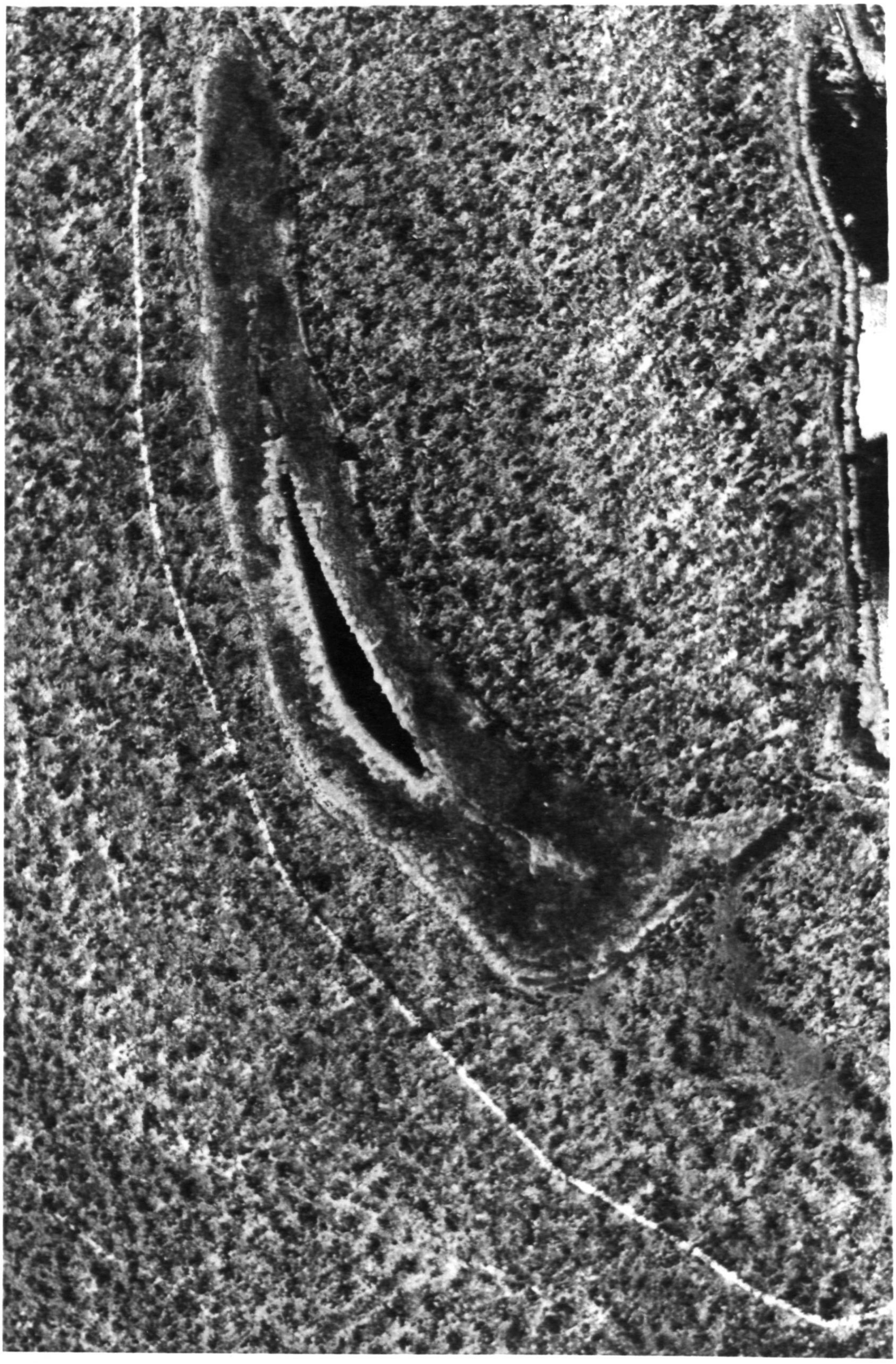
Fig. 3.5 : CHANGES IN AQUATIC VEGETATION PATTERNS, LAKE III

A-PRESENT VEGETATION PATTERN, LAKE 3



B-1965 VEGETATION PATTERN, LAKE 3





While little work has been done on the ecological requirements of Australian aquatic species (Aston, 1973), it is possible to observe changes in the vegetation patterns on aerial photographs and thence to determine the causes of this by studying the features of the typical present-day habitat of the species. As this type of work may aid in identifying ecological changes, such as in water depth, a more detailed and systematic study of the aquatic vegetation is required at Thirlmere Lakes.

3.5.3 Climatic Evidence: Having thus established that lake level changes have occurred in the past at Thirlmere Lakes, it is necessary to try to determine when they occurred. Discussion here will be restricted to historical lake level changes, as evidence of prehistorical (i.e. Late Quaternary) ones is largely contained in the sediments of the lakes and can only be documented with the aid of absolute dating techniques.

A study of the rainfall records for Picton since 1880 (Fig. 3.6) suggests that periods of above average rainfall may be correlated with relatively high lake levels at Thirlmere Lakes. Although it is well recognised by the writer that lake level will respond to more than just changes in amounts of precipitation from year to year, the lack of other data for the significant parameters of Equation A (Section 3.5.1) excludes assessment of their absolute influence. However, the above suggestion may be justified on the following grounds.

A comparison of a graph of rainfall over Lake George, N.S.W., since 1886 with that of monitored lake levels for the same period (Fig. 3.7) shows that there is a very strong correlation between years of above average rainfall and higher water levels; similarly, low lake levels correspond to years of below average rainfall. Since there is an almost one-to-one correspondence in the direction of change in rainfall from year to year at Lake George and at

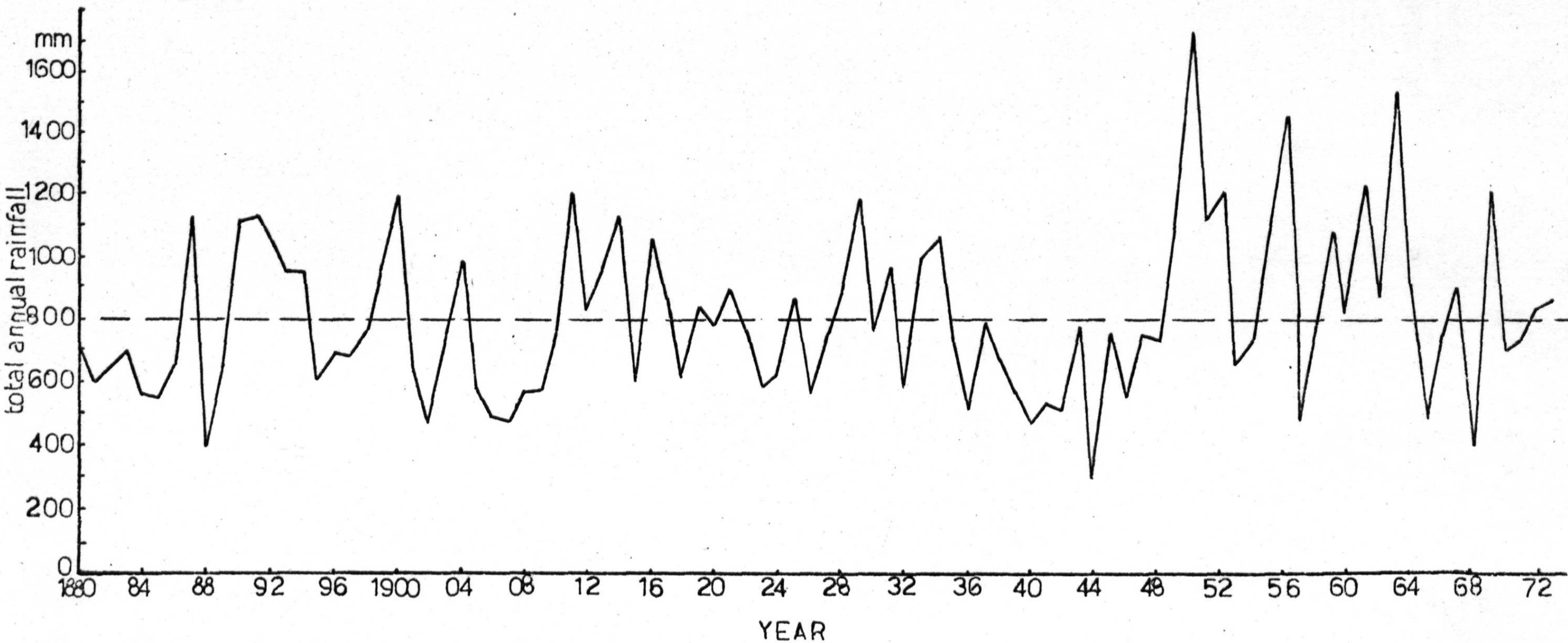
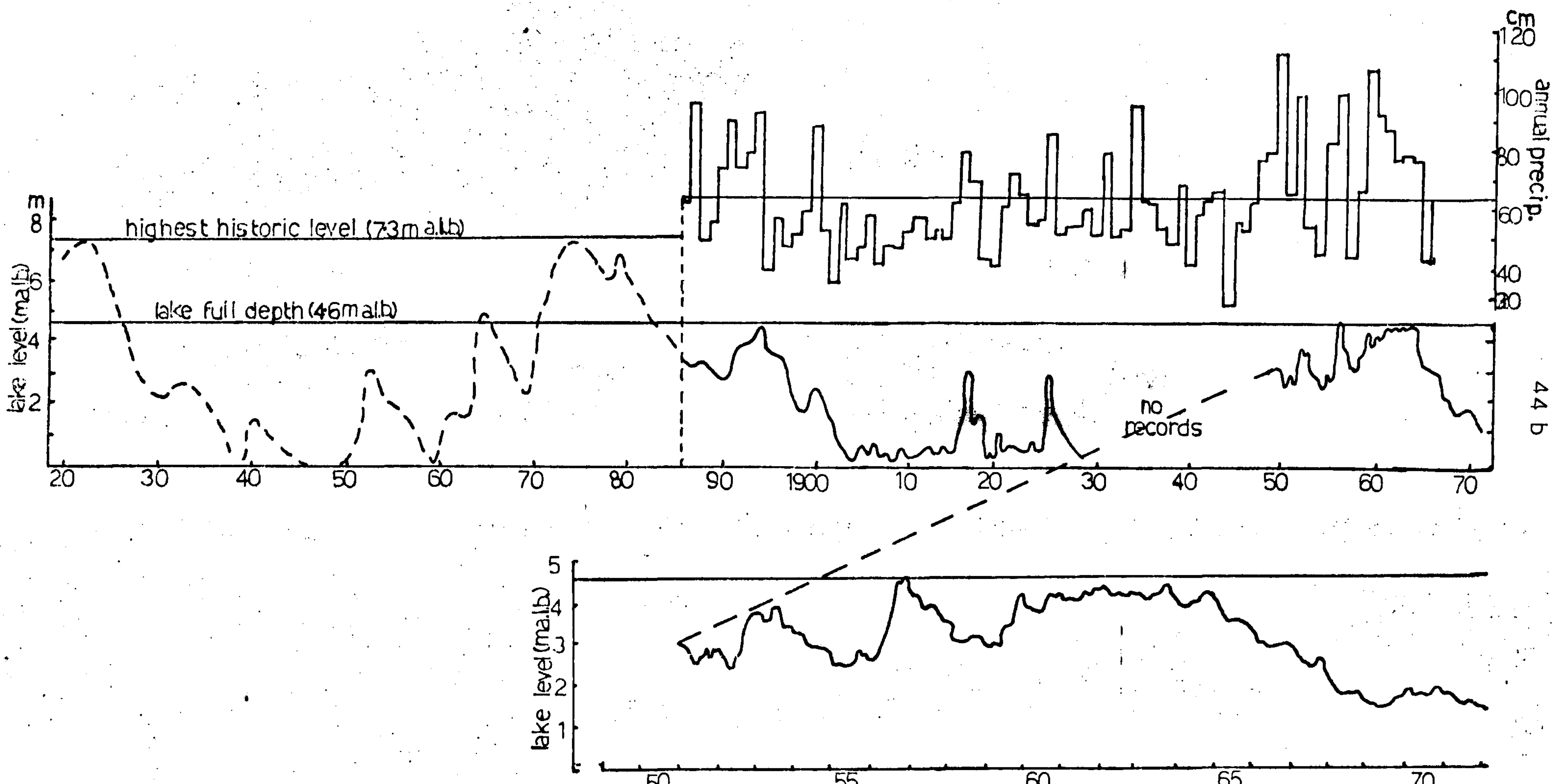


Fig. 3.6 : TOTAL ANNUAL RAINFALL AT PICTON N.S.W., 1880 - 1973



source: Coventry (1973)

Fig. 3.7 : TOTAL ANNUAL RAINFALL AND CORRESPONDING WATER LEVELS AT LAKE GEORGE N.S.W. 1886-1965

44 b

Picton (compare Fig. 3.6 with Fig. 3.7), the situation which appears to have existed at Lake George may also have existed at Thirlmere Lakes. Thus, since rainfall records began in 1880, higher lake levels may have been experienced in and around 1890, 1900, 1915, 1930, and from 1950 to 1965; lower lake levels may have occurred in and around 1908 to 1910, 1920 to 1927, and 1938 to 1945. This latter period corresponds with that reported by a local resident, Mr. W. Racklyeft (see Section 3.4 above).

The level of Lake George has been steadily falling since 1965, and Thirlmere Lakes may have been doing the same up until the present year, when the hypothesis given in Section 3.5.1 above that in the present year, the lakes have attained their highest possible level is supported by the fact that Picton (and elsewhere) has received rainfall far above the average (total rainfall to August, 1974 is 960 mm, compared with an annual average 804 mm - Australian Bureau of Meteorology Records). The situation at Lake George may be the same, but no records are available at present.

Additional validity may be given to the above argument by the following facts :

1. It has already been noted (Section 3.5.1) that the thick vegetation cover possibly renders direct precipitation onto the lakes surfaces the major source of inflow;

2. Lake level was observed to respond rapidly to precipitation e.g. after torrential rainfall on 25th May, 1974, the level of the lakes was observed to have risen by approximately 20 cm in one week, but the pre-wet period level was restored in a matter of weeks.

Given that the above arguments are valid, then from Figs. 3.6 and 3.7 it can be seen that Thirlmere Lakes may not have been as high as the present time for about 100 years, i.e. since 1874, and before that, since 1822; in both of these years, Lake George reached its highest historical level. Thus, Thirlmere Lakes may have been a closed basin for part or all of this time.

3.6 SYNTHESIS

Data given in this chapter suggest the following about the evolution of the Thirlmere Lakes basin :

1. Prehistorical and historical lake level changes have occurred, resulting in, firstly, oscillations of location of the littoral zones; secondly, the formation of floating peat islands; and, thirdly, changes in the vegetation patterns on the lake perimeters.

2. The "ageing" process which is common to all lakes is evident at Thirlmere Lakes, mainly in terms of the accumulation of organic deposits.

3. The attainment of an outlet into Blue Gum Creek has been a relatively recent phenomenon, in terms of an historical time scale. If this level is maintained, "ageing" is likely to be accelerated, in that erosion of the outlet will occur thereby lowering base level, to which the tributary (albeit ephermeral) streams will grade their beds; more inorganic sediment will be deposited in the lakes, at the same time that they are being drained by the increased discharge through the outlet.

CHAPTER FOUR

VALLEY FILL STRATIGRAPHY

4.1 INTRODUCTION

The bedrock cliffs constituting the valley sides at Thirlmere Lakes, previously described in Section 2.3.1., recline at angles of between 45^{o} and 70^{o} and a few holes augered at short distances from their bases indicate that they probably continue at that angle for some depth. Assuming that this was so, extrapolation of the cliffs beneath the debris slopes at the same angle gave an estimate of the depth of valley fill of around 50 metres. The nature of these sediments was investigated through a series of shallow (up to 4 metres depth) auger holes and deep (up to 33 metres depth) drill holes, with the following aims in mind :

1. to determine whether the lakes were formerly more extensive; and

2. to determine, as far as possible, the environment(s) of deposition of the top thirty metres of valley fill, and thereby to unravel part of the valley's depositional history.

Lake basins are considered to be ideal environments for the study of past climatic changes, through changes in the postulated environment of deposition of the sediment within the basin, because, firstly, they can present a relatively long and complete record, and, secondly, their simple hydrologic balances render them sensitive to environmental change (Bowler, 1970; 1972). The possibility existed that Late Quaternary climatic fluctuations exhibited in the sediments of lakes elsewhere in southeastern Australia (see, for example, Bowler, 1970, and Coventry, 1973) may be reflected in the sediments of Thirlmere Lakes. However, the relatively great depth of peat which has accumulated in the present lakes (see Section 3.3) indicates that this period of geologic history may be contained within the lakes themselves, and that the sediments to be described below are consequently of very great age.

Interpretation of the data has been made mainly on the basis of changes in the texture of the sediments and their similarity to surface deposits in the present-day environment. Biological criteria such as organic Carbon content and the presence or absence of sponge spicules have also been used. It must, however, be remembered that the geometry of the beds encountered in the drill holes is largely unknown, and that the true nature of the lithology and sedimentary structures may be obscured by the churning effect of the drill. However, broad changes in the type of material deposited in the valley has allowed hypotheses to be formulated about the history of deposition, and thus has enabled some connections to be made between the origin of the bedrock valley (to be discussed in Chapter Five) and the evolution of the lakes as they are today.

4.2 DEPTH OF THE VALLEY FILL

A seismic survey was conducted under the direction of Mr. J. W. Tayton, School of Earth Sciences, Macquarie University, in order to determine, firstly, the depth of sediment in the valley and, secondly, the location(s) of sediment layers as revealed by changes in the velocity of the sound waves as they travelled through layers of different densities. The location of the survey transect is shown in Fig. 1.2.

The bedrock cliffs on either side of the valley were found to continue at approximately the same angle beneath the overlying valley fill. However, interference with the sound waves because of the narrowness of the valley resulted in the bedrock base remaining undetected; its depth was calculated to be beyond 50 to 60 metres. Changes in velocity occurred at 2 to 3 metres, from 300 metres/sec. to 1,100 - 1,200 metres/sec., with a subsequent progressive increase with depth to about 2,000 - 2,100 metres/sec; the former reflects the change from unsaturated to saturated sediment (the velocity of sound waves in water is 1,400 metres/sec.), while the latter probably reflects increasing compaction of the sediments. Velocity changes were at approximately the same depth across the valley, which lead Mr. Tayton to believe (pers. comm.) that the zone of bedrock weathering had not been encountered; its profile would follow the outline of the bedrock valley sides, which would be reflected in a non-uniform depth of velocity change across the valley.

Thus, the bedrock valley is, as suspected, very deep and is filled with unconsolidated sediment which may be the products of a variety of depositional processes.

4.3 STRATIGRAPHIC DESCRIPTION AND INTERPRETATION OF VALLEY FILL DEPOSITS

4.3.1 Shallow Bore Holes: Two transects of shallow auger holes were dug across the valley at the locations indicated in Fig. 1.2. These are illustrated in Fig. 4.1, and detailed descriptions of each hole are given in Appendix D.

The sequence of textural changes exhibited in holes I to IX and XVI to XX of Transect A represents soil development on colluvial and alluvial material deposited by sheetwash and channelled flow on the alluvial fans across which the transect runs (see Sections 2.2 and 2.3 above). The surface material exhibited an accumulation of organic matter, and clay content generally increased with depth. In some holes, angular sandstone fragments were encountered; these

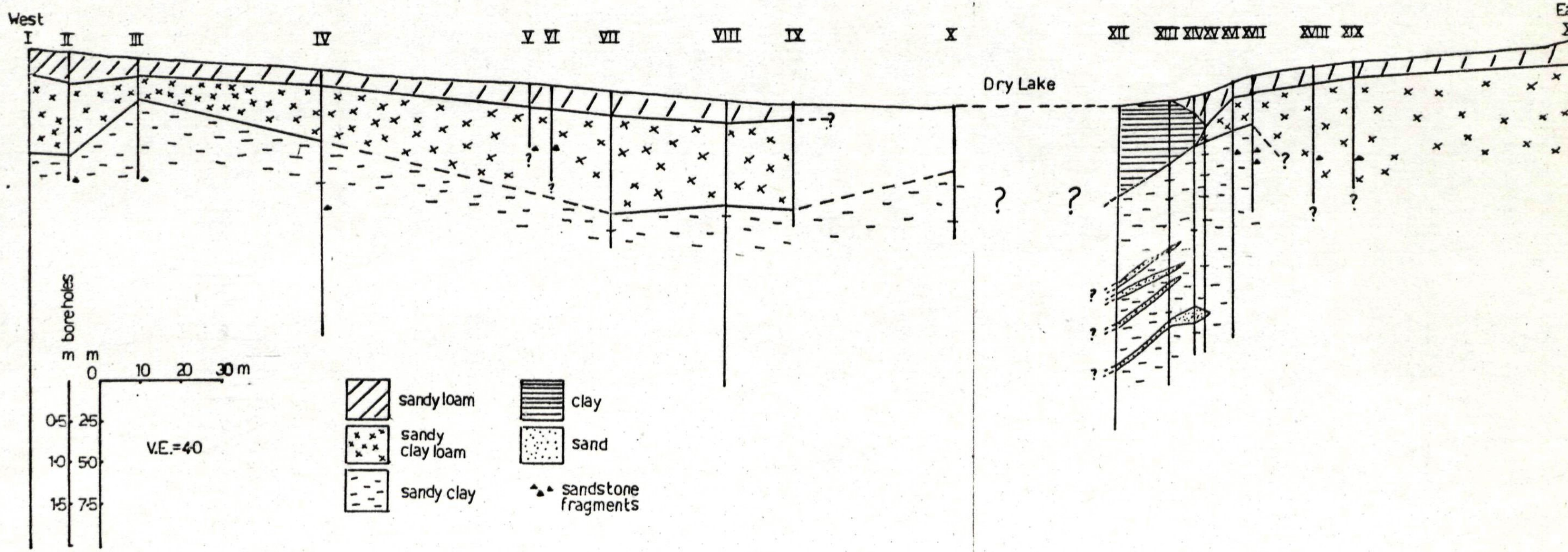


Fig. 4.1a : SHALLOW BORE HOLE STRATIGRAPHY, TRANSECT A

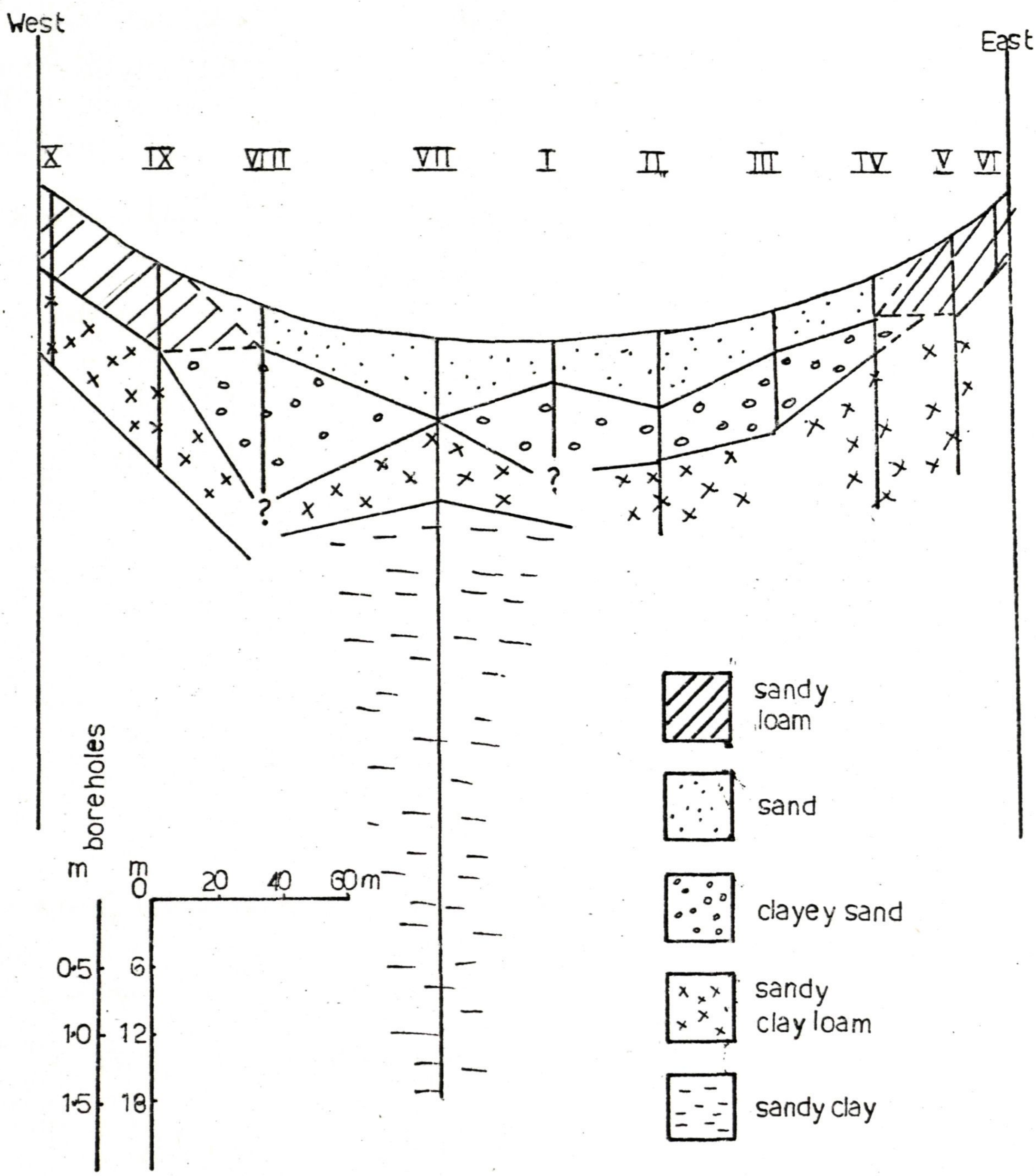


Fig. 4.1b : SHALLOW BORE HOLE STRATIGRAPHY, TRANSECT B

may be gravels deposited by a distributary stream system on the alluvial fans. The material encountered in holes X to XV reflects the influence of fluctuating water levels in the Dry Lake. The medium sand layers are probably reworked shore facies related to water levels higher than the present, while the finer material indicates deposition beneath deeper water (see Section 3.3). The predominantly grey colour of most of the sediment reflects excessive leaching of minerals, particularly iron, from the profile, while the strong mottling may be the result of a fluctuating water table.

A factor of significance in the history of the evolution of the land surfaces to its present form is the limited lateral extent of the Dry Lake deposits. It was initially expected that deposits similar to those found on the bottom of the present lakes and towards the centre of Dry Lake (i.e. organic clays) would be found lensing out beneath the alluvial fan deposits, reflecting former more extensive open water conditions. That this was not so indicates that Dry Lake may have been deeper than at present but not wider. A hole drilled at the northern end of Dry Lake (BH1 - see Section 4.3.3 below) showed, by the absence of organic clays in the profile, that the lake had never been longer than at present during the time represented by the top 20 metres of sediment. Drilling in the centre of Dry Lake should reveal alternations of pure clay with sandy clay and sand, as found in cores retrieved from the margins of the present lakes (see Section 3.3), reflecting fluctuating water levels and periodic drying out of the lake. A core obtained from beneath 0.6 metres of water at the southern end of Dry Lake revealed the following sequence :

0 - 30 cm	:	black fibrous peat
30 - 45 cm	:	brown fibrous peat with possibly higher inorganic content
45 - 49 cm	:	clayey sand, with sharp contact to
49 - 64 cm	:	grey-brown clay, grading to

64 - 65.5 cm	:	grey-brown clay, with some sand grains
65.5 - 68.8 cm	:	dark grey clay
68.8 - 70 cm	:	dark grey clay, with some sand grains

Thus, in the topmost 0.7 metres of sediment, periodic influx of coarse material has occurred, possibly at times of lower water level.

A textural sequence in which clay content increases with depth is also found in the holes along Transect B (Fig. 4.1). Sheetwashed sand from the residual sandy loam soils on either side of the valley is deposited in the bottom of the valley to form the sandy surface layer.

4.3.2 The Significance of the Sponge Spicules: Microscopic examination of sediment from the surface of Dry Lake revealed the presence of siliceous skeletal remains of a sponge, later identified by J. Stanisic (pers. comm.) to be the same as those of the fresh-water sponge, *Radiospongilla sceptroides* Has., which at present inhabits the open lakes. The sponge is found covering submerged logs and the stems of the littoral sedges in the lakes, and is identified by its bright emerald green colour, which is due to the presence of a chlorophyll-type pigment (Penney and Racek, 1968). The only other known recording of subfossil remains of this sponge was by Traxler (1896, in Racek, 1969) in alluvial sediments in northern Victoria. In most locations, the sponge regularly produces asexual reproductive structures called "gemmules", the siliceous remains ofwhich are called "gemmoscleres"; in Thirlmere Lakes, however, no gemmules have been found in living speciments and, for this, Stanisic (1972) has attributed the stable environment of the lakes, especially in terms of pH and water temperature to which the sponge appears to be sensitive.

In the surface sediment of hole XII of Transect A (Fig. 4.1) and the core described in Section 4.3.1 above, gemmoscleres were found and were identified by Stanisic (pers. comm.) as being derived from *Radiospongilla sceptroides*. Samples of sediment from the core, taken at 10 cm intervals, were examined, and it was found that the gemmoscleres were restricted to the surface, while the megascleres (the major type of skeletal spicule) increased in relative abundance with depth. Megascleres were also abundant in the surface sediment of Lake II.

Thus, if it is true that this particular species of freshwater sponge will produce gemmules under stressful conditions, as Stanisic (1972) implies, then the decreasing abundance of megascleres up the core and the presence of gemmoscleres in the surface sediment indicates the onset of increasingly harsh conditions in Dry Lake, most likely related to diminishing water depth. Stanisic (1972) considers that a change in the pH of the water is the most important criterion, based mainly on the fact that, in a home aquarium in which the pH was allowed to change from 6.6 to 7.8, the sponge began to produce gemmules. However, during this time, the water level in the tank dropped from 30 cm to 10 cm, but Stanisic tends to emphasise the pH factor at the expense of the water level factor. In the Thirlmere Lakes environment, the pH of the water would not be expected to change very much because of the presence of a high bicarbonate concentration (Table 3.2) which would buffer any fluctuation in pH (Stanisic, 1972, p.48). Assuming that this has always been the case since the lakes originated, then the presence/absence and relative abundance of gemmoscleres and megascleres in deposits elsewhere in the vicinity of the lakes could be used as an indication of water depth.

4.3.3 Deep Bore Holes: The locations of the deep bore holes are shown in Fig. 1.2, and their stratigraphy is illustrated in Fig. 4.2. Detailed descriptions of each hole is given in Appendix D.

Grain size analyses carried out on samples from BH2 (Table 4.1) show that the sandy clay material exhibits a bimodal grain size

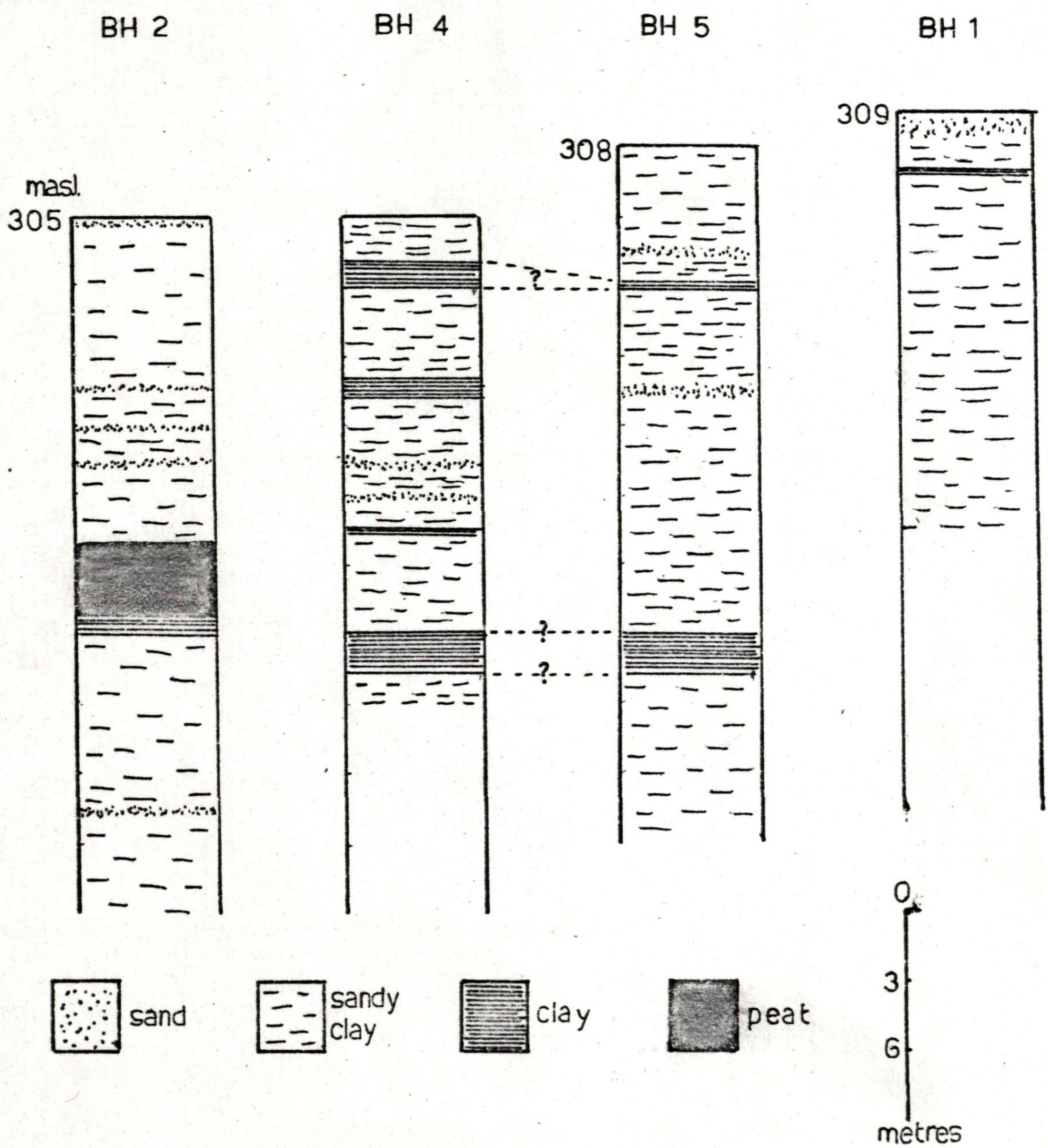


Fig. 4.2 : DEEP BORE HOLE STRATIGRAPHY

SAMPLE NUMBER	% GRAVEL (>-1ϕ)	% COARSE SAND (- .0-1.0ϕ)	% MEDIUM SAND (1.0-2.0ϕ)	% FINE SAND (2.0-4.0ϕ)	% SILT (4.0-9.0ϕ)	% CLAY (<9.0ϕ)	MEAN SIZE (ϕ)	σ (SORTING; ϕ)		SKEWNESS (ϕ)		KURTOSIS (ϕ)	
BH2/6.6	0.42	27.06	33.18	11.94	11.40	16.00	3.77	3.75	vps	0.79	v + s	1.39	l
BH2/8.3	0.04	33.50	43.14	10.56	7.76	5.00	1.47	1.70	ps	0.46	v + s	3.32	el
BH2/10	0.14	17.00	41.50	19.32	10.44	11.60	2.43	2.47	vps	0.65	v + s	2.39	vl
BH2/11.6	0.02	14.08	41.06	17.34	8.90	18.60	4.30	3.90	vps	0.78	v + s	1.44	l
BH2/13.3	0.02	13.06	40.60	14.20	10.72	21.40	4.40	3.92	vps	0.80	v + s	0.94	m
BH2/15	0.24	35.68	38.44	9.72	7.92	8.00	1.70	2.33	vps	0.63	v + s	2.90	vl
BH2/21	0	22.36	30.22	11.72	17.70	18.00	4.00	3.78	vps	0.73	v + s	1.31	l
BH2/22.5	0.12	26.74	31.66	12.42	15.46	13.60	3.17	3.23	vps	0.71	v + s	1.28	l
BH2/23.3	0.16	22.48	37.02	13.66	11.68	15.00	3.47	3.33	vps	0.75	v + s	1.40	l
BH2/26.6	0.06	16.94	31.44	16.22	15.34	20.00	4.20	3.73	vps	0.72	v + s	0.70	p

TABLE 4.1 : Summary of grain size analysis of Bore Hole 2 sediments (vps - very poorly sorted; ps - poorly sorted; v + s - very positively skewed; el - extremely keptokurtic; l - leptokurtic; m - mesokurtic; p - platykurtic)

distribution, with peaks in the medium sand and clay sizes, and is very poorly sorted. The exceptions are two samples (BH2/8.3 and BH2/15) field textured as medium sands; these exhibit unimodal size distributions and although still classified as poorly sorted by the definition of Folk and Ward (1957), they exhibit better sorting than the other samples analysed from this bore hole. Analyses of the clay layers were not undertaken because of the inability to remove all of the organic matter by treatment with hydrogen peroxide. However, their textural appearance strongly resembled that of clay layers encountered in cores extracted from the present lakes (see Section 3.3).

The lack of sufficient numbers of samples, and also the possibility of contamination of those available by the churning action of the available drilling equipment excludes any possibility of statistical correlation between the bore hole samples and the surface samples discussed in Section 2.3.2 above. However, there is a strong textural resemblance between the sandy clays in the bore holes and the surface material of the alluvial fans and debris slopes; one possible mode of deposition of this material is therefore via sheetwash from the adjacent hillslopes.

Although the bore holes are situated apart from each other in different present-day microtopographical situations (Fig. 1.2), broad correlations between the clay layers may be made, as indicated in Fig. 4.2. These clays are interpreted as the result of open, still water deposition, while the medium sand layers may be reworked littoral deposits. However, more extensive drilling and correlation between marker horizons, with the aid of absolute dating techniques, would be required to ascertain whether the correlation lines were time lines.

4.3.4 <u>Environment of Deposition of the Buried Peat</u>: A layer of strongly humified peat encountered between 14.3 and 17.3 metres in BH2 (Fig. 4.2) has been interpreted as the product of an open water environment, similar to that in the present lakes, on the following grounds :

1. It contains abundant algal remains and the pollen of *Melaleuca sp.* (Dr. G. S. Hope, pers. comm) both of which are found in and around the present lakes;

2. It contains megascleres of the sponge *Radiospongilla sceptroides*, but no gemmoscleres; given that the argument in 4.3.2 is valid, then one may infer that the water level in this paleoenvironment was greater than that in Dry Lake today;

3. It is underlain by gleyed clay, similar in appearance to that found beneath the peat in the present lakes.

The alternative interpretation, i.e. that of a backswamp on an alluvial plain, is negated by the narrowness of the bedrock valley and the relatively great thickness of the peat, which would have required an expanse of water in which to form. At the present time, the peat is 3 metres thick, and would have been much thicker before being compacted by the overlying sediments. In a coastal marsh in Conneticut, U.S.A., where sedge peat is overlain by 35 feet (11.5 metres) of post glacial estuarine mud, Bloom (1964) calculated that the present thickness of the deposit was as low as 13% of the original thickness.

If the above interpretation of environment of deposition is correct, then it represents a time when Lakes III and IV were connected; since that time, infilling and possibly drainage of the large lake has ensued. The age of the peat was found to be beyond the range of radiocarbon dating[1], i.e. older than 40,000 years, testifying to the relatively great age of the earliest known lake deposits in the Thirlmere Lakes valley. Charcoal from the clay layer at 6.9 to 8.4 metres in BH4 was also found to be beyond the range of radiocarbon dating[2]. This confirms the hypothesis given in Section 4.1 above that the period of Late Quaternary climatic fluctuations which has been documented from lakes elsewhere in southeastern Australia may be represented at Thirlmere Lakes by sediment within the bounds of the present lakes, and that the sediment described in this chapter is very old.

4.3.5 Synthesis: Given that the interpretations of the environments of deposition of the sediments described above are correct, then a lentic[3] environment, as opposed to a lotic[4] one, has been in existence in the area for a period represented by at least the top twenty metres of sediment in the valley. Within this period, interfingering of lake deposits with alluvial fan deposits has occurred in BH4 and BH5, both of which are located on the toes of alluvial fans (Fig. 1.2). While there is no obvious alluvial fan at the location of BH2, the coincidence of a semicircular depression in the cliffs of the central ridge at this point with the tributary valley between Lakes I and II to the east (Plate 1.1) suggests the existence of a line of weakness in the bedrock running an east-west direction; hence weathering and erosion are greater at this point, and a similar interfingering of sheetwash deposits with lake deposits may also be hypothesised.

The similarity between this sequence and that illustrated in Allen's (1965) model of alluvial fan and meandering stream deposits in an enclosed basin is illustrated in Fig. 4.3: one only needs to superimpose lacustrine deposits over the alluvial flat

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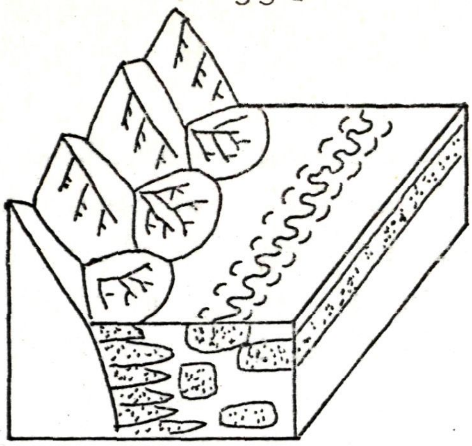
1 Teledyne Isotopes No. I-8126

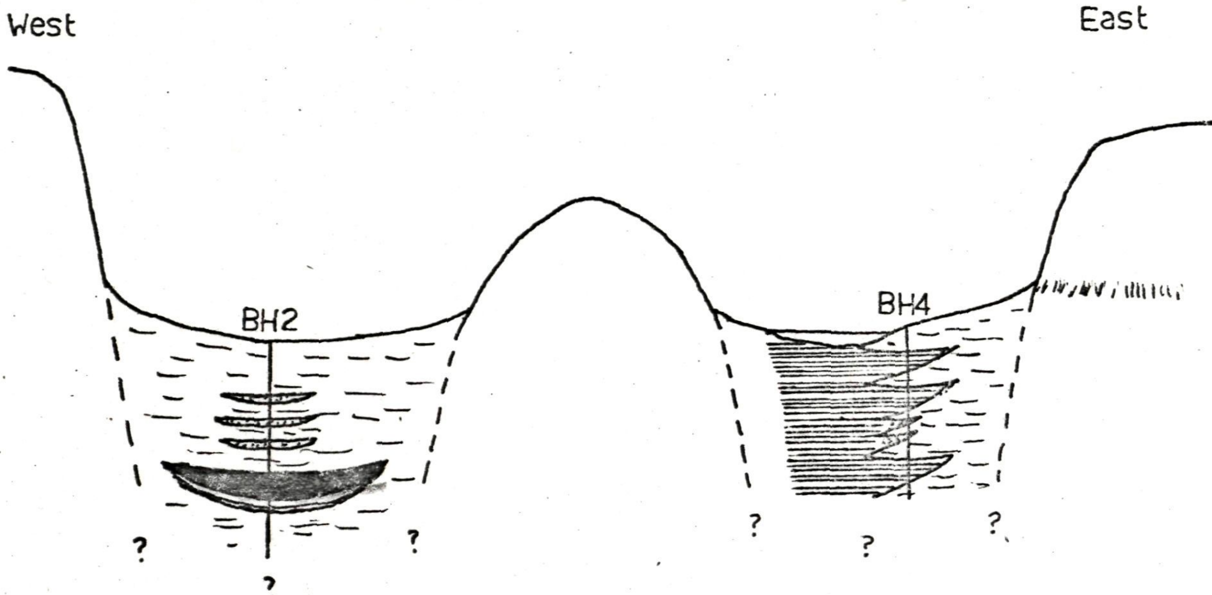
2 Teledyne Istopes No. I-8127

3 Lentic: open, still, fresh water, e.g. lakes and ponds.

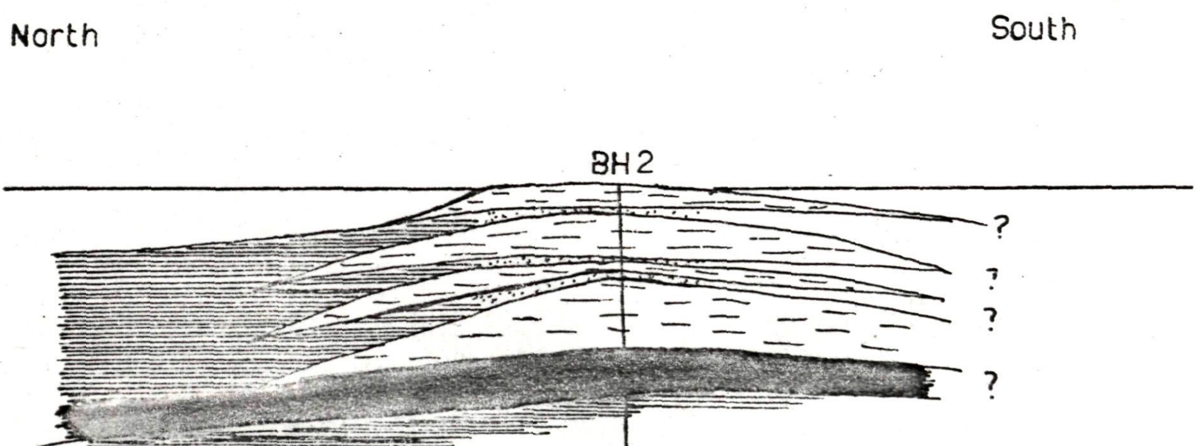
4 Lotic : fresh, flowing water, e.g. streams and rivers.



a-Allen's model of alluvial fan and stream deposition



b-sedimentary sequence in central valley fill



c-sedimentary sequence between Lakes 3 and 4

Fig. 4.3 : POSTULATED SEDIMENTARY SEQUENCE IN THIRLMERE LAKES VALLEY DOWN TO - 20 METRES

sequence of Allen's model. Of course, the questions of depth of lacustrine sediments beneath the present lakes, and of the environment(s) of deposition of the valley fill between -20 metres and bedrock in the Thirlmere Lakes valley have not yet been resolved. The first can only be answered by deep drilling beneath the lakes. In the second case, the great depth to bedrock (> 50 - 60 metres) makes it necessary for stream aggradation to have occurred after the bedrock valley was cut, but assuming that much of the sediment load of this stream may have been locally derived, it would be impossible to distinguish between fluvial deposits and alluvial fan and hillslope deposits in this environment. This is because of, firstly, the relatively short distance of travel which reduces the chance for sediment sorting, and, secondly, the lack of knowledge of the bedding geometry and the types of sedimentary structures present.

There exists the possibility that some of the sediment above the level of the buried peat (i.e. above - 20 metres) is fluvially deposited. Complete drainage of the lakes could have occurred, with subsequent fluvial deposition at least up to the level of the clay layer at - 6.9 metres in BH4, when damming of the stream again occurred. However, there is no evidence for this sequence of events and it is simpler to merely postulate one "lake full" stage, with subsequent infilling between the present Lakes III and IV.

The question of the presence of an outlet during the period represented by the top 20 metres of sediment is difficult to resolve. The possible reduction in the extent of the lakes as represented by the change from sub-lacustrine to sub-aerial deposition in BH2 points to lake drainage, but as stated in Chapter Three, infilling can occur concurrently with drainage, or it can be the sole "ageing" mechanism if an outlet is unattainable. Thus the hypothesis put forward in Chapter Three above, that the attainment of the outlet into Blue Gum Creek has been a relatively recent phenomenon, is still valid. When lacustrine deposition in the valley was initated, the lakes were possibly much more extensive, at least to the west; subsequent infilling via alluvial fans and debris slope accretion has reduced the lakes to their present size, and Blue Gum Creek has cut back through the valley fill until it breached the alluvial fan deposits at the western end of Lake IV (Plate 2.2). The sequence of events in the evolution of the lakes to their present form will be further discussed in Chapter Five.