BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

RECORD 1985/4

RECORD

GEOLOGY OF THE LAKE GEORGE BASIN, N.S.W.

by

R.S. Abell

with

an appendix by E.M. Truswell

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SUMMARY

New information derived from geological mapping, subsurface stratigraphic studies and palynological dating provides a basis for modelling the geological history of the Lake George basin. The early part of this Record reviews the geology and geomorphology of the basin. The later part gives results of a drilling program undertaken on the dry bed of Lake George during the 1982-83 drought.

The Lake George basin is situated along the highland crest of southeast Australia about 40 km northeast of Canberra. The basin originated by tectonic activity which probably rejuvenated meridionally trending late Palaeozoic faults. The Cainozoic sediments in the basin record a fluvio-lacustrine sequence beginning in the late Tertiary (late Miocene) and extending into the Quaternary.

The wide variety of sediment types and complex facies relationships suggest that during the Cainozoic surficial sedimentation took place in an environment dominated by tectonic and climatic events.

Fluvial gravel and sand, with minor silt and clay, represents channel and overbank sediments. The facies distribution of the sediments is affected partly by contemporaneous fault movements and a palaeotopography which preserves the remains of a drainage system which originally flowed NW. During the late Tertiary (Pliocene) and Quaternary faulting waned, fluvial deposition decreased and lacustrine clay and silt deposits represent a closed basin environment influenced largely by climatic change.

INTRODUCTION

The Lake George Basin is within the Southern Tablelands of New South Wales. The basin has an area of about 930 km^2 and lies about 40 km northeast of Canberra at approximate latitude $35^{o}10'$S and longitude $149^{o}30'$E.

Lake George is the focus of an internal drainage system in the basin and when "full" is the largest natural inland lake in New South Wales. A prominent east-facing fault scarp on its western side is evidence of a tectonic origin for the basin as a fault angled depression which preserves a unique late Cainozoic fluvio-lacustrine sedimentary record.

Various field research, water resource and mineral prospecting activities over the last two decades has led to an accumulation of geological, geophysical and hydrological data peripheral to the lake. When the lake dried out in July 1982 an unusual opportunity existed to extend the Cainozoic record in the basin through field observation and stratigraphic drilling on the lake bed.

Objectives of the investigation were (1) present a description of the drillhole core with emphasis on lithology, geophysics and clay mineralogy; (2) interpret depositional environments and establish stratigraphic units and (3) formulate a model and discuss the Cainozoic history of the basin. This report also incorporates geological data obtained in a field research program on the Canberra 1:100 000 sheet (Abell 1981, 1982 and in prep.). This study also includes previously unreported stratigraphic drilling and geological logging of bores undertaken by BMR in the basin between 1979 and 1980.

PREVIOUS WORK

A summary of previous work grouped under general headings is given in Table 1. The reference listings are not exhaustive. Additional unpublished reports referring to mineral and water resource investigations in the basin are held by the NSW Geological Survey and Water Resources Commission. The references illustrate the multidisciplinary approach and extent of interest shown in the Lake George Basin over the last two decades.

In the past there has naturally been a strong emphasis on studies involving the readily accessible Quaternary sediments and speculation on the origins of the Lake George escarpment. A considerable amount of useful information is available in various ANZAAS and college excursion guides. There are many papers which refer briefly to Lake George in a geological, geomorphological and palaeoclimatic context. Investigations contributing most knowledge of the basin are the geomorphological observations of Taylor (1907), the description and analysis of late Quaternary sediments at the northern end of Lake George (Coventry, 1976) and the retrieval by drilling of a full continental Quaternary record and recognition of Tertiary sediments in the basin (Singh, Opdyke and Bowler, 1981).

Analysis of previous work suggests that scientific investigations on the geology and resources of the basin have been conducted on a localised basis. These studies have led to the accumulation of a large body of unintegrated information which is now available for use in formulating a basin history.

REGIONAL GEOLOGY

A simplified map of the bedrock geology in the Lake George drainage basin is given in Figure 1. Data sources are based on geology shown on the Braidwood 1:100 000 scale sheet, 1st edition (Felton and Huleatt, 1977), the Canberra 1:100 000 scale preliminary sheet (Abell, 1982) and the Goulburn 1:250 000 scale sheet (Brunker and Offenberg, 1968).

The pre-Cainozoic bedrock geology comprises a thick pile of marine turbidite sediments of Middle to Upper Ordovician age overlain unconformably by late Silurian acid volcanics and early Devonian ?turbidite units. The sediments have been invaded by different generations of Siluro-Devonian acid and basic intrusions. The sequence was folded, faulted and weakly metamorphosed by a series of Palaeozoic earth movements which give a strong meridional trend to the geological structure. Late Palaeozoic and Mesozoic rocks have not been found in the basin and it seems unlikely that Permo-Triassic sedimentation extended southwestwards beyond the confines of the Sydney Basin. Since the Permian the local region has remained sufficiently stable for an ancient landscape to have formed by the late Cretaceous.

Table 1. Summary of previous work

Subject	Summary	Reference
Pre-Cainozoic regional geology	Lower Palaeozoic turbidite deposits; acid and basic volcanics; acid and basic intrusions,	Garretty (1936) Gilligan, Felton and Olgers (1979) Abell (1981, 1982 and in prep.)
Tertiary	Sedimentological analysis, palaeomagnetic chronology and long-term hydrologic changes.	Singh, Opdyke and Bowler (1981)
Quaternary	Abandoned lake shore sequences, palaeoclimatology and history.	Coventry (1973, 1976)
	Basin geomorphology; radiocarbon chronology of sediments.	Coventry and Walker (1977)
	Stratigraphy and sediments; palaeoclimatology; palaeomagnetic chronology.	Singh, Opdyke and Bowler (1981)
Geophysics	Gravity Seismic refraction Seismicity Electrical and other methods	Kevi (1964) Polak and Kevi (1964) Cleary (1967) Unpublished reports held by Mines Dept., Sydney
Basin origin and age	Truncation E-W drainage by normal faulting. Tertiary-Quaternary age.	Taylor (1907, 1911)
	Differential erosion associated with northward drainage; E-W warping. Tertiary-Quaternary age.	Garretty (1937)

	Disruption of pre-existing drainage system by post-Palaeozoic warping or faulting. Compromise view incorporating elements of Taylor and Garretty theories.	Jennings, Noakes and Burton (1964)
Hydrology (Lake George)	Water level observations Bathymetry of lake bed Water balance and chemical data Water balance and salinity studies.	Russell (1886) NSW Dept. Public Works (1903) Burton (1972) Jacobson and Schuett (1979)
Resources	Base metals, Sand and gravel. Groundwater.	The Woodlawn papers (GSA Journal 1979) Van den Broek (1979) Unpublished reports held by WRC, Sydney and Jododex (Woodlawn mines).
General References	Quaternary climatic record. Regional geomorphology. Lake George - It's geography, geology and history	Galloway (1965) Galloway (1969) Woolley (1974)
	Quaternary climatic record.	Bowler, Hope, Jennings, Singh and Walker (1976)
	Quaternary climatic record. Regional geomorphology. Lake George. Lake Tertiary and Quaternary climatic record.	Churchill, Galloway and Singh (1978) Ollier (1978) Jennings (1981) Bowler (1982)

Tertiary volcanic rocks are unknown in the Lake George Basin. Scattered remnants of basalt form the Nerriga Volcanic Province east of the Mulwaree fault zone (Wellman and McDougall, 1974) and in the vicinity of Crookwell (Young, 1981). During the Tertiary, faulting formed shallow tectonic basins along this portion of the highland crest of southeast Australia e.g. Lake George and Lake Bathurst (Ollier 1978. fig. 17b). The oldest known continental Tertiary sediments are occasional outcrops of indurated ferruginous and silicified quartz gravels which lie unconformably on weathered Palaeozoic bedrock. At the northern end of Lake George lacustrine sediments of Pliocene age have been proved in drill core (Singh, Opdyke and Bowler, 1981).

In the Quaternary, climatic changes relating to Pleistocene Ice Ages caused colluvial deposits to accumulate in a periglacial environment on the flanks of hills and along the Lake George escarpment. At the northern and southern ends of Lake George, strandline, lagoonal and aeolian deposits resulted from changes in the level of Lake George.

Since the Pleistocene alluvial deposition has continued along major streams. With the advent of European settlement in the 19th century land clearing, gully erosion and sand mining have modified the natural landforms in the basin.

GEOMORPHOLOGY

The Lake George drainage basin (Fig. 2) is a narrow meridionally trending area of internal drainage reaching a maximum length of 68 km and width of 19 km. Topographically, the basin margin is defined by the Great Divide to the east and the Lake George Range to the west. At its northern and southern limits, the margin is partially obscured by a subdued topography containing low saddles, a complex of natural and artifical drainage lines and swampy lagoonal areas.

Relief

Within the basin, topographic relief commonly ranges from 680-900 m a.s.l. (above sea level). It is generally undulating with hills and ridges gradually sloping in elevation towards Lake George. The bed of the lake approximating to an elevation of 674 m a.s.l. (above sea level) is essentially flat but variations in the bottom topography are depicted in a contour map produced by the NSW Dept. Public Works (1903). At the southeastern margin of the basin relief reaches beyond 1100 m in the Butmaroo Range. The Lake George Range is an escarpment continuous along the western margin of the basin. In the vicinity of the lake a wall-like escarpment reaches over 200 m a.l.b. (above lake bed); this feature gives way gradually to more subdued and rounded topography north of Collector, and south of Bungendore.

The Lake George escarpment shows some irregularity in relief. Gearys Gap is a low saddle about halfway along the escarpment (Fig. 3). At its lowest point it forms a V-shaped notch about 0.5 km wide lying 30-40 m a.l.b. Still higher and extending about 4 km along the scarp a wider depression contains relict terrace deposits of quartz gravel. The lower notch may represent a late Quaternary overflow point for Lake George when it was 37 m deep (Coventry, 1976), whilst the higher depression is the remains of the old Yass river valley prior to its truncation by faulting (Taylor, 1907 and Ollier, 1978)

Changes in direction of the Lake George escarpment are related to processes and rates of westward scarp retreat from a meridional fault zone shown to pass beneath a cover of unconsolidated sediment in Lake George (Fig. 1). The curved shape and steepening of the escarpment adjacent to Lake George is attributed to lake shore abrasion at times of high lake levels in the late Quaternary (Jennings 1972 and Coventry, 1976). The steep slopes are mantled by colluvial slopewash deposits, which have been dissected by more recent drainage forming alluvial fans at the foot of the escarpment. A small nick point on Grove Creek (MR 167/113)*at about 716 m (a.s.l.) may be associated with late Quaternary slope trimming. About 4 km west of Bungendore the escarpment trends southwards to beyond the limits of the basin. This section has not been steepened by lake shore erosion and the topography is rounded, with a thicker mantle of colluvial and alluvial fan deposits. Slight curvature of the scarp is indicated by headward erosion of Millpost Creek. A nick point on Millpost Creek (MR175/937) at about 760 (a.s.l.) may be related to mid-Tertiary faultline rejuvenation. Similar features occur beyond a north-northeast bend in the escarpment southwest of Collector.

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*Map references given in the text refer to grid co-ordinates on the Canberra 1 : 100,000 topographic sheet 8727.

Drainage

Lake George Basin is a local sump and base level in an area of internal drainage between rivers draining eastwards to the Wollondilly and Shoalhaven catchments and westwards to the Lachlan and Murrumbidgee catchments. Streams in the basin occupy wide open valleys in their upper reaches. They converge towards Lake George, meandering across flat alluvial plains. Colour aerial photography taken by BMR in August 1982 shows that these streams are still active enough to build small alluvial deltas onto the lake bed. Major drainage lines such as Collector, Turallo and Butamaroo Creeks are locally controlled in their higher reaches by meridional structures in the underlying geology. Only minor creeks enter the basin from the Lake George Range, the most important being Millpost Creek.

Drainage modification in and peripheral to the basin (Fig. 2) relates to Cainozoic tectonism. At the northern end of the basin evidence for stream capture is given by the barbed drainage pattern of Collector and Tarago Creeks. West of the Lake George Range the topographic maps show these creeks line up with Frankfield, Lerida and Meadow creeks draining northwest towards the Lachlan River. The faulting which formed Lake George Basin blocked the upper catchment and these diverted creeks now bend acutely south and drain towards Lake George. Dry Lagoon (el. 720 m) and Rose Lagoon (el. 750 m) are small basins with temporary outlets to Collector and Tarago Creeks. They probably formed as marshy depressions when these drainage lines were disrupted by stream capture. Their present day morphology probably results from wind deflation during arid periods in the Quaternary. The captured portion of the Lachlan catchment left within the Lake George Basin is shown in Figure 2.

A more local example of stream modification by faulting is afforded b Shingle House Creek west of Gearys Gap (Fig. 2). This creek was once part of a much enlarged Yass river headwater system. Uplift west of the Lake George fault blocked this headwater system. Shingle House Creek maintained its course across the Cullarin Block to where it joins the Yass River south of Gundaroo. Gearys Gap remains as a wind gap; the site of the original course of Shingle House creek. Brooks Creek, originally a minor north-flowing tributary of Shingle House Creek was able to incise its course and extend its catchment southwards parallel to the Lake George escarpment. This creek now forms a prominent right angled bend about 2 km northwest of Gearys Gap where it joins Shingle House Creek.

CAINOZOIC GEOLOGY
(INVESTIGATIONS BEFORE 1982)

A map of the Cainozoic geology of the Lake George Basin is shown in Figure 4. Compilation of the map was based on geological information taken from Coventry (1976) and Abell (1982). Additional data was supplied by BMR air colour photography taken in August 1982.

The late Cainozoic sequence is a complex arrangement of continental deposits preserving a unique stratigraphic and palaeoclimatic record. Early Palaeozoic bedrock is unconformably overlain by patchily exposed Tertiary gravels. A widespread cover of Quaternary sediments makes the bulk of the late Cainozoic sediments exposed in the basin.

TERTIARY SEDIMENTS

Fluvial sediments

Patches of ferruginous quartz pebble gravel occur close to the crest of the Lake George escarpment (Fig. 4). An early reference to these gravels is given in Taylor (1907) and detailed descriptions by Coventry (1967). The deposits which are a few metres thick form local cappings on hills west of Gearys Gap. The gravels consist of well rounded clasts of milky quartz, locally derived angular clasts of blue grey chert and a few lithic clasts up to 30 cm in size set in a sandy matrix cemented by brownish-yellow iron oxides (geothite-limonite). The gravel lies unconformably on an Ordovician bedrock surface of strongly cleaved kaolinised phyllite. Sedimentary structures eg. channel deposition and low angled current bedding suggest the gravels were deposited as river bed load along the course of ancient drainage lines. This interpretation is supported by a progressive decrease westwards in the altitude of the bases of similar deposts outcropping along the valley of Shingle House Creek. Coventry (1967) noted that the proportion of locally derived angular chert clasts in these fluvial gravels also increased towards the west. Attempts to date the gravels by palaeomagnetic methods have been unsuccessful. M. Idnurm (pers. comm. 1983) reports that the geothite-limonite cement is magnetically unstable iron probably resulting from successive weathering cycles. The weathering profile preserved in these deposits and the underlying bedrock may correlate with a mid-Tertiary deep weathering profile more fully preserved in the Lake George Basin; the gravels are therefore mid-Tertiary or older.

Photo. 1 Geopetal capping on the upper side of a quartz clast (sectional view)

Photo. 2 Geopetal capping on the upper side of a quartz clast (plan view)

A small deposit of silicified quartz gravel (silcrete) outcrops at the base of the Lake George escarpment. Brief references to the deposit are given in Taylor (1907), Garretty (1937) and Browne (1972). The silcrete has been exposed as a low lying-outcrop on a narrow wave-cut bench eroded across bedrock about 1 km south of Gearys Cap (Fig. 5). The deposit is composed of a poorly sorted framework of rounded to angular vein quartz and rare lithic clasts ranging in size from sand grains to cobbles. The framework is set in a matrix of microcrystalline silica which imparts a light grey colour to the rock; the silcrete falls within the F-(floating) fabric type classification of Summerfield (1983). Geopetal structures (photo 1 and 2) on the upper side of some quartz clasts are a capping of iron-titanium sand; the nature and origin of these cappings is speculative. Bulbous growth surfaces also occur. The logs of 2 shallow drillholes summarised in Figure 6 indicate the silcrete like the elevated gravels above the escarpment overlie weathered bedrock. Displacement of these gravels by normal faulting (Fig. 5) provides a suitable site in a low-lying area at the foot of the escarpment for the precipitation of silica from impeded surface drainage or shallow groundwater. Sources of Si and Ti are from the weathering of abundant acid and basic rocks in the basin. The age of the silcrete is unknown, but may post-date the ferruginous weathering in gravels on the escarpment.

Fluvio-Lacustrine sediments

Attempts to investigate the nature and age of subsurface Cainozoic sediments, in particular the existence of Tertiary sediments in the basin began in 1968 when BMR drilled Scouthole No. 1 (C1) at the southern end of Lake George (Burton 1972). The hole was 120 m deep and about 15 m of core was recovered over 11 short intervals (mostly in bedrock betwen 100-120 m). The Cainozoic sediments consisting of fluvio-lacustrine sands and clays were undated. A geophysical log and lithological interpretation are given in Figure 27. In 1971 BMR Scouthole No. 4 (C4) was drilled at the northern end of Lake George. This hole was cored to a depth of 71.3 m with an average recovery of 60%. The hole intersected mainly lacustrine clays with a few thin layers of fluvial sand. The top of a deep weathering profile was placed at 50-51 m (Singh, Opdyke & Bowler, 1981). In 1976 Tertiary sediments were proved in ANU drillhole LG4 at the same locality (Singh, et al., 1981). The hole penetrated 36 m of lacustrine clays; the sequence was palaeomagnetically dated to the Gauss magnetic chron at approximately 3.5 my (mid-Pliocene). In 1979 two cored holes (C294 and C295) were drilled by BMR at the southern end of the basin. The holes passed through a Cainozoic fluvio-lacustrine sequence to bedrock (lithological and geophysical logs are given in Figures 28 & 29). In C294, the deepest hole, samples submitted for palynological analysis above 18 m did not give pollen older than the Quaternary (Truswell 1980).

QUATERNARY SEDIMENTS

Late Quaternary sediments are widely distributed in the Lake George basin (Fig. 4). Most exposures occur within broad alluvial valleys and marginally around Lake George. The variety of depositional facies represented in the basin reflects a complex history of climatic change. The sediments and associated landforms are grouped into five morphostratigraphic units (a) colluvial; (b) lacustrine; (c) alluvial; (d) strandline and (e) aeolian. These morphostratigraphic units are defined partly on landform, and partly on material. Stratigraphic relationships are deduced from geomorphological relationships between landforms, drillhole evidence and exposures in creeks and sand pits. The morphostratigraphy shown in Figure 4 is grouped into a broad depositional setting and then further subdivided into types having a distinctive morphology following a proposed standard outlined by Grimes (1983). A differentiation of alluvial fan deposits within colluvial mantles is not attempted because of the limitations of map scale. A schematic section (Fig. 7) across the southeastern margin of Lake George shows relationships between the various units.

Colluvial deposits (Qr)

Colluvial mantles are most widespread along the east-facing slopes of the Lake George escarpment and to a lesser extent on hillslopes in more elevated terrain. Near the top of the escarpment slopes supported by bedrock are covered by trees while lower down more gentle slopes define the top of the colluvial mantle. These deposits are commonly polygenetic reflecting several cycles of erosion and pedological differentiation. They comprise angular poorly sorted scree clasts of predominantly sandstone, acid porphyry, slate and milky quartz which range often to cobble size (70 mm)*. Clasts show a tendency for downslope orientation with some rounding suggesting minor abrasion during transport; stratification is very imperfect. The deposits rarely exceed a thickness of 10 m. A discontinuous bench at the top of a colluvial mentle along the western shore of the lake is about 30 metres a.l

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* Size ranges are based on the Wentworth-Udden size scale for sediments

This minor landform may result from cliffing by wave ction during the highest level of Lake George when it overflowed throuh Gearys gap. However proof of the relationship awaits accurate levlling along this bench. Colluvial mantles are dissected by small crees which deposit alluvial fans at the foot of the escarpment.

The full age range of colluvial deposits n the Lake George Basin has not yet been determined. In Fernhill Gully (MR 24/282) charcoal from a poorly sorted subangular quartz gravel worked by waes gives a maximum radiocarbon age of 26, 870$\pm$900 yrs BP, (Coventry and alker 1977). This age compares favourably with a radiocarbon date of abut 27,000 yrs BP obtained for colluvial deposits at Black Mountain, AC by Costin and Polach (1973). The origin of these deposits is uncertain. hey may have formed during periods of slope instability originating from reduced vegetation cover in cool dry conditions during the last Glacial aximum in SE Australia (30,000-25,000 yrs BP).

Thicker and more extensive colluvial mantes on the escarpment north and south of the lake area have not been denude by past high lake levels. They offer the prospect that in creek sectios through the deposits datable material may be preserved which may correlatewith the earlier Pleistocene glacial/interglacial cycles recognised inlacustrine clays in Lake George (Singh et al., 1981), but no such materia has yet been found.

Lacustrine deposits (TQ1 and Qcl)

Lacustrine clays have their greatest extet and thickness in the vicinity of Lake George but some lacustrine claysare also preserved in small lagoonal depressions at higher levels and atvarying distances from Lake George (Fig. 4).

A detailed description of 36 m of lacustrie clay from ANU hole LG4 at the northern end of Lake George is given n Singh, Opdyke and Bowler (1981). At 27 m the base of the Quaternary wa placed at the Matuyama chron at about 1.9 my BP. In the upper 8.6 m of this sequence 4 glacial/interglacial cycles covering the last 350,000years were recognised from plant microfossils. This is currently the most ontinuous biostratigraphic record for the Quaternary in southeast Australia.

Lagoonal clay pans (Qcl) near the northern and southern margins of Lake George lie in depressions behind the steeper outer flank of strandline ridges (Fig. 7). The pans periodically fill with water after heavy rain or when water levels in Lake George are high. Many pans have been modified to create pasturage e.g. Murrays Lagoon. Drainage channels have been cut through strandline ridges to remove floodwater; a few remain in their natural state to provide watering areas for stock and a habitat for birdlife. The pans are floored by a layer of grey-black clay. A WRC water bore (29243) drilled in Murrays Lagoon intersected a thickness of 11.3 m of clay overlying 1.5 m of sand before ending in bedrock? clay at a depth of 22.0 m. The nature and thickness of lacustrine sediments in Rose Lagoon and Dry Lagoon is unknown. A clay-filled depression behind a low gravel bar south of Wave Hill station (MR 196/927) provides evidence for the most southerly extent of Lake George during the Late Quaternary.

Strandline deposits (Qcb)

Strandline features around Lake George provide some of the more obvious evidence for Quaternary sedimentation in the basin; their outline on aerial photographs allows for accurate mapping of their form and distribution. An important geomorphic characteristic of these constructional beach ridges is their almost concentric arrangement around the lake margin (Fig. 4). The morphology of some of the lower elevated ridges adjacent to the lake is currently under threat by sand mining. However the pits provide access and valuable temporary sections through the uppermost portions of these deposits. The account of the lacustrine shoreline features given here is based largely on information in Jennings, Noakes and Burton (1964) and Coventry (1973). Detailed descriptions of the embankment geomorphology, sediments and soils at the northern end of Lake George are given in Coventry (1976).

The gravel embankments are best developed at the northern and southern ends of the lake. Some banks form elongate regularly curving ridges or bars which traverse portions of the basin e.g. Winderadeen embankment, while others subparallel the longitudinal axis of the basin e.g. Woolshed and Turalla embankments. These larger ridges display an assymmetrical form in cross section with a gradual slope facing the lake and a steeper outer flank. Strandline deposits with limited topographic expression occur along the eastern margin of the lake. Minor vegetational changes associated with drier and wetter soil zones on the undulating surface of these banks mark subparallel geomorphic lineations on aerial photographs which assist in mapping these deposits. Their reduced topography may result from exposure to persistent westerly winds which have promoted beach drift and flattened the ridges by removal of fine sand and clay to other parts of the basin. In contrast the more pronounced strandline ridges at the northern and southern ends of the lake appear to have maintained their form in the more sheltered environment of the Lake George range. Strandline deposits are almost absent from the western shore; a few beach lines and berms (beach terraces) are found in association with alluvial fans. From the elevation and distribution of lacustrine beach deposits Coventry (1976) was able to map the extent of Lake George during the Late Quaternary when it stood at its highest level of 37 m a.l.b.

Sediments of the beach ridges consist of poorly to well sorted rounded gravel interbedded with varying amounts of well sorted medium to coarse grained sand. The clastic material which originates from colluvial and fluvial sources consists of quartzite, milky quartz, acid porphyry, dolerite and black slate. The presence of numerous well rounded and flattened pebbles (cleaved lithic clasts) up to 30 mm long is evidence of abrasion and deposition in a shoreline environment. Sedimentary structures are well defined in a gravel pit close to the Federal Highway south of Collector at MR 191/273. Here individual sedimentation units can be traced along the northwestern wall for some distance parallel to the ridge crest. Current bedding is common; well sorted foreset beach sands dip with a shallow angle towards the lake while poorly sorted wash-over beds dip at a higher angle away from the lake. There is a lateral change from gravel to sand towards the free end of the ridge and particle size variation with depth; both a product of size grading associated with wave action. Cut and fill structures and other evidence of fluvial scouring in the sequences is absent. In a disused gravel pit on Turalla bank (MR 198/983) a red podzolic soil profile is exposed in bedded sands and gravels on the crest of the beach ridge.

Erosional features associated with lacustrine shorelines are seen at various places around the lake. A sequence of three beach terraces is preserved east of Ondyong Point (MR 208/207). The terraces form a stepped landscape feature with the highest bench at approximately the 690 m contour. A favoured interpretation is that these beach deposits were laid down during a similar high lake level to that which constructed the Winderadeen bar. Since the late Quaternary the terraces have formed by erosion and reworking of the beach deposits during periods of stationary lake level within a longer period of lake level decline. Similar terracing and cliffing can be seen in a subaerial alluvial fan at Silver Wattle Point (MR 178/080). A series of small bays and headlands along the eastern shore north and south of Taylors Creek represent the remains of an old shoreline. Resistant outcrops of Ordovician metasediments have been cliffed up to the 700 m contour. Beach drift in a southerly direction is apparent along this stretch of the lakeshore. Sediment has accumulated on the windward side of bay headlands while on the leeward side it has been eroded away. The pattern of sediment movement shown in Fig. 4 is based on BMR aerial colour photography taken in August 1982. Beach drifting arises from persistent westerly winds which in times of high lake level create currents that erode and slowly move strandline and fluvial material southwest along the eastern shoreline of Lake George. This sensitive depositional evnironment exemplifies the importance of seasonal and long term climatic change whereby beach drift and fluvial processes act in close association.

Radiocarbon dating of shoreline deposits at the northern end of Lake George gives a series of ages ranging from about 27,000 yrs BP to 3,000 yrs BP (Coventry 1976). In this area there is a southward younging and reduction in elevation of the oldest and highest beach ridge (Winderadeen embankment) to the youngest and lowest beach ridge (Vault embankment). This developmental sequence is based on a general recession of lake level stands since the last Glacial Maximum. The strandline sequences along the eastern shore and similar ridges at the southern end of the lake have not been dated or described in detail. Their lower elevations and closeness to the lake suggest they are a younger sequence.

The gravel banks at the northern and southern ends of the lake are almost certainly the product of wave action on colluvial and alluvial deposits. The broader disposition and lower elevation of the strandline banks along the eastern shore of the lake suggest that beach drift and at times wind were active agents in their construction.

There is broad similarity in the elevation of Late Quaternary beach lines in alluvial fans near the base of the Lake George escarpment on the upthrown side of the fault, and strandline deposits marginal to the lake on the downthrown side of the fault. In detail the morphology and height of the Winderadeen embankment (36 m a.l.b. suggests correlation with the Turallo embankment at the southern end of the lake. These lines of evidence suggest that the Lake George Basin has not been tilted or faulted since the late Quaternary sediments were deposited.

Aeolian deposits (Qdp)

An early reference to wind blown sand deposits near Lake George is given in Garretty (1936). The distribution of these deposits shown in Fig. 4 is taken from Coventry (1976) and Coventry and Walker (1977). These sands were mapped as a patchy cover in alluvial embayments and on bedrock slopes in the eastern portion of the basin. Where aeolian deposits are recognised in the field they occur as thin undulating sand sheets and low linear dunes often banked against west facing bedrock slopes. The sediments consists of fine to medium-grained well sorted quartz sand. The sands appear to have been derived from strandline and fluvial deposits around the eastern margin of the Lake George; their association with areas of granitic bedrock is probably fortuitous.

The eastern convex outline of Lake George, Dry Lagoon and Rose lagoon attest to the importance of wind in shaping the morphology of these lake basins. Coventry (1976) studied modern regional wind patterns and compared them with palaeowind patterns deduced from current bedding measurements in strandline deposits. He concluded that the prevailing WNW wind direction at Lake George has been consistent at least over the last 4,000 years. The movement and accumulation of aeolian sand deposits during late glacial and post glacial time suggest periods of cold dry conditions and poorly vegetated country subject to slope instability. Four phases of aeolian sand deposition have been dated in Fernhill Gully spanning a period 23,000-2,000 yrs BP (Coventry and Walker 1977).

Alluvial deposits (TQa)

Sediments laid down by alluvial processes are (a) alluvial fans (b) flood plain deposits and (c) stream channel deposits.

Alluvial fans are common along the Lake George escarpment where streams flow onto alluvial flood plains bordering Lake George. They form cone-shaped deposits with convex surfaces; sediments show a wide size range of poorly sorted angular to subangular locally derived rock fragments. Below a height of about 36 m a.l.b. many alluvial fans are interbedded with lacustrine beach deposits of rounded and subrounded pebble gravel. Alluvial fans build out gradually from colluvium. Coarse poorly sorted depositional lobes are laid down below the feeding gullies during periods of floodwater runoff (Fig. 8). The origin of these deposits is complex but a model for contemporary fan growth along the Lake George escarpment is given by Wasson (1974).

Alluvial fans are of two types (a) old (b) young. Towards the northern and southern margin of the basin older colluvial-alluvial fans occur along the base of the Lake George escarpment. These fans coalesce to give bajada with a surface area of about a square kilometre. Sediments become finer towards the toe of the fan. Many show two or three terraces; the oldest terrace is the remains of the earliest part of the fan deposited and may support a strongly differentiated podzolic soil profile. At lower terrace levels soil profiles are weakly developed on account of limited subearial exposure time between lake level stands. A longer and more complex history is reflected by the radiocarbon dates from deposits at the northern end of the basin which range from 26,840 (+2860 - 2100)y BP to 2380 $\pm$ 360y BP (Coventry and Walker 1977).

Younger fans occur along the part of the Lake George escarpment near the lake. These fans do not coalesce and are no more than 0.25 sq kms in area. The size of fan is proportional to the size of its catchment. They show little downfan differentiation in clast size, shape and sorting and thickness rarely exceeds 10 m. Terraces set into these fans only show weakly differentiated podzolic soil profiles. Deposits in two of these fans south of Gearys Gap have been dated by Coventry and Walker (1977) as 1630 $\pm$ 110y BP and 2350 $\pm$ 75y BP. The younger fans consist of alluvium deposited at times of low lake levels in the Late Quaternary.

Flood plain deposits comprise sediments in alluvial embayments surrounding Lake George (Fig. 4). These sediments have not received detailed study but their considerable complexity is revealed by drillholes in the Turallo Creek flood plain near Bungendore and the Montrose-Willeroo alluvial plain west of Woodlawn Mine. The floodplain sequence probably contains two systems of horizontally bedded deposits (Fig. 9). The lower sequence contains weathered, well sorted pale grey coarse-grained sand and gravel interbedded with thin clay layers. These sediments are confined to erosion channels in bedrock and are channel deposits. The upper sequence comprises a complex of brown, yellow and white clay with beds of poorly sorted subangular sand and gravel; the colour variation results from weathering. The sequence shows considerable vertical and lateral variability and is regarded as fluvio-lacustrine in origin. Unpublished data (G. Singh pers. comm 1983) based on plant microfossils suggest these sediments range into the Tertiary.

Stream channel deposits of present day creeks. Although the creeks appear to be underfit they have been able to incise their courses into the surrounding floodplain (Fig. 9). The more active streams are currently developing small deposits of point bar sands in the convex portions of meander loops eg. Butmaroo Creek. A few old meander scars define the narrow width of their channel floodplains. Beach drift along the eastern shore of Lake George has caused a deflection in the northwest-flowing course of Butmaroo Creek. The creek has extended its course and now forms a small delta into Lake George about 1 km southwest of its original entry point. Elsewhere fluvial processes are active enough for major creeks to cut across lacustrine strandline features and construct small deltas into Lake George. The extension of such drainage systems appears to be a response to receding lake levels.

MODERN ENVIRONMENT

A uniquely sensitive environment exists in the Lake George basin. The area represents an interface between natural sedimentary and hydrological processes and resource development resulting from the impact of human culture. The modern basin environment is broadly divisible into (a) marginal areas bordering Lake George which are largely erosional and represent the greater portion of the basin and (b) a fluvio-lacustrine depositional environment around Lake George.

Marginal areas

Based on the observation of early explorers and settlers the landscape in marginal areas consisted of well-wooded, eucalypt covered terrain (relics of which still remain). The terrain was drained by streams converging onto well grassed alluvial plains surrounding Lake George. The occurrence of fragmentary charcoal in the late Quaternary sediments suggests bushfires may have affected the landscape at times. Stone tools and fire hearths of aboriginal culture have been found on some of the undisturbed strandline ridges marginal to the lake and an aeolian deposit at the eastern limit of the basin. However studies and documentation of aboriginal culture in the basin has only begun recently.

The appearance of the largely erosional present day environment reflects in large measure the impact of European culture on the landscape. Subdivision of the land followed by extensive clearing of vegetation for grazing and cultivation has led to land quality deterioration and erosion gullying particularly in areas blanketed by colluvial and alluvial slope deposits. In more recent times the expansion of Canberra and Queanbeyan has placed continuing demands on building materials. Currently open cast pits extract sand and gravel from strandline and aeolian deposits situated around the northern and southern margins of Lake George. This activity has led to the deterioration and in some cases disappearance of natural vegetation and landforms associated with these deposits. Fortunately as quarrying operations are completed the authorities undertake restoration work by replanting grass and native tree species.

Fluvio-lacustrine areas

Lake George is an intermittent lake which is sensitive to climatic change. A composite lake hydrograph based on historical records from 1818-1977 is given in Jacobson and Schuett (1979). Water level fluctuations show changes in response mainly to rainfall, evaporation and runoff. During historical time the lake has completely dried out on a number of occasions; the most recent being for an approximate 8 month period, July 1982-March 1983. Lake George is a shallow turbid body of water with a depth rarely exceeding 5 m. Large scale wave-like oscillations terms seiches have been measured on the lake; a typical example is given in Figure 10. Seiche measurements indicate periods up to 2 hrs and temporary changes in level in excess of 15 cm leading to an advance and retreat of water over distances of 2 km (Burton, 1972).

Lake George is not a typical saline lake. Jacobson and Schuett (1979) show that the salinity of lake water varies inversely with water volume. Records for October 1961 to January 1973 show salinity ranging from 1183 mg/litre to 36,960 mg/litre TDS. The NaCl rich water is more saline than the bicarbonate rich creek and groundwater. The variable salinity of the water is not conducive over extended periods to the support of animal and plant life in the lake and bottom sediments. Nevertheless historical records (Taylor, 1907) show the lake can support fish life in periods when water volumes are high and salinity levels low. Gastropod, ostracod tests and vertebrate remains have been recorded from core in the upper few metres of bottom sediment (Singh et cl., 1981 and De Dekker, 1982).

The area in and around Lake George represents the base level for deposition in the basin. Clastic sediment supply to the lake area is contributed mainly by bedload sediment deposited as small deltas from creeks draining into Lake George (see Fig. 4). Colluvial and alluvial sediments along the western escarpment may be deposited directly into the lake, washed out onto the lakebed by alluvial processes or be eroded by wave action and redistributed in the lake. In "lakefull" conditions suspended sediment may be distributed by currents in the lake. In dry lake bed conditions sediment may be redistributed by wind until fixed by a grass cover which quickly establishes itself during dry phases. The lake area is not an environment favourable for the deposition of sediments by chemical and biological processes.

When the lake dried out in July 1982 it was possible to observe some of the sedimentary processes operating on the dry lake bed. Trend lines apparent on the dry lake bed from BMR aerial colour photography were interpreted as regressive water level stands as the lake dried out towards its deeper eastern margin (Fig. 4). Mudcrack systems with polygonal patterning were widespread on the lake bed. Following a classification of Plummer and Gostin (1981) the dessication mudcracks at Lake George probably formed by tension induced by shrinkage of muddy sediment as the lake dried out.

During the latter part of 1982, clay dunes were observed to form during windy spells. During this time dunes formed as thin discontinuous ripples slightly crescentic in shape, about a metre long, 20 cm in width and 5 cm in height. They were oriented north-south and transverse to prevailing westerly winds. Dunes were distributed in an en-echelon pattern over the middle and eastern portion of the lakebed. In the terminology of Bowler (1973) they are classified as thin ripple-layered lunettes with smooth crescentic margins. The dunes were composed of sand-sized aggregates of clay pellets formed by the mechanical disintegration of mudcurls. The transport of clay pellets into dunes was achieved by wind driven saltation. The role of salt in the formation of dunes is not clearly understood but it is possible that salt efflorescence contributes to the breakdown of clays. After rainfall dunes stabilise quickly by the hygroscopic absorption of moisture by salt. Dune build up was terminated in early 1983 by rain and flooding.

Dust storms on the lakebed in late 1982 were severe on several occasions. The quantity of fine material carried by wind caused a loss of visibility sufficient to stop drilling operations. From the magnitude of these storms it is quite possible that aeolian processes if persistent long enough might remove significant quantities of fine sediment and salt eastwards from the lake bed (Jacobson and Schuett 1979, Jennings 1981).

1982-83 DRILLING PROGRAM

A six month drilling program at Lake George started in November 1982 and was terminated in May 1983 by wet weather. The drillhole locations are shown on Figure 11 and a summary of the drilling information is given in Table 2. Total metreage drilled was 1621.2 m. Total thickness cored in 8 holes was 876.6 m and overall recovery obtained was 67.8%. Core recovery was generally better in clay/silt lithologies than sand/gravel. Detailed drilling logs for holes C351, 352, 353, 354, 355, 358, 359 and 360 are shown in microfiche (Appendix 2). Some of the core was colour coded using a Japanese standard soil colour chart based on the Munsell system. The core was also sliced thinly and a cylindrical sample weighing 3-4 gms was taken at 25 cm intervals where recovery and core quality permitted. A total of 1695 samples were taken from 6 holes (Table 2). Some samples have been analysed by X-ray diffraction for clay and non-clay mineralogy (holes C353 and C354) and by emission spectroscopy for major elements (C354). The results and interpretation of this part of the investigation will be reported separately by R. Abell, J. Fitzsimmons and T. Slezak (BMR publication in preparation). A few samples were processed and analysed for palynology by E. Truswell (Appendix 1). Co-ordinates and levelling of the drillholes was undertaken by P. Boersma and staff of the Australian Survey Office, Canberra.

Table 2. Summary of Drilling Data

Hole No.	Co-ordinates (1:100,000 scale)	Height (m)	Depth (m)	Thickness Cored (m)	Recovery %	Geophys. Logs Gamma	Geophys. Logs Neutron	Nos. Samples
C351	721003/611319	673.2	131.5	87.7	66.9	x	x	-
C352	719914/611340	673.4	163.0	143.8	72.4	x	x	-
C353	718890/611360	673.6	160.2	125.2	51.2	x	x	231
C354	717882/611378	674.0	197.5	165.0	78.4	x	x	500
C355	716932/611398	674.2	139.5	95.2	38.3	x	x	134
C356	722033/611306	673±.2	157.0	-	-	x	x	-
C357	721207/611616	673.4	168.5	-	-	x	x	-
C358	719306/611653	673.6	129.0	116.7	75.3	x	x	358
C359	720279/611633	673.6	84.5	77.4	79.1	-	-	255
C360	718035/611677	674.0	74.0	65.6	81.3	x	-	217
C361	719051/610841	673.2	96.4	-	-	x	x	-
C362	719434/610990	673.2	132.8	-	-	x	-	-

Geophysical logging

In the 1982-83 drilling program gamma ray and neutron logging was used to assist in (a) the recognition and confirmation of lithologic and stratigraphic boundaries (b) location and definition of aquifers and (c) provide extra lithologic data from poorly recovered portions of drillholes. Once a lithological correlation was established against the geophysical logs from the earlier cored holes it became easier and quicker to drill uncored holes and interpret the lithology directly from gamma and neutron logs. Downhole geophysical logs for BMR drillholes in the Lake George basin are listed in Table 2 and in Figures 26-28 and 36-47. A selection of water bores north and west of Bungendore were logged in 1980 (Figures 29-35).

Considerable time was spent attempting to equate the depths of lithological and stratigraphic boundaries from drilling and geophysical logs. The poor initial correlation was attributed to cable stretch on the logging equipment or inaccurate conversion of imperial to metric units on the depth recorder. An approximately depth correspondence was eventually achieved which is accurate to within a limit of a metre. The adjustments have been made on the log charts listed under Figures 36-47 but for further detail on lithology the microfiche drill logs should also be examined.

Efforts to obtain electric logs (spontaneous potential and resistivity) were unsuccessful. In earlier drilling programs conducted under similar geological conditions this type of log was recorded in holes C294, C295, BMR Scouthole No 1 (see Figs. 26-28) and by Woodlawn Mines from water bores in the Montrose-Willeroo alluvial plain. The lack of success during this investigation may have been equipment error, or downhole saline ground water and mud minimising lithologic contrasts in the unconsolidated sedimentary sequences. Emerson and Haines (1974) have discussed this problem and note that more research is needed on the chemical behaviour of muds and formation of fluids and how they respond to electric logging devices; the nature of invasion processes in unconsolidated sediments is also poorly known.

High radioactivity levels at depths of 35-45 m have been recorded in an abandoned borehole (WRC 31363)1 km north northwest of Bungendore (Fig. 35). The high gamma counts correlate with two thin clay beds locally distributed in sand and gravel close to a palaeodrainage line near the base of the Cainozoic sequence.

GEOLOGICAL RESULTS

BEDROCK

During the investigation all drillholes except C359 penetrated to bedrock. In the uncored drillholes (C356, C357, C361 and C362) bedrock depths were interpreted from geophysical logs. Fresh bedrock was identified in 3 holes (C352, C353 and C355). Prior to this investigation weathered bedrock (saprolite) had been cored in BMR Scouthole 1 and fresh bedrock in BMR drillholes C294 and C295.

Nature of Sediments

In most places bedrock consists of interbedded phyllite, siltstone and quartzite of probable Ordovician age. The weathered portions of the sequence are soft and friable. Where fresh, the harder pale grey quartzite units grade into dark grey and green laminated siltstone and phyllite. Cleavage is well preserved in the finer units. Rocks of similar type have been encountered in water bores around Bungendore and in the Montrose - Willeroo alluvial plain. There is no evidence in the cores of Silurian volcanics, Devonian acid intrusions or Tertiary basalts. Red and yellowing-brown ferruginous and pale grey kaolinitic weathering profiles are well preserved. Bedding laminations subparallel the cleavage and dip at angles of 50-70°; manganese staining is common on cleavage planes. Ferruginous colour banded weathering structures are common and dip at lower angles (<50°) than bedding-cleavage structures.

Delineation of boundary

The weathered bedrock boundary can be satisfactorily determined from core and downhole gamma and neutron logs. In cores the top of weathered bedrock is placed where cleavage and/or bedding can be positively identified. Using gamma ray logs the bedrock boundary is normally picked where there is a substantial increase in natural radiation at the base of the Cainozoic sequence. Compared with lacustrine clays, the higher radiation levels in weathered bedrock clays suggest they are more efficient at selectively fixing K^+ ions to increase the natural radionucleide Potassium-40. A low neutron count (decreased hydrogen index) also typifies the weathered bedrock boundary. In partly cored BMR Scouthole C1 the depth to weathered bedrock was resolved from gamma ray and resistivity logs. Fresh bedrock is easily recognised in core. In uncored drillholes C357 and C356 fresh bedrock was identified by a gross decrease in gamma ray activity and increase in the neutron count.

Near Bungendore and west of Woodlawn mine surface geophysics has been used to trace the topography of the bedrock surface in an attempt to locate buried river channels. A variety of techniques have been used including seismic refraction, resistivity, gravity and induced polarisation. These techniques pick with reasonable accuracy the depths to fresh bedrock but the top of the weathered bedrock profile is more difficult to detect. Identification of this boundary is hampered by deep weathering in pre basin fluvial sands and gravels which penetrates down into underlying bedrock. Unpublished information from water supply investigations around Bungendore indicate that the seismic refraction method can pick this boundary. Re-examination of seismic refraction profiles at the northern and southern ends of Lake George (Polak and Kevi, 1964) suggest a gradual increase in seismic velocities with depth (0-3,000 m/sec). From this data it appears the weathered top of the bedrock profile is a diffuse zone which cannot be accurately defined. By comparison the fresh bedrock boundary is clearly shown by a sudden increase in seismic velocity from 3,500 to 5,000+ m/sec.

Topography

The bedrock topography beneath Lake George is depicted by structure contours drawn at the base of the Cainozoic sequence (Fig. 12). Structure contours were compiled from depths at which weathered bedrock was struck during drilling (all depths were converted to metres above sea level). Beneath the lake bed the structure contour map shows the preservation of a moderately dissected landscape with buried relief reaching up to 100 m. Converging towards Gearys Gap is a palaeodrainage system that lines up with the direction of modern drainage entering the lake.

Geophysics (mainly induced polarisation) and drilling by Jododex (Aust) Pty Ltd has outlined two narrow erosion channels in bedrock at the western margin of the Montrose-Willeroo alluvial plain. The channels have lengths in excess of 1000 m and widths of 100-150 m; bedrock depths in these channels range from 38-56 m below ground surface. Around Bungendore, WRC (Sydney) have delineated a similar buried channel by surface geophysics and water bore drilling. The channel is outlined as a narrow sinuous valley trending north northwest beneath the line of Turallo Creek (Fig. 12).

The channel reaches a depth of about 50 m below ground level in its narrowest portion, a width of up to 150 m and a length of 4000 m. Palaeodrainage does not enter the lake from the north because Collector and Tarago creeks drained northwest to the Lachlan river prior to the formation of the basin.

STRATIGRAPHY

A summary of the Cainozoic stratigraphy based on the deepest hole C354 is given in Figure 13. The sequence is provisionally divided into two lithostratigraphic units: a lower, Gearys Gap Formation and an upper, Lake George Formation. The availability of these names is still subject to the reservation procedures for stratigraphic units as laid out by the Stratigraphic Nomenclature Committee. Figures 14 and 15 depict these units in cross sections on two lines extending from the Lake George escarpment eastwards onto the lake area.

The sites of lacustrine and fluvial deposition have changed continually with progressive infilling of the basin often causing abrupt facies changes. Descriptions and correlation of the stratigraphic units which follow are based largely on the subjective interpretation of drillcore evidence. Lateral recognition and extent of these units beyond the limits of the section lines and marginal to Lake George is poorly known.

Gearys Gap Formation (new name)

(a) Derivation - named after Gearys Gap, a low saddle on the Lake George escarpment about halfway along the western watershed of the basin.

(b) Nomenclature - at this stage the Gearys Gap Formation is informally divided into upper and lower units. In cored holes the top of the deep weathering profile defines the top of the lower unit; in uncored holes it is arbitrarily placed at the top of the thickest sand and gravel beds in the sequence. These fluvial sediments appear to pass transitionally across the weathered boundary into finer fluvio-lacustrine sands and clays of the upper unit. An expected diastem or disconformity at the weathered boundary was not observed in the core. Lack of evidence of this hiatus relates to poor core recovery and weathering processes which have degraded the structure and texture of the sediments. Since the stratigraphic parameters of the lower unit beneath the lake bed are poorly known, it is currently grouped within the Gearys Gap Formation. As more subsurface data becomes available it is expected that the lower part of the Gearys Gap Formation will warrant re-definition as an older formational unit predating the stratigraphy of the Lake George Basin.

(c) Distribution - the lower portion of the unit maybe identified with a patchy outcrop distribution of ferruginous quartz gravels exposed on the escarpment near Gearys Gap, a silicified gravel (silcrete) outcropping on the western shore of Lake George and sediments in palaeodrainage lines. The upper part of the unit is only known from core obtained in drillholes on the lake bed.

(d) Type section - a representative section is not exposed. Core recovery from this formation is generally poor. The type section is designated by the best recovered intervals of core from the drillholes as given in Table 3.

Table 3. Type section intervals for the Gearys Gap Formation

HOLE	CORE INTERVALS (m)
C351	36.0 - 48.2
	53.5 - 55.0
C352	42.5 - 48.0
	54.0 - 57.5
	62.0 - 84.0
	95.5 - 100.0
C353	58.0 - 71.0
C354	116.5 - 132.0
	135.5 - 149.5
	160.0 - 164.5
C358	43.5 - 59.0
C359	42.0 - 58.5
C360	49.0 - 58.0

(e) Lithology - the formation consists of sand, gravel, clay and silt. Lithological change is well defined by gamma and neutron logs. A few beds are cemented but generally the formation is characterised by a lack of hard pan layers. A possible distribution of sand and gravel beds in the formation is shown in the lithostratigraphic sections.

The formation in its lower part comprises se-grained sand and gravel with minor carbonaceous clay and silt in eds. Sand and gravel beds which may reach a thickness of 15 m are posed of subangular quartz and lithic clasts up to 4 cm in size. Near base of the formation silt or clay grading up into coarse-grained sand an avel may represent reverse graded units. In hole C354 at a depth of 1 -53 m strongly ferruginous gravelly clay containing subangular lit clasts of kaolinised shale, silt and sand may represent a local colluvial ies near the base of the sequence. Greyish white sandy clay, sandy silt d sand at a depth of 110-153 m is similar to drill log descriptions of f al sediments from palaeodrainage lines in the Montrose-Willeroo plain. erruginisation is associated with a thick kaolinitic weathering profil hich affects both the lowest Tertiary sediments and the Palaeozoic bed k. The top of this deep weathering profile may correlate with a discon ity and strong zone of oxidation recorded at a depth of 50-51 m in C4 (gh et al., 1981).

Towards the top, the sedimentary sequence f s gradually upwards to mottled, laminated and gravelly clay and silt; s of the fine grained sand beds may be aeolian. Normal graded sand units common in the upper parts of the sequence. Reddish brown ferruginous we ering profiles occur intermittently near the top of the formation.

(f) Boundary relationships - the base of the Gearys Gap nation was deposited on an irregular bedrock topography. The marked uncor rmity suggests a long period of weathering and erosion preceded deposition the Cainozoic sequence. The Gearys Gap Formation is conformably ov lain by the Lake George Formation; the upper boundary is taken at the highe and most persistent sand bed in the sequence which can be picked on gamm d neutron logs. Along the western margin of the basin the formation abuts a nst the eastern margin of the Lake George fault; its lateral extent the north, south and east is unknown.

(g) Thickness - as the formation was deposited on an irre lar bedrock topography thickness variations are commonplace. Where drillhol have penetrated topographic lows, a maximum thickness of 110 m (C354) s been recorded. On topographic highs the unit thins abruptly to a mi um thickness of 15 m. Sand units are thicker in palaeodrainage lines, but o rwise tend to thicken towards the eastern margin of the lake area.

(h) Environment of deposition - fluvio-lacustrine. The fluvial sediments in the lower part of the Gearys Gap Formation suggest floodplains with braided and point bar sands and gravels. The thick ferruginous and kaolinitic weathering profile indicates that widespread lacustrine conditions did not exist in the older pre-basin landscape.

Towards the top, a gradual decrease in thickness of normal graded sand units and increase in clay represent a change from fluvial to lacustrine conditions. In the wetter lacustrine environment, weathering profiles become thinner and more intermittent suggesting fluctuating wet and dry climate.

(i) Age - the precise age of the Gearys Gap Formation is presently unknown. Macrofossils were not found in the core but carbonaceous clays above and within the deep weathering profile provide datable material for palynology (E.M. Truswell - Appendix 1). Pollen assemblages suggest a probable late Miocene age for the uppermost part of the formation. However a portion of the valley fill sediments in the palaeodrainage lines may predate the formation of the Lake George basin suggesting that the lowest part of the Gearys Gap Formation may be early Miocene or older.

(j) Correlation - the lower part of the Cainozoic stratigraphy outlined in Figures 13, 14 and 15 was not recognised in drillholes C4 and LG4. Singh et al. (1981) describe lacustrine clays to a depth of 72 m in C4. The sandy layer defining the upper boundary of the Gearys Gap Formation appears to be absent. The core recovery levels in C4 suggests that sand does not increase in the lower parts of the sequence. The discrepancy in correlation with the northern holes may be explained by rapid facies variation over short distances or the non-deposition of fluvial sands and gravels.

Beyond the limits of the lake area fluvial sediments in buried river channels in the Montrose-Willeroo plain and north of Bungendore correlate with lower portions of this unit. High level ferruginous quartz gravels exposed near the Molonglo River southwest of Hoskinstown and the Yass river in the vicinity of Gundaroo (Abell, 1982) possibly correlate with basal quartz gravels of the Gearys Gap Formation.

In other highland areas of New South Wales late Tertiary lacustrine sequences at Cadia and Kiandra (Owen, 1975) and at Lake Bunyan (Tulip, Taylor and Truswell, 1982) may, in part correlate with the Gearys Gap Formation.

Lake George Formation (new name)

(a) Derivation - named after Lake George, NSW.

(b) Distribution - outcrops of the unit approximate to the modern day extent of the lake.

(c) Type section - a representative section is not exposed. It is proposed that core from BMR stratigraphic hole C354 is designated the type section for the Lake George Formation. From the surface a thickness of 54 m of clay and silt was recovered (mostly in excess of 90%) representing the thickest part of the formation so far drilled in the basin. A detailed description of the upper 36 m of this formation in LG4 is given in Singh et al., (1981)

(d) Lithology - the formation consists of three litho-types - (i) colour-mottled clays, (ii) gravelly clay with quartz and lithic clasts, and (iii) clays with colour, carbonaceous or silty laminations. Colour varies in shades of grey, green, olive and black. Reddish-brown ferruginous weathering profiles occur intermittently through the sequence. High gamma counts in C358, C361 and C362 denote the local distribution of above average radioactivity levels in the clay at depths of 6-8 m.

(e) Boundary relationships - the base of the Lake George formation is not exposed but is taken to be at the top of the highest and most persistent sand bed of the Gearys Gap Formation. The top of the unit is the lake bed, exposed when the lake dries out. The upper part of the formation grades laterally into sands and gravels of strandline features crossing alluvial embayments at the north, south and east margins of the lake area. Westwards the unit grades laterally into alluvial fans and colluvial slopewash deposits at the base of the Lake George escarpment.

(f) Thickness - maximum known thickness is 54 m as recovered in drillhole C354. The unit thins towards the margin of the lake area.

(g) Environment of deposition - lacustrine depositional facies. Four subfacies are recognised:

- horizontal, plane laminated clays deposited by vertical sedimentation from suspension in a low energy environment below wave base. Some low angled colour and silty laminations (approx 5°) suggest differential compaction over buried relief.

- colour-mottled unlaminated clays in shades of green, grey and blue are typical of hydromorphic clays (gleys). These clays form typically in waterlogged conditions undergoing reduction. Disruption of lake bottom sediments by wave action, seiche activity or bioturbation may also give mottled textures.
- ferruginous colour-mottled and banded clays related to oxidation and pedogenesis during periods of prolonged dry lake conditions.
- gravelly clay originating as colluvial slopewash from the escarpment and then redeposited on the lake bed by stream and current action.

Late Quaternary palaeoenvironments in the Lake George Formation have been studied from core in LG4. The upper 8.6 m covering the last 350,000 years gives a sequence of vegetation and climatic changes indicating four glacial/interglacial cycles (Singh et al., 1981). The early part of this story going back 60,000 years is verified in the upper 3 m of core by the ostracod ecology (De Dekker, 1982) and finds agreement with the history of lake level fluctuation proposed by Coventry (1976).

(h) Fossils and age - the fossil content is mainly plant microfossils, gastropod shells and ostracod tests. The flora and fauna in the upper 8.6 m of the Lake George Formation has been studied in detail by Singh et al., (1981) and De Dekker (1982). W.F. Ponder (pers. comm, 1983) has identified gastropod shells in this unit as a species of Coxiella, *C. striata* (Reeve 1842). He notes the genus is confined to salt lakes and the head of very saline estuaries e.g. St Vincents Gulf.

Based on the magnetostratigraphy obtained by Singh et al. (1981) from 36 m of core in LG4, the upper 27 m of the Lake George Formation is judged to be Quaternary in age and the remainder Pliocene. The extrapolated middle Miocene or older age for lacustrine sediments in C4 given by Singh et al. (1981) does not reflect a maximum age of the Lake George Formation. The base of this unit was not recognised and bedrock was not reached in this hole. Further palaeomagnetic work is required to resolve the age of the sediments in the lower part of the Lake George Formation.

(i) <u>Correlation</u> - the Lake George Formation lithologically correlates with sediments in other perched drainage basins associated with normal faulting. Sediments retrieved from BMR core in the Lake Bathurst drainage basin adjacent to the Mulwaree fault have been dated by palaeomagnetism to the Brunhes - Matuyama transition (730,000 years BP). Other reversals noted below this transition suggest a likely Pliocene-Pleistocene age for this basin (D. Gillieson, pers. comm. 1984). Near the Murrumbidgee Fault an undated sequence of surficial sediments of probable late Tertiary ? - Quaternary age have been described in the Lanyon basin (Kellett, 1981).

WEATHERING

Field observation and drilling show that a long and complex weathering history is preserved in the Lake George basin (Figs. 16 and 17). A deep weathering profile in the older parts of the Cainozoic sequence and underlying bedrock consists of related iron-rich and kaolinitic zones. Intermittent, poorly differentiated ferruginous weathering profiles occur in the younger parts of the Cainozoic sequence.

Deep Weathering

A deeper profile which once covered most of the region is preserved in a few surface patches and beneath the sediments of Lake George. A deep weathering profile crops out on the watershed separating the Lake George and Molonglo drainage systems. In brick shale pits and drainage ditches along the Bungendore-Hoskinstown road south of Woodlands kaolinitic and ferruginous weathering occurs in Palaeozoic sediments. The weathered profile also affects Tertiary gravels exposed on top of the Lake George escarpment and further west in the valley of Shingle House creek.

The strongly leached weathering profile exposed in sections at the northern end of a pit close to the Bungendore-Hoskinstown road (MR 210/870 - photo 3) consists of uniformly kaolinised beds of cleaved pale grey and white shale and sandstone. Ferruginous reddish-brown and purple colour banding cross cuts or parallels bedding planes. An upper soil profile with an abrupt boundary at the base is probably a younger pedogenic sequence unrelated to deep weathering. Fresh rock is not exposed in any of the pits, but deep weathering has penetrated to a depth of at least 50 metres.

In the brick shale pits there are good exposures of colour banded weathering structures. The commonest type are the regularly spaced structures which average 10 cm in thickness. They consist of bands of enriched iron about 1 cm thick which progressively develop into a zone of depletion where iron is reduced and concentrated in thin laminae about 1 mm thick. There is no refraction of colour bands as they pass across lithological boundaries, but they may be deflected by joints and fractures (photo 4). There are few geological investigations given authoritative leads on the origin of colour banding phenomenon in weathered profiles. In a review of the literature (Ollier 1967, 1971) suggests some form of physico-chemical diffusion process (similar to that postulated for Liesagang rings), operating in a zone of groundwater fluctuation explains the alternating iron enrichment and depletion zones. In the brick pits it appears that the source of iron necessary for the formation of colour banding may be quartz-iron oxide veins which on weathering release iron hydroxides into the groundwater system. The mobility and rhythmical precipitation of limonitic iron relates to a zone where watertables have fluctuated in response to short term climatic change in the Quaternary.

The deep weathering profile increases in thickness northwards to Lake George where it reaches in excess of 90 metres in drill hole C354. The thickness of deep weathering at the northern end of the Lake George Basin is unknown. The ferruginous portion of the profile contains sesquioxides of iron (haematite and limonite) and occasional manganese. The underlying pallid kaolinitic zone sometimes with pale brown iron mottling and colour banding occurs in pre basin fluvial sediments and penetrates down into bedrock. In hole C354 the pallid zone is divided by a strongly ferruginous clay containing kaolinised lithic clasts. The base of deep weathering appears to have a relatively abrupt boundary with fresh rock. Repeated episodes of deep weathering are suggested by its thickness, compositional complexity and lack of hard pan layers. Following the weathering model of Mann and Ollier (in press) it is postulated that in the pre-Lake George landscape this deep weathering profile formed by progressive upward vertical migration of iron solutions from a bedrock weathering front (the original source of iron) to the water table where iron is precipitated. The protection of the deep weathering profile by a cover of late Tertiary-Quaternary sediments has prevented further sub-aerial weathering.

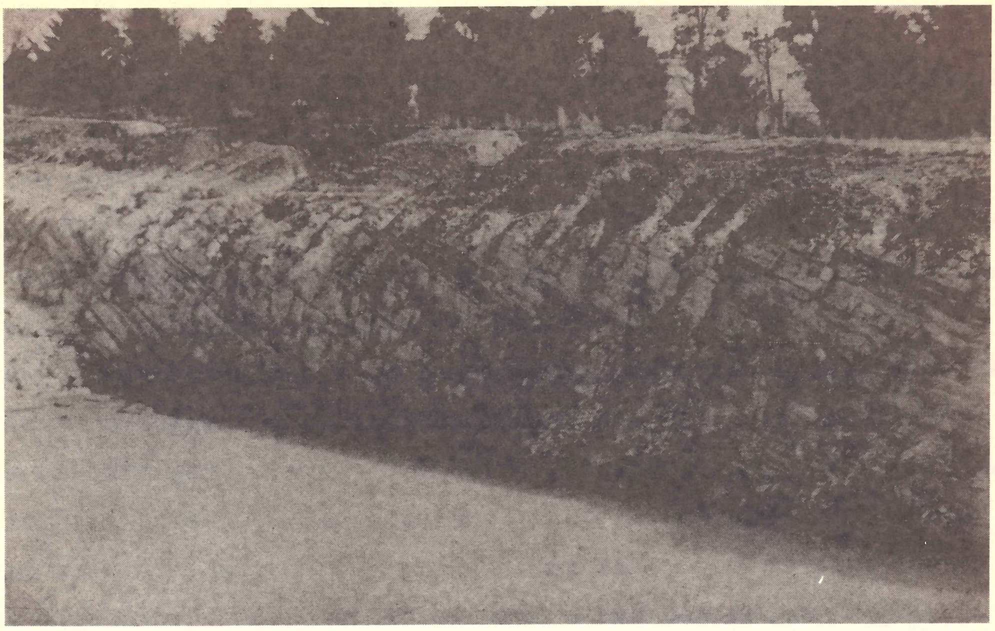

Photo. 3 Deep weathering profile. White kaolinitic quartz-rich turbidites overlain by brown ferruginous soil. Abrupt planar boundary cross cuts bedrock structure

Photo. 4 Regularly spaced colour laminated weathering structures in deeply weathered bedrock

contains sesquioxides of iron (haematite and limonite) and occasional manganese. The underlying pallid koalinitic zone sometimes with pale brown iron mottling and colour banding occurs in pre basin fluvial sediments and penetrates down into bedrock. In hole C354 the pallid zone is divided by a strongly ferruginous clay containing kaolinised lithic clasts. The base of deep weathering appears to have a relatively abrupt boundary with fresh rock. Repeated episodes of deep weathering are suggested by its thickness, compositional complexity and lack of hard pan layers. Following the weathering model of Mann and Ollier (in press) it is postulated that in the pre-Lake George landscape this deep weathering profile formed by progressive upward vertical migration of iron solution from a bedrock weathering front (the original sources of iron) to the water table where iron is precipitated. The protection of the deep weathering profile by a cover of late Tertiary-Quaternary sediments will prevent further sub-aerial weathering.

Deep weathering can be equated with an early or even pre-Tertiary landscape surface and it is also probable that contemporaneous weathering and sedimentation occurred during the early depositional history of the basin. The top of the profile is in fluvio-lacustrine sediments in the Gearys Gap Formation prior to the formation of Lake George. A similar deep weathering profile was penetrated by drillholes C296 (MR 197/818) and C297 (MR 178/820) in the Molonglo Flats north west of Hoskinstown. Palaeomagnetic measurements (remanence inclination) were done on a small number of core samples in an attempt to date the profile. M. Idnurm (pers. comm. 1983) reports that magnetisation directions in Cainozoic sediment and bedrock samples containing haematite were found to be stable. Results fall into two distinct groups suggesting mid and late Tertiary ages for the profile. In other local areas a mid-Tertiary weathering event has been dated on the Shoalhaven Plain (Ruxton and Taylor, 1982) and a late Tertiary event near Cooma (Schmidt, Taylor and Walker, 1982). In southwest Queensland, Idnurm and Senior (1978) have weathered profiles palaeomagnetically dated to the early and mid-Tertiary. In the Lake George basin pollen and spore retrievals from clay layers near the top of this deep weathering profile give preliminary ages of Late Miocene (Truswell - Appendix 1) suggesting the later portion of the profile in the basin may be late rather than mid-Tertiary. This is supported by evidence from hole C4 where the top of the major deep weathering profile represents a disconformity and the end of widespread humid conditions 5-6 million years ago near the Miocene-Pliocene boundary (Singh et al., 1981, Bowler, 1982).

Intermittent weathering

A series of ferruginous weathering profiles occur in the upper part of the Gearys Gap Formation and the Lake George Formation. These profiles as logged in drillcore range from about 0.5-7 m in thickness. Across the basin they show broad zones of correlation as individual profiles or groupings of weathering units. Mottled zones of pedogenic iron enrichment and lack of in situ kaolinization characterise this weathering pattern. The process relates to alternate oxidising and reducing conditions that developed when water tables were fluctuating.

STRUCTURE AND TECTONICS

The regional landscape prior to the Cainozoic was a broad deeply weathered plain dating back possibly to the Permian. This terrain was modified by Tertiary faults which formed small Cainozoic basins along the highland crest of southeast Australia. The tectonic modification of this landscape in the local region is exemplified by the Murrumbidgee, Lake George and Mulwaree faults which form a series of subparallel and meridionally trending linear escarpments. Fluvio-lacustrine deposits along the eastern margin of these escarpments show that drainage lines have been strongly modified by these faults. The landscape therefore bears signs of ancient topography, to some extent controlled by ancient structures and younger features related to Tertiary faults.

Bedrock structure

In the Lake George basin, bedrock structures have originated from the late Palaeozoic deformation of the Captain Flat Trough (Abell, 1981). Complex folds with associated cleavage and foliation indicate more than one orogenic episode. The meridionally trending Lake George and Ballallaba fault zones (Fig. 4) were also initiated in the late Palaeozoic. Basic intrusions and volcanics associated with these faults point to their being deep seated structures typical of an old rift zone.

Normal faulting (Taylor 1907, Ollier 1978)

The Lake George basin resulted from mid-Tertiary downfaulting. The fault plane cannot be located in the field because the base of the escarpment (the site of the fault) is blanketed by colluvial and alluvial fan deposits. However, the Queanbeyan fault which also forms a major escarpment can be seen in an abandoned road cutting immediately east of Queanbeyan. Assuming that quartz gravels at the top and bottom of the Lake George escarpment (Fig. 5) are correlatives, then a minimum displacement for normal faulting with a downthrow to the east is approximately 100 m, an estimate which is in close agreement with Taylor (1907). Based on the relative heights of the Ordovician bedrock surface in drillcore shown on the section lines (Figs. 14 and 15) and on the escarpment, a more realistic minimum displacement would be 280 m. In broader terms Jennings (1972) states the escarpment does not show the geomorphic character of a young reverse fault such as small superficial normal faults through failure of the hanging wall. Morphotectonic evidence of young relief associated with normal faulting is demonstrated by the fault-line scarp, the remnant of a broad topographic depression (wind gap) at Gearys Gap and the barbed drainage of creeks flowing into the northern end of Lake George.

Reverse faulting (Jennings, Noakes and Burton, 1964)

A high angle reverse fault is exposed in a railway cutting close to the Kings Highway about 8 km south of Bungendore (Wilson, 1964; Crook & Powell, 1976). This fault was once regarded as indicating a reverse fault origin of the Lake George fault scarp. A late Palaeozoic age of the fault is indicated by the late Silurian - early Devonian? Captain's Flat Formation which overlies the younger Carwoola Formation (Abell, 1982). Since Tertiary rocks do not outcrop in the immediate vicinity and there is no topographic break, it is concluded that this fault was not reactivated during the Tertiary.

Warping. (Garretty, 1937)

Warping across a north-flowing river has been invoked at various times as a mechanism for basin formation (Garretty, 1937; Jennings, Noakes and Burton, 1964). Sediments are thickest in the Gearys Gap area, the postulated downwarp, but this is the location of most landscape lowering before faulting and progressive infilling by lacustrine sediments. The series of structure contour maps (Figs. 18 and 19) indicates a buried landscape with old river courses now protected by overlying sediments. As irregularities in the older landscape were infilled with sediment, palaeosurfaces became smoother and palaeogradients shallower, e.g. a gradient of 1:180 at the top of the deep weathering profile decreases to 1:337 at the top of the Gearys Gap Formation. The bathymetric contour map (NSW Dept. Public Works, 1903) shows that the lake bed approximates to a horizontal surface (gradient 1:3000) suggesting that irregularities in the older landscape have now disappeared.

Resurgent tectonics

It seems reasonable to postulate that the Palaeozoic faults could act as a zone of weakness and become reactivated by vertical movements associated with epeirogenesis (resurgent tectonics). To some extent this is supported by the irregular alignment of the Lake George escarpment similar linear escarpments to the east and west. The inconsistent pattern of pressure axes derived from the focal mechanism of the earthquakes suggests recent fault movements in southeast Australia are associated with the geometry of pre-existing faults or zones of weakness (Denham, Weeks and Krayshek 1981).

Tectonic processes and their causes

Various models now exist which attempt to explain regional uplift and denudational processes along the continental margin of S.E. Australia (Wellman 1982, Young 1982, Jones & Veevers 1982, Ollier 1982, Smith 1982 and Stephenson & Lambeck in press) Whatever mechanism is proposed it appears the uplift process leads to epeirogenic doming (cymatogenesis).

Uplift might in turn be caused by processes related to tension and compression. Normal faulting is generally associated with tension. Regional support for tension along the eastern highlands is afforded by prolonged basltic activity during the Tertiary which Wellman and McDougall (1974) attribute to tensional stress in the lithosphere.

Denham et al (1981) show evidence of regional compressive stress in the southeast Australian crust from earthquakes and in situ stress measurements. There is no evidence of fold structures in bedrock outcrops which indicate crustal shortening in the Cainozoic. It cannot be assumed that the modern stress pattern is responsible for the rejuvenation of the Lake George Fault. Most earthquakes in the region of the Lake George Fault basin lie near a strong northeast-trending lineament in the Yass-Gunning area. There is no evidence of recent earthquake activity along the line of the Lake George Fault.

AGE OF INITIATION OF LAKE GEORGE BASIN

A Tertiary age for the basin can be postulated by the displacement of fluvial quartz gravels (lower unit of the Gearys Gap Formation) along the Lake George escarpment. An absolute age for these gravels has not been obtained but their oligomict composition, bedrock relationships and similarity to ancient river gravels in the Molonglo and Yass river catchments suggest a Tertiary age or older. A definite pre-Quaternary age for the basin is deduced from the undeformed nature of the Quaternary morphostratigraphy.

An early Neogene age for the basin can be inferred from the studies of Young & Bishop (1980) and Young (1981). They describe a basalt flow south of Crookwell aged 23 million years draped over a linear low escarpment which is interpreted as a northward continuation of the Lake George fault zone. As there appears to be no visible sign of tectonic deformation of basalts in the Crookwell - Goulburn area they conclude that the lava flowed over an existing slope so this portion of the escarpment existed prior to the early Miocene. If the fault scarps were all formed at the same time then the sedimentary sequence in the Lake George basin would also date from this time.

Singh, Opdyke and Bowler (1981) have palaeomagnetically dated the top 36 m of a lacustrine sedimentary sequence in the basin to the Pliocene (3.5 my). Based on sedimentation rates they extrapolated the tectonic formation of the basin to be middle Miocene or older. Palynological dating of a few sediment samples from core obtained in the 1982-83 drilling program have given preliminary ages of late Miocene (Truswell, Appendix 1). However the base of the sequence which is sandy and deeply weathered has not yet been dated.

GROUNDWATER

The hydrogeology of the basin is shown by a map and cross sections in Figure 20. A hydrologic model devised for the Lake George Basin depicts groundwater occurrence as a two component system: an open 'evaporating pan' at the surface and a confined aquifer system at depth.

The upper system is normally a lake which evaporates to dryness in drought periods. Neutron logs taken from recent drillholes show the lake bed clays (Lake George Formation) are undersaturated below the water table. It is suggested that in dry conditions the upper system behaves as a perched unconfined aquifer. Bracketed with this upper system are piedmont deposits at the base of the Lake George escarpment which comprise colluvial mantles passing downslope to alluvial fans. They consist of a mixed and poorly sorted assemblage of gravel, sand and clay which grades laterally into lacustrine sediments. Groundwater recharge to these shallow aquifers is accomplished from creeks which are entrenched into the proximal portion of these deposits (Fig. 21). Marginal to Lake George some of these sands and gravels behave as shallow semi-confined aquifers. After heavy rain, groundwater has been observed to reappear as seepage discharge at the distal margin of these piedmont depsits where they lens into lacustrine clays. During drier periods, groundwater discharge is indicated by clumps of coarse grass and reeds e.g. between Gearys Gap and Lindau HS. The importance of piedmont deposits for water supply is amply demonstrated by good yields of potable groundwater obtained from boreholes on recently settled properties south of Silver Wattle Point. The numerous earth dams excavated to these gravels tap shallow, low salinity groundwater which stock can use when lake levels recede. Low salinity groundwater in this aquifer system is attributed to short flow paths and retention times operating between recharge and discharge zones in the permeable gravels.

Drilling and geophysical logs (gamma and neutron) reveal a lower system comprising sand and gravel aquifers (Gearys Gap Formation). These aquifers may be confined by impermeable clays of the Lake George Formation. The existence of a hydraulic connection between lower and upper aquifer systems has not yet been investigated but groundwater seepage at the surface was observed after completion of drillholes C351 and C353. Effective recharge to the lower aquifer system can be accomplished in alluvial embayments marginal to the lake where there is a high % of sand. This is shown by potable groundwater supplies retrieved from buried river channels west of Woodlawn mine and near Bungendore. Groundwater movement is expected to take place as down-valley flow under Lake George. Hydrologic base is taken to be weathered bedrock at the bottom of the Cainozoic sequence. Neutron logs suggest however that local aquifers probably exist in fissured fresh bedrock.

In the Lake George Basin it is probable that the upper groundwater flow system mimics to some extent the surface water hydrology. Some evidence is provided by the available water level data which suggests groundwater movement is directed towards the lake area. At this stage hydrogeological investigations are needed to prove if the deeper groundwater system is open or closed. An <u>open system</u> demands a mechanism for groundwater discharge beyond the limits of the basin. There are two possibilities: (a) groundwater outflow is directed towards the Lachlan catchment in the vicinity of Cullerin and Breadalbane by a decreasing hydraulic gradient directed northwards. However hydrodynamic data from the south and east parts of the basin point to groundwater flow paths converging towards the centre of the basin, (b) groundwater leakage from the basin may take place laterally or to deeper levels along meridional tectonic structures or permeable bedrock. This hypothesis is difficult to prove and in addition deep weathering may have clay-sealed fracture zones in bedrock. In a closed system shallow groundwater in recharge areas may be lost by evapotranspiration processes. Lack of an effective outlet for deeper groundwater implies a gradual build-up of groundwater salinity in the basin. During the drilling program water quality measurements were not undertaken but a few of the groundwater samples tested were strongly saline. If there is no outlet for groundwater in the lower aquifers, the salinity levels may relate a) to increasing salinities along groundwater flow paths converging towards the centre of the basin and b) to connate waters which date from the mid-Tertiary formation of the basin.

A water balance model has been developed for Lake George by Jacobson and Schuett (1979) using in part hydrolological data of Burton (1972). This model refers to the upper hydrologic system and assumes groundwater is of minor importance.

BASIN HISTORY

Prebasin environment

Towards the end of the Jurassic eastern Australia was part of the supercontinent of Gondwanaland. An eastern continental margin was formed initially by complex rifting which probably occurred between the Jurassic and Mid-Cretaceous. Sea floor spreading which finally split up Gondwanaland probably followed during a period 80-60 Ma ago (Jongsma & Mutter 1978, Weissel & Hayes, 1977 and Falvey & Mutter 1981).

Prior to the break up of Gondwanaland a pre-Tertiary drainage system probably covered what is now the southern and central tablelands of New South Wales (Taylor 1911 and Ollier 1978). The palaeodrainage divide was probably situated in a position approximating to the present edge of the continental shelf off the southeast coast of Australia on the western side of this ancient rift system. This palaeodrainage was directed northwest and superimposed on the meridionally trending folded and faulted Palaeozoic rocks of the Lachlan fold belt; its dendritic pattern suggests the existence of a deeply weathered palaeoplain. A drainage scheme for part of the New South Wales tablelands prior to the initiation of the Lake George Basin is shown in Fig. 22.

During the early Tertiary, the Eastern Highlands developed through the processes of upwarping which produced gentle arching along the eastern margin of the continent. Uplift was accompanied by regional volcanic activity (but not in the Lake George area). In response to uplift and warping numerous drainage modifications occurred, and a new coastline and base level of erosion formed (Ollier 1982). Rivers with short steep gradients flowed to the Tasman Sea and rapidly eroded the eastern slopes to provide an escarpment and narrow coastal plain.

On the tablelands, rates of geomorphic processes remained slow as evidenced by broad open valleys and underfit drainage. Outlines of the northwest palaeodrainage system remain largely through the incised tributary patterns of the Yass, Queanbeyan, Molonglo and Lachlan river systems. South of Woodlands HS, deeply weathered bedrock is exposed along the northwest-trending southern margin of the Lake George basin. Ollier (1978) concluded that the absence of river gravels in this area meant that the Molonglo river never flowed northwards to the Lachlan catchment as proposed by Garretty (1937) and Jennings, Noakes and Burton (1964). The Molonglo river is an example of antecedent drainage where it cuts across the Cullerin block east of Queanbeyan.

Erosion processes have been much quicker on the dissected eastern slopes of the tablelands. Pre-Tertiary drainage schemes have progressively disappeared. River capture and drainage reversals have led to the development of major drainage systems such as the Shoalhaven and Wollondilly rivers.

Prior to the formation of the Lake George basin this region was therefore part of a moderately dissected landscape with drainage lines directed to the northwest. A humid climate supported a landscape which was well forested and where oxidising conditions were sufficient to promote deep weathering processes. By the mid-Tertiary, tectonism began to affect the Lake George region. Normal faulted tilt blocks formed possibly by reactivation of the late Palaeozoic faults. The Lake George basin is now situated between contrasting landscape environments separated by a major drainage divide (the Great Divide) that has migrated progressively westwards across the Eastern Highlands during the Cainozoic.

Sedimentation

In the Lake George depositional basin sedimentation has been controlled largely by a combination of tectonic and climatic factors. The depositional model typifies a basin in which fluvial and lacustrine sediments derived from the surrounding cratonic environment have accumulated in a fault angled depression (Fig. 23). A gradual change from fluvial to lacustrine sedimentation in the basin is well illustrated by the cores and geophysical logs. This trend in sedimentation is accounted for by movement on the Lake George Fault and similar faults to the east. The weathering history indicates climatic changes become progressively more oscillatory and seasonal (Fig. 24).

During its early history, the basin functioned as little more than a sediment trap for the deposition of coarse fluvial clastics. Sands and gravels in the lower portion of the sequence are well enough sorted to have been deposited within the channels of meadering rivers. Gravel sometimes found at the bottom of a cycle may constitute a lag deposit while the more commonly graded and sand/silt units may represent point bar deposits. The poor development of silts and clays suggest restricted overbank deposition. At this stage the basin was hydrologically open with a drainage outlet maintained at Gearys Gap. Water inflow and precipitation were largely balanced by evaporation and water outflow.

The upper portion of the Gearys Gap formation represents a transitional fluvio-lacustrine sequence in which clay units become thicker and dominate over sand. The pattern of sedimentation reflects an increase in fault activity. From the late Miocene, tectonism had been sufficient to have raised the spillway threshold at Gearys Gap. The result was final truncation of the westerly flowing drainage and formation of a greatly enlarged lake with the deposition of clay and silt (Lake George Formation). Alluvial sediments became gradually restricted to the margin of the basin as lacustrine conditions dominated. When a lake had fully developed the basin became hydrologically closed. A new but delicate hydrologic balance now started to reflect climatic rather than tectonic influences. Rapid and frequent changes in lake levels began to produce shifting shorelines, waterflow decreased and the hydrologic balance became essentially a close relationship between precipitation and evaporation. From the dating work of Singh et al., (1981), it appears that Lake George was established by the Pliocene.

The palaeoclimatic history of the Quaternary is evident in the lacustrine sediments underlying the bed of Lake George. Singh et al., (1981) have deduced from plant microfossils a palaeoclimatic history covering the last 350,000 yrs which includes four glacial/interglacial cycles. Deposits marginal to the lake (colluvium, alluvium, strandline and aeolian) attest to the complex environment of surficial sedimentation and late Quaternary history going back to the last glacial maximum (approx. 27,000 yrs BP - Coventry 1976). The present day morphology of the lake area is mostly a reflection of its late Quaternary history. Shoreline abrasion during high lake levels probably explains slope trimming and scarp retreat along the Lake George fault zone in the vicinity of the lake area. At the northern and southern ends of the basin abandoned shoreline features point to fluctuating lake levels. The convex outer margin of Lake George is a geomorphic response to westerly winds which have induced longshore current activity and onshore deflation. Since the Quaternary, alluvial deposition has continued along major streams, but in recent times with the advent of settlement, land subdivision and clearing, gully erosion and sand mining there has been progressive change in the landscape.

CONCLUSIONS

1. The fluvio-lacustrine sequence at Lake George presents a record of tectonic, sedimentologic, climatic, biochemical, geochemical and hydrologic conditions in the basin that provides a guide to the evolution of continental environments and a reference section for the Late Cainozoic history of southeastern Australia.
2. The early Tertiary pre-basin environment comprised a deeply weathered, undulating palaeoplain developed across meridionally trending sediments, volcanics and intrusive rocks of early Palaeozoic age. A northwest drainage system with broad open valleys was superimposed on the bedrock geology. The westerly migrating Great Divide was still to the east of its present position.

3. In the mid-Tertiary normal faulted tilt blocks were formed, possibly by re-activation of faults formed during the late Palaeozoic. The precise timing of movements forming the Lake George basin are unknown.
4. The drillholes and downhole geophysical logs provide the following new information on the basin:
   (a) Lower Palaeozoic bedrock is unconformably overlain by an unconsolidated Cainozoic sequence of fluvio-lacustrine sediments.
   (b) Remnants of the pre-basin landscape are denoted by undulating surfaces corresponding to the Palaeozoic/Cainozoic unconformity and top of the deep weathering profile.
   (c) The sedimentary sequence is divisible into two stratigraphic units. The older unit is the Gearys Gap Formation comprising fluvio-lacustrine sand, gravel and minor clay. The fluvial deposits of the lower portion of the formation probably relate to the pre basin drainage system. The younger unit is the Lake George Formation which comprises silt and clay of consistent thickness. The two stratigraphic units are separated by a laterally persistent layer of sand and silt.
   (d) The extent of normal faulting based on the displacement of the bedrock surface beneath the lake bed and on the escarpment is estimated to vary from 250 - 300 m.
   (e) Gamma and neutron logs are consistent with the existence of sand and gravel aquifers in the Gearys Gap formation.
   (f) A long and complex weathering history is indicated by thick ferruginous and kaolinitic deep weathering profiles in the lower portions of the Cainozoic sequence and underlying bedrock. Thinner but intermittent ferruginous weathering profiles indicate dry lake conditions in the Lake George Formati
   (g) The greatest thickness of the Cainozoic sequence so far drilled is 163 m (drillhole C354). It is estimated that the maximum total thickness of the Cainozoic sequence in the Lake George basin approaches 200 m.
5. The sedimentation model typifies a fault angle basin in which small scale subsidence accompanied early sedimentation. There was a progressive infilli of irregularities in the fossil landscape; sedimentation patterns were subsequently controlled by changing climatic events.

Initially fluvial sands and gravels were associated with the northwesterly pre-basin drainage. The transition to a lacustrine environment of clays and silts and a closed basin of deposition was accomplished by the truncation of the drainage outlet at Gearys Gap. The late Quaternary sediments exposed in the basin illustrate climatically induced transgressive and regressive phases of fluvial deposition marginal to the lacustrine environment of Lake George.

6. Preliminary palynology results (E. Truswell - Appendix 1) date the Cainozoic sequence in the basin to the late Miocene. The deeper portions of the fluvial sequence remain undated. The late Miocene rainforest-dominated pollen suite (assemblage B) in holes C354 and C358 has been recorded at the bottom of drillhole C4. However the depth at which this marked change to open vegetation types (assemblage A) occurs in other drill holes has yet to be identified.

7. Morphotectonic analysis shows that normal faulting and tilting of the Cullarin block has produced diversions, truncation, defeat and antecedence of the original northwest-flowing drainage system.

8. Analysis of the drilling program suggests that subsurface geological data can be obtained quickly by drilling and geophysically logging uncored holes. This type of program will be effective if carefully logged lithological changes in a few, suitably sited, well cored holes (>90% recovery) are recorded accurately by downhole geophysical logging. These holes can then be used as standards for the interpretation of geophysical logs of uncored holes. If this approach had been taken in the early stages of the 1982-83 drilling program more subsurface data could have been obtained at no extra cost.

FUTURE INVESTIGATIONS

Future investigations in the Lake George Basin depend on the use of existing core and/or further field work and drilling. In the short term it is recommended that studies are based on the core obtained in the 1982-83 drilling program.

In this respect programs studying Cainozoic sequences should include (a) sedimentological investigations to define in some detail the fluvio-lacustrine sedimentation model for the basin (b) investigations into the origin of weathering structures and formulation of models to explain deep and intermittent weathering patterns (c) establishment of a palaeomagnetic chronology for the Cainozoic sequence, particularly in the deeper portions of the basin. These programs will need detailed core logging and sampling to obtain data on lithological variations (clay-silt ratios, sand types etc), sedimentary structures, colour banding and relationships between ferruginous and kaolinitic weathering. Although these studies may be attempted separately it would be preferable, considering the amount of core, to combine sedimentology, weathering and palaeomagnetism into a program suitable for Ph.D research.

In the longer term there is still a need to continue Quaternary investigations in the basin. A full biostratigraphic and palaeoclimatic description of the subsurface Quaternary sequence in the ANU and BMR drillholes is not yet complete. Surficial and geomorphological mapping with reference to drainage modifications and the origin of lagoonal clay pans is needed at the northern watershed boundary of the basin. A sampling program to extend the late Quaternary radiocarbon chronology established from beach ridges and colluvial deposits south of Collector to similar deposits at the southern end of the basin and on the eastern side of Lake George. These mapping and sampling programs will tie in the drillhole data obtained from Pleistocene sequences in the lake bed and assist in evaluating the basin-wide distribution of Holocene sediments. Drilling is also required to establish bedrock lithologies, and the extent and nature of subsurface Tertiary and Quaternary deposition in the basin north of Collector.

Hydrogeological investigations based on a drilling program of uncored holes to elucidate the groundwater flow system in the basin and the distribution of hydraulic head in the lake area. A water sampling program to assess the water quality pattern and attempt a groundwater chronology in upper and lower hydrologic systems. A pre-requisite to this program will be the collection and assessment of all available hydrogeological data in the basin.

Pilot seismic refraction and reflection surveys to evaluate if these methods can define structure, subsurface bedrock topography and lateral facies distribution of the sediments in the basin. It is unlikely that there is strong differentiation into high and low velocity zones and as a first approximation the lithological sequence in the basin can be treated as a two layered system. Hidden layers or blind zones (Sharma 1976) are not expected to be a problem in the interpretation of seismic refraction data. Vertical and lateral variation in the fluvio-lacustrine sequence suggests that seismic reflection will pick bedding discontinuities and will be the more accurate method for delineating the stratigraphy and structure of the basin. A geophysical survey might be attempted from a boat towing a sparker device but it will require deep water conditions and avoidance of submerged fence lines.

The hydrogeological and geophysical investigations depend on a significant drying out of the lake to allow access for drilling rigs onto the lake bed.

ACKNOWLEDGEMENTS

The author is grateful to colleagues at BMR for their helpful suggestions and advice, in particular to Dr C.D. Ollier and Dr G. Wilford for their supervision and manuscript editing. G.A.M. Henderson and A. Schuett (Special Projects and Geological Services Division, BMR) assisted at various times with core logging, core packaging and purchase of equipment. Dr J.M. Bowler (Dept. Biogeography and Geomorphology, ANU) kindly provided refrigerated premises for the temporary storage of core before its final removal to Fyshwick. The holes were drilled by the BMR drilling section under the field supervision of A. Zoska. The downhole geophysical logging was undertaken by G. Jennings and D. Pownall of the Geophysics Division, BMR. The figures were drawn under the supervision of M. Moffat of the BMR Drawing Office (Continental Geology Division).

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APPENDIX 1

Preliminary palynology of deep sediments in the Lake George Basin

by

E.M. TRUSWELL

Twelve boreholes were drilled by BMR in Lake George during the drying out of the lake in the 1982/83 summer. The aim of the drilling program was to provide a cored sequence of the lake basin sediments as a basis for establishing a depositional and climatic history. Two of the boreholes have been sampled in a preliminary way for palynology. The sampling of coreholes 354 and 358 (see Fig 13) was designed to evaluate the age of the sediments near the base of the sequence. Sampling was undertaken during the drilling program, and was confined to those sediments considered sufficiently unweathered to be likely to yield pollen. The samples were taken from the lower of two sedimentary units provisionally identified within the sequence by R.S. Abell. This lower unit, terms the Gearys Gap Formation, is of mixed lithology, with clays interbedded with sands and silts - possibly of mixed fluviatile/lacustrine origin. It underlies lacustrine clays of the Lake George Formation.

Corehole 354

From this corehole, the deepest drilled during the program, fifteen samples were taken for palynological examination. The samples come from two intervals. The deeper, between 107 m and 110.25 m, lies just above a deeply weathered section of the sequence. This weathering extends from 111 m, through the deepest sediments penetrated, at 165 m, into Palaeozoic basement rocks drilled to a total depth of 197 metres; weathering throughout this interval was considered sufficiently severe to make preservation of palynomorphs unlikely. The second interval sampled encompassed dark grey to black clays between 75 m and 88 m.

Eleven of the fifteen samples yielded pollen and spores. Samples from 108, 110m and 110.25 m yielded assemblages in which pollen of temperate rainforest taxa was well represented. The percentages of the major taxa are illustrated in Fig. A. Pollen of Nothofagus is a numerically significant component, with the N. brassi type being best represented, and including the fossil taxa Northofagidites emarcidus, N. heterus, N. falcatus, and, very rarely, N. deminutus. Pollen of the menziesii group is represented by Northofagidites asperus, which reaches 7 percent at 108 m; rare grains of N. brachyspinulosa represent the fusca type. Other taxa of the rainforest association include grains produced by Podocarpus, Dacrydium, and, as rarer elements, Dacrycarpus and Phyllocladus. Symplocus (as Symplocoipollenits austellus) is another component of the rainforest.

Non-rainforest taxa include Casuarina, well-represented in this interval, with frequency figures of 9 and 25 percent. Myrtaceous pollen is low (3-6 percent), and includes eucalyptoid types, and other closer to rainforest taxa. A fern element includes a high frequency of Gleicheniaceae (27 percent at 110m). Minor taxa include Banksia and other Proteaceae, Epacridaceae, Restionaceae, Acacia, and the form-taxon Stephanocolpites oblatus, of unknown affinity.

The age of this assemblage, which is designated Assemblage B on Fig. A, for ease of reference, is not easy to determine. Most of the forms within it are long-ranging, making age establishment difficult. The difficulties are compounded by the lack of independently dated reference sections in southeastern Australia for the Late Miocene/Pliocene interval. Data for a critical reference section, that of the offshore Gippsland Basin, where marine sequences allow correlation with global timescales, remain largely unpublished.

Within Assemblage B, the presence of Symplocoipollenites austellus, Proteacidites symphonemoides, and rare Tubulifloridites antipodica suggest correlation with the Triporopollenites bellus zone of the Gippsland Basin (Stover and Partridge, 1973), which has an age range extending from the latest Early Miocene into the Late Miocene. A maximum age of late Early Miocene can therefore be established for Assemblage B with reasonable confidence. Younger age limits are more difficult to ascertain. Broad aspects of the assemblage suggest that the Late Miocene part of the T. bellus zone is represented, but this determination is tentative. One taxon which accords with such an estimate is the form *Stephanocolpites oblatus*. This was reported by Martin (1973a, b) as first appearing at the top of a rainforest-dominated interval in the Lachlan River Valley, which she estimated to be Late Miocene in age, although precise time control was lacking.

The presence of rare Cyperaceae (sedge) pollen with Assemblage B would, according to Gippsland Basin comparisons, confirm a Late Miocene age. However, this group appears much earlier in the Murray Basin, so its biostratigraphic significance is currently unknown. The frequencies of *Nothofagus* pollen in the assemblage, although a significant component, are low in comparison with frequencies known from the Early and Middle Miocene, which is another reason for considering the assemblage to be Late Miocene. *Nothofagus*, particularly *N. brassi* pollen diminishes markedly in abundance near the Miocene/Pliocene boundary in the Gippsland Basin (Partridge, 1975).

Data from Lake George will eventually permit both regional and local aspects of palaeoenvironmental reconstruction to be addressed in detail. On present data, it may be noted that the presence of *Nothofagus* and other rainforest taxa in Assemblage B suggest that a rainfall considerably in excess of the present 650 mm per year pertained at least on the more elevated areas surrounding the Lake George Basin: a figure in the vicinity of 1500 mm per year is possible, with a uniform distribution throughout the year. *Nothofagus*, on the basis of its present ecological requirements, seems likely to have occupied the better-drained sites within the catchment. *Casuarina* may have grown on drier slopes, or on the lake margin. Some elements which have high local representation, such as the fern *Gleichenia* and the Restionaceae (rushes) could have grown on raised bog surfaces, in the manner described by Luly et al (1980) for the Gippsland Basin.

Assemblage B is separated from the palyniferous section above by 20 metres of sand and silt, with poor core recovery. The spore and pollen assemblage recovered from samples within the interval 75.25 m to 87.75 m, designated Assemblage A on Fig. A, differs dramatically from Assemblage B. None of the rainforest elements remain. In their place are the Tubuliflorae of Compositae (daisies), present in pollen frequencies of 45-55 percent. Grass pollen is consistently present, in frequencies of 8-11 percent. The only tree pollen in significant quantity is that of *Casuarina*.

On the basis of data presently available, assemblages of this composition are not believed to occur in Australia before the Pliocene. The presence of rare grains of Monotoca (Epacridaceae) in Assemblage A accords with a Pliocene age. The overall composition of the assemblage favours, on current thinking, a Late Pliocene, even early Pleistocene age. The basis for such age assignments must however be treated cautiously. In northern New South Wales, Martin (1977) distinguished Pliocene from Pleistocene sediments using proportions of Compositae pollen - on that basis, the Lake George assemblage would be Pleistocene. The inherent danger in using pollen frequencies as time markers should be stressed however, as figures must be subject to regional variation. The possibility cannot be entirely ruled out that what is represented in Lake George is an older, Early Pliocene or even latest Miocene, occurrence of this open vegetation type. The assemblage does suggest that a significant time break exists between Assemblages A and B, but its magnitude is not determinable. It also points to a dramatic environmental shift, from an environment moist enough to support rainforest, to one with sufficient rainfall to support only open Casuarina forest and grassland.

Corehole 358

In this corehole, some 20 samples of dark grey to black clays in the interval 90.55 m to 101.10 m were examined palynologically. This interval lies immediately within a deeply weathered interval which extends from 48 m down into basement rocks at 107 m. Fifteen of the samples taken were productive of spores and pollen. All belonged to Assemblage B, and are, tentatively, of Late Miocene age. The rainforest elements of Nothofagus brassi and Podocarpaceae are present, but the assemblages have a strong local imprint, with those between 90.55 m and 92.3 m being dominated by Restionaceae, suggesting a depositional site close to reed banks. When the Restionaceae are subtracted from the pollen sum, the frequencies of the rainforest N. brassi pollen fall between 15 and 35 percent. The same samples contain high proportions of the alga Botryococcus which indicates according to Singh (in Singh et al., 1981) that prolonged open water conditions may be reflected in this interval. A great diversity of cysts of the algal family Zygnemataceae also occurs in the interval; the ecological implications of these are unknown.

Conclusions

This preliminary examination suggests a Late Miocene age for sediments between 107 m and 110 m in corehole 354, and 90-101 m in corehole 358. This palynological association, designated Assemblage B, suggests the presence of temperate rainforest in the Lake George catchment at this time.

In corehole 354, a pronounced vegetation change is indicated by samples taken between 75 m and 87 m. Assemblage A from this interval, could be as young as Late Pliocene or Early Pleistocene, and indicates a change to an open vegetation of much drier aspect.

The task now, with examination of more material from closely spaced samples, is to reconcile these tentative dates with those obtained by Singh et al. (1983) from coreholes in the northern end of Lake George. In those holes, magnetic reversal studies identified the Matuyama/Gauss boundary 2.47 m.y.) at 30 m depth. Should the tentative Late Pliocene date suggested here for sediments at 75-87 m in BMR corehole 354 be confirmed by further work, then the Pliocene sequence in the lake centre must be much thicker than it is in the northern end of the lake. Should this interval in corehole 354 be eventually proven to be older than Late Pliocene - perhaps by magneto-stratigraphic methods - then the site records the oldest occurrence yet known in Australia of an open vegetation dominated by grass and composites. The difficulties surrounding the palynological dating of the Lake George core emphasize the need for biostratigraphic and magnetostratigraphic studies to be undertaken concurrently in future studies of the sequence at the site.

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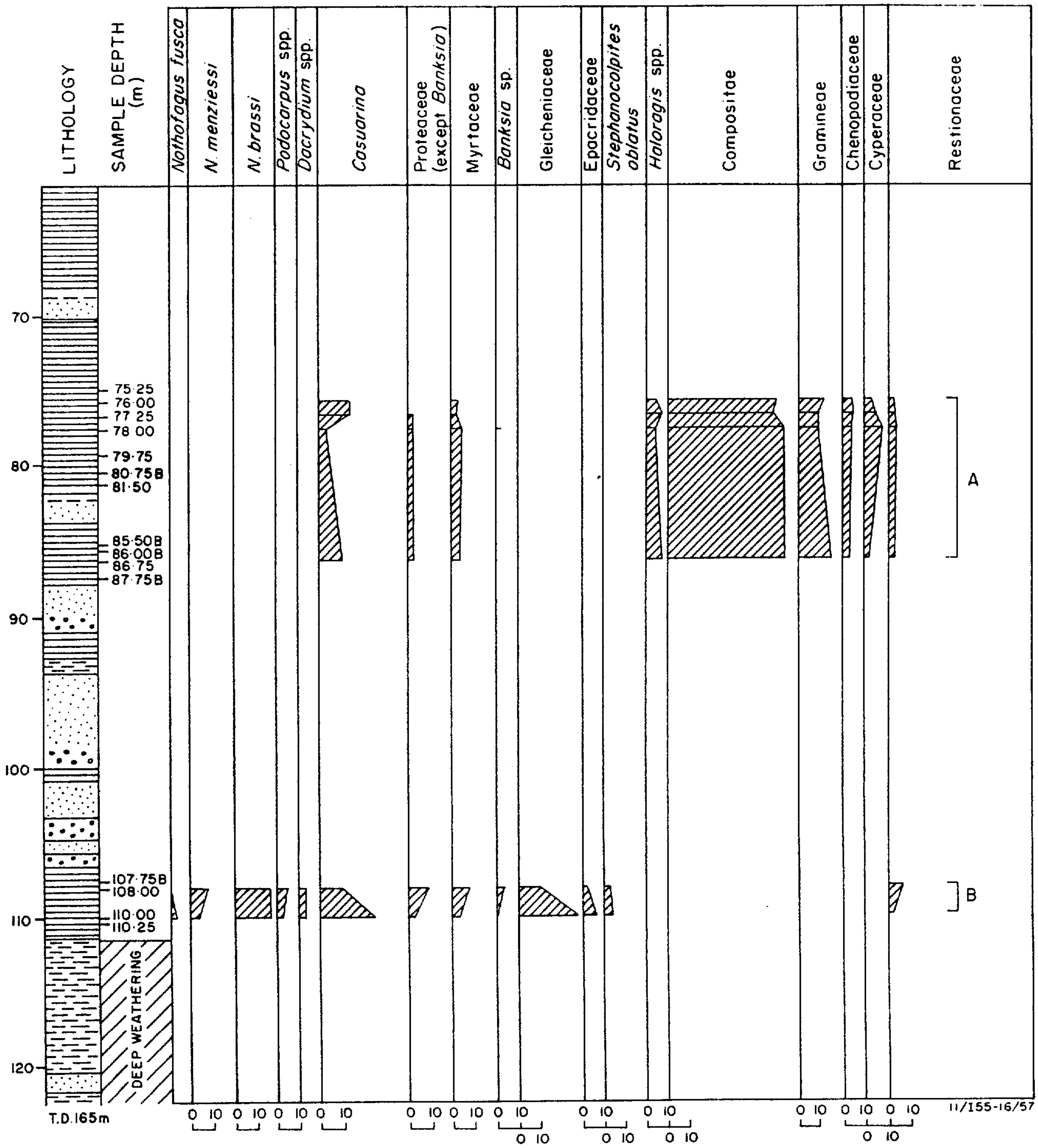


Record 1985/4

Fig. A Frequeney of major taxa in Cainozoic sediments in BMR drillhole C354

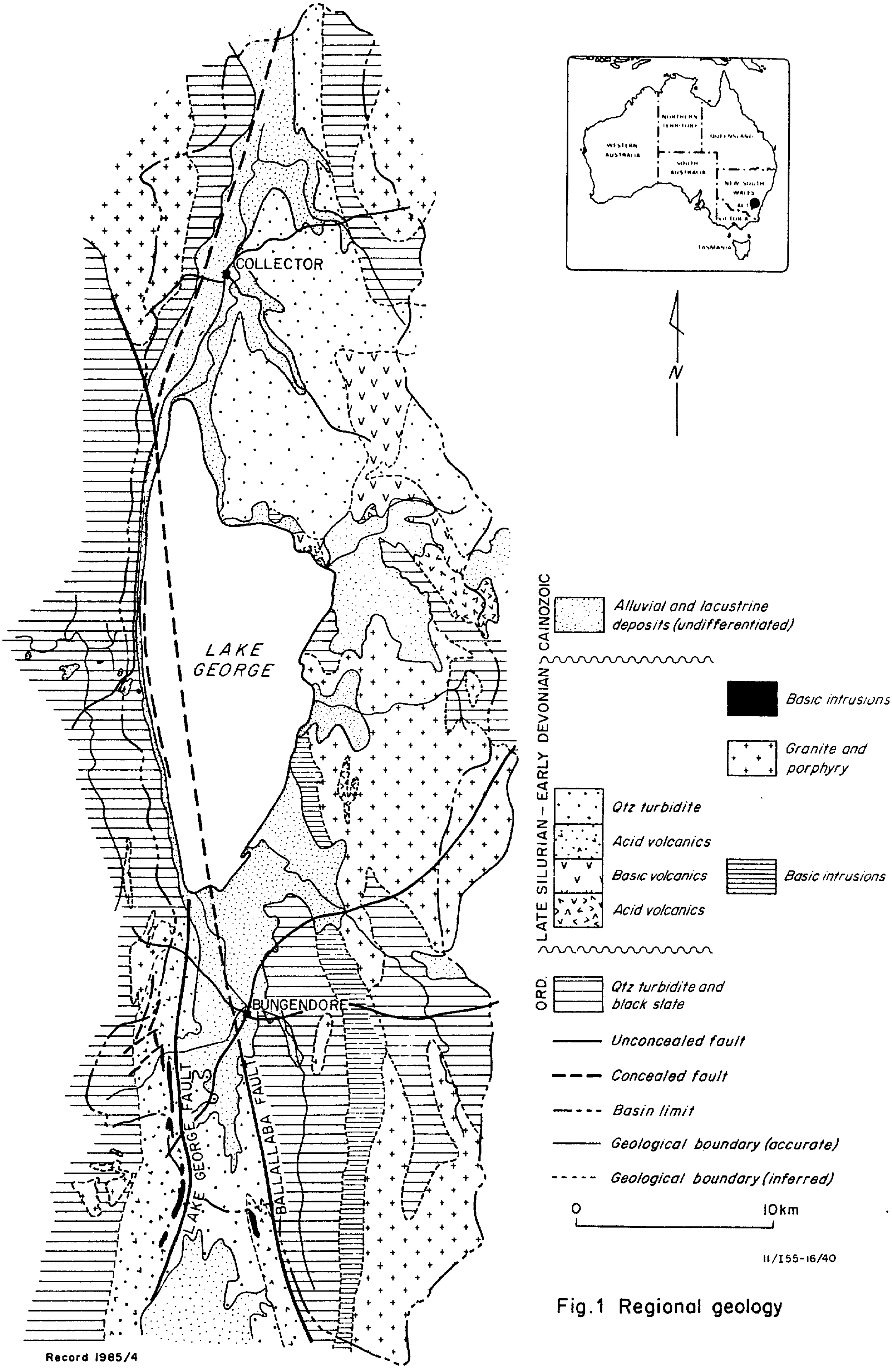


Fig.1 Regional geology

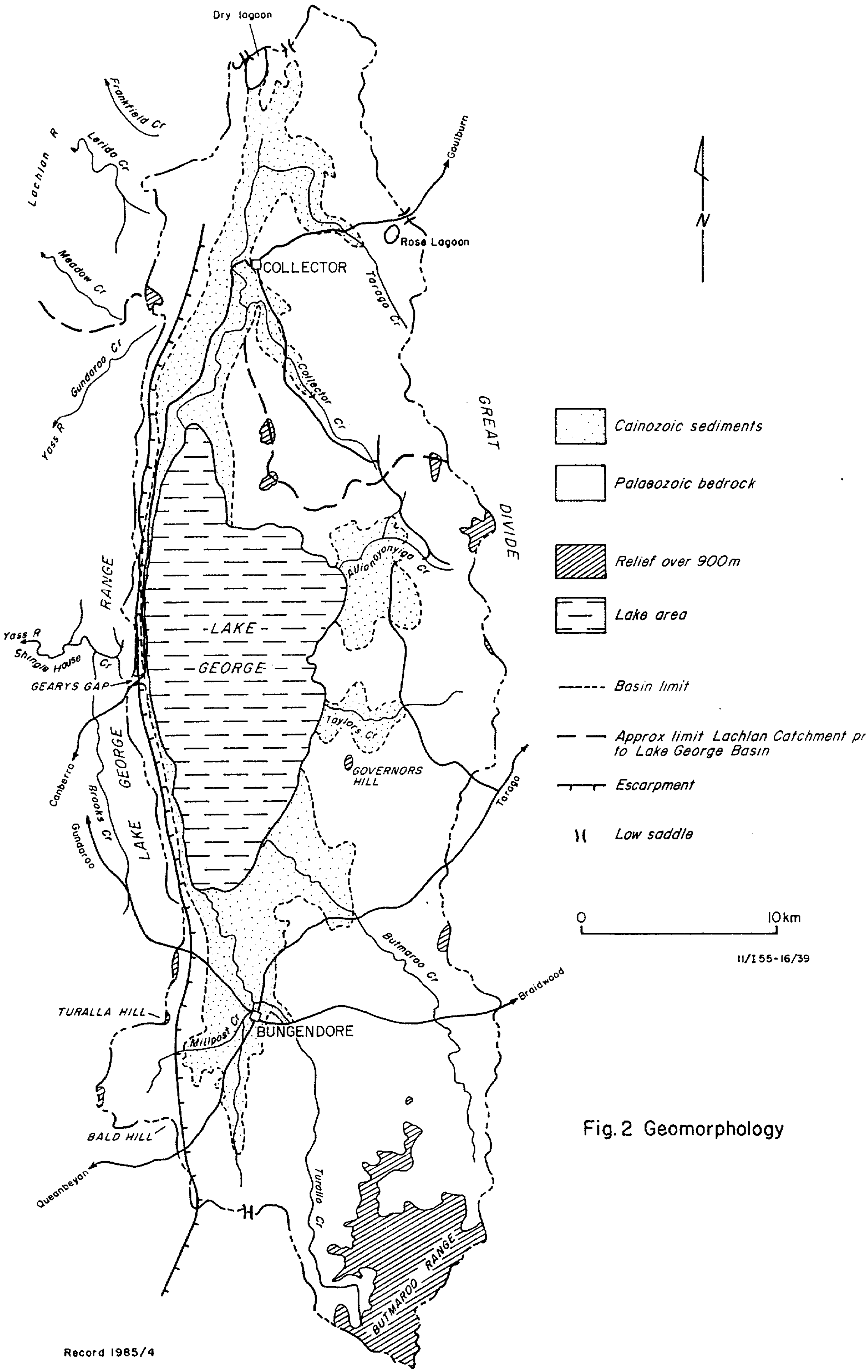


Fig. 2 Geomorphology

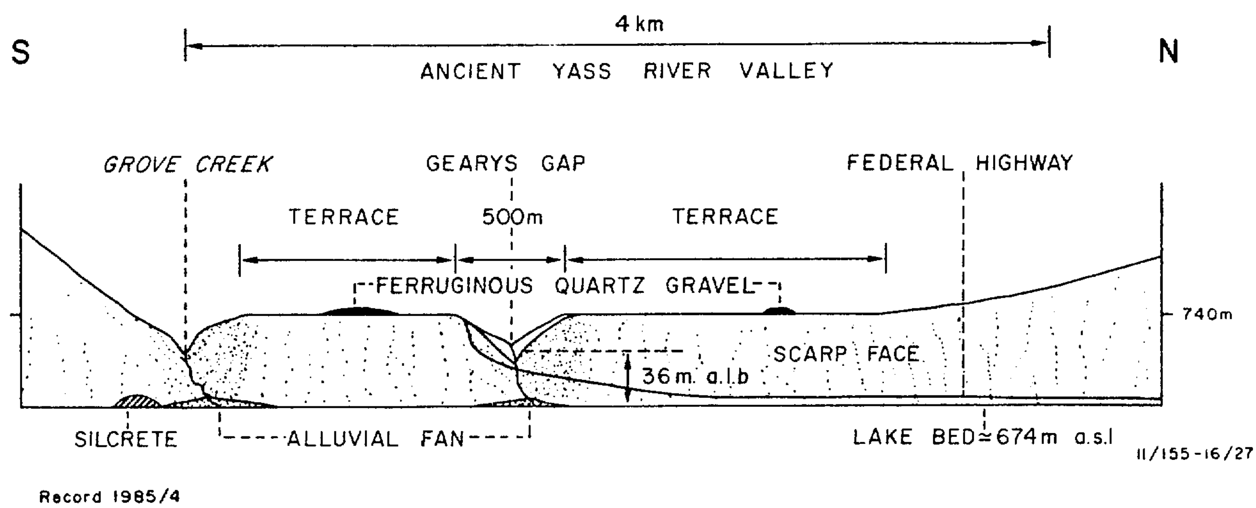
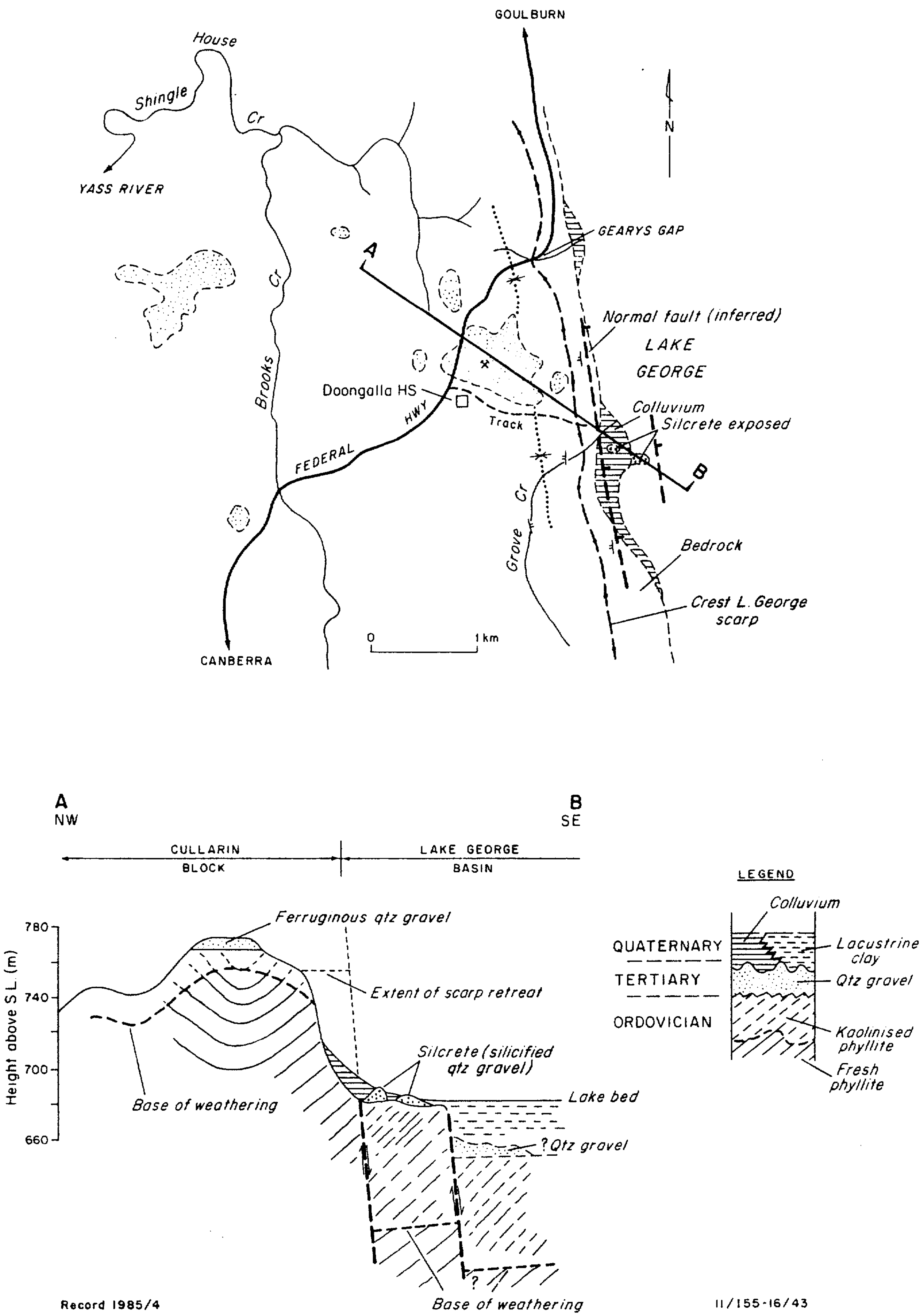


Fig. 3 Lake George Escarpment across Gearys Gap

Fig. 4 Cainozoic geology



Record 1985/4

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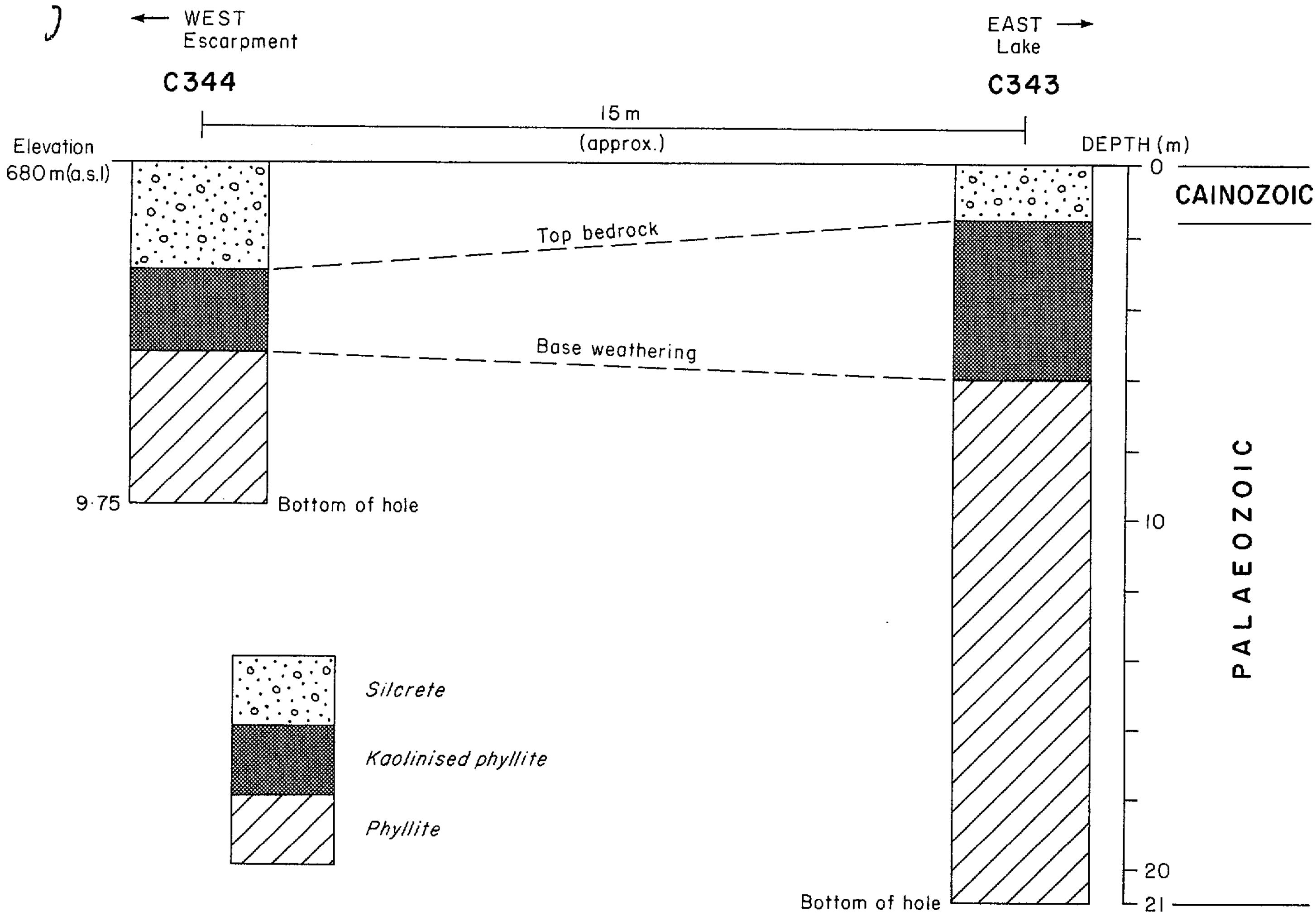
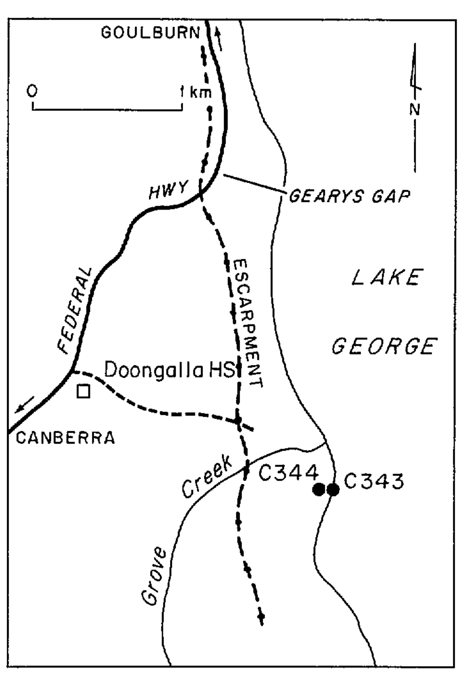
Fig.5 Distribution and relationships of quartz gravels in the Gearys Gap area



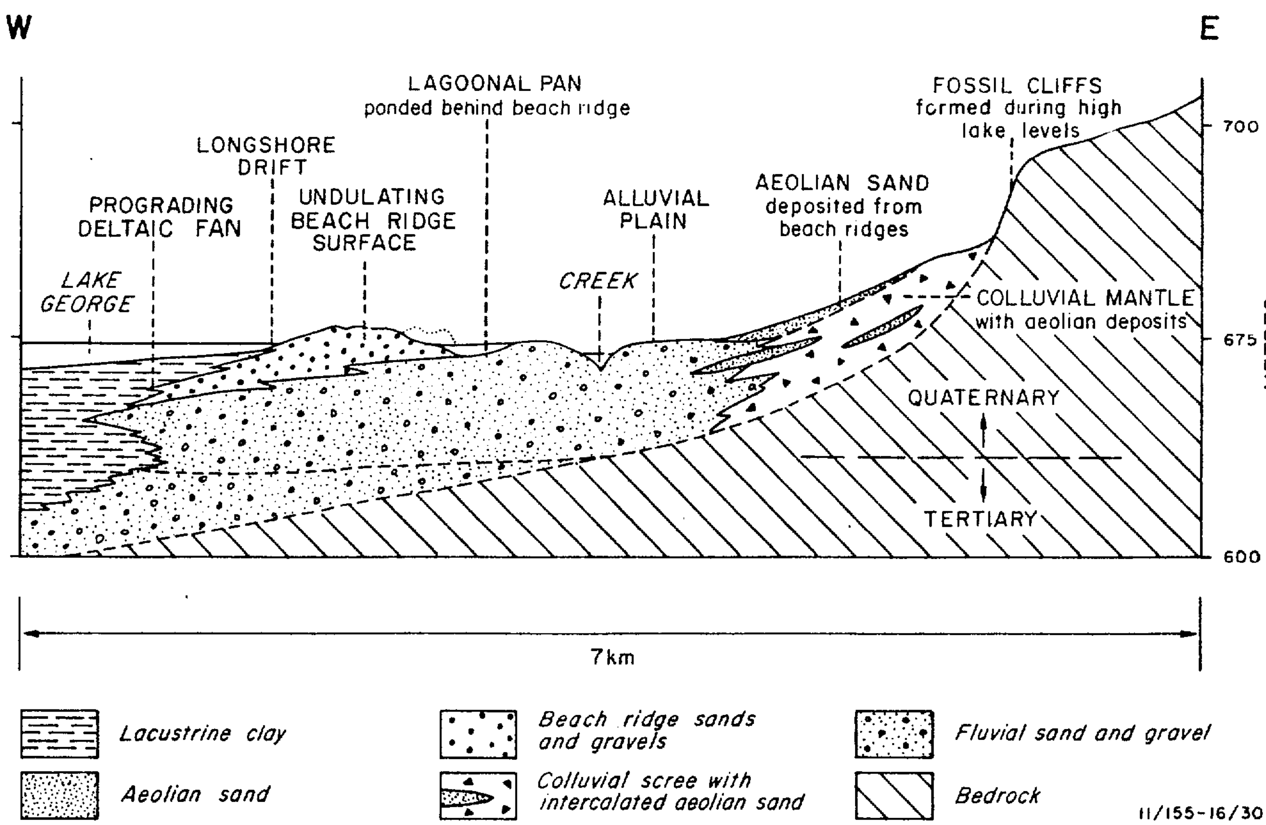


LOCATION OF DRILLHOLES
Grid reference 170/112, Canberra
1:100000 sheet 8727

11/155-16/36

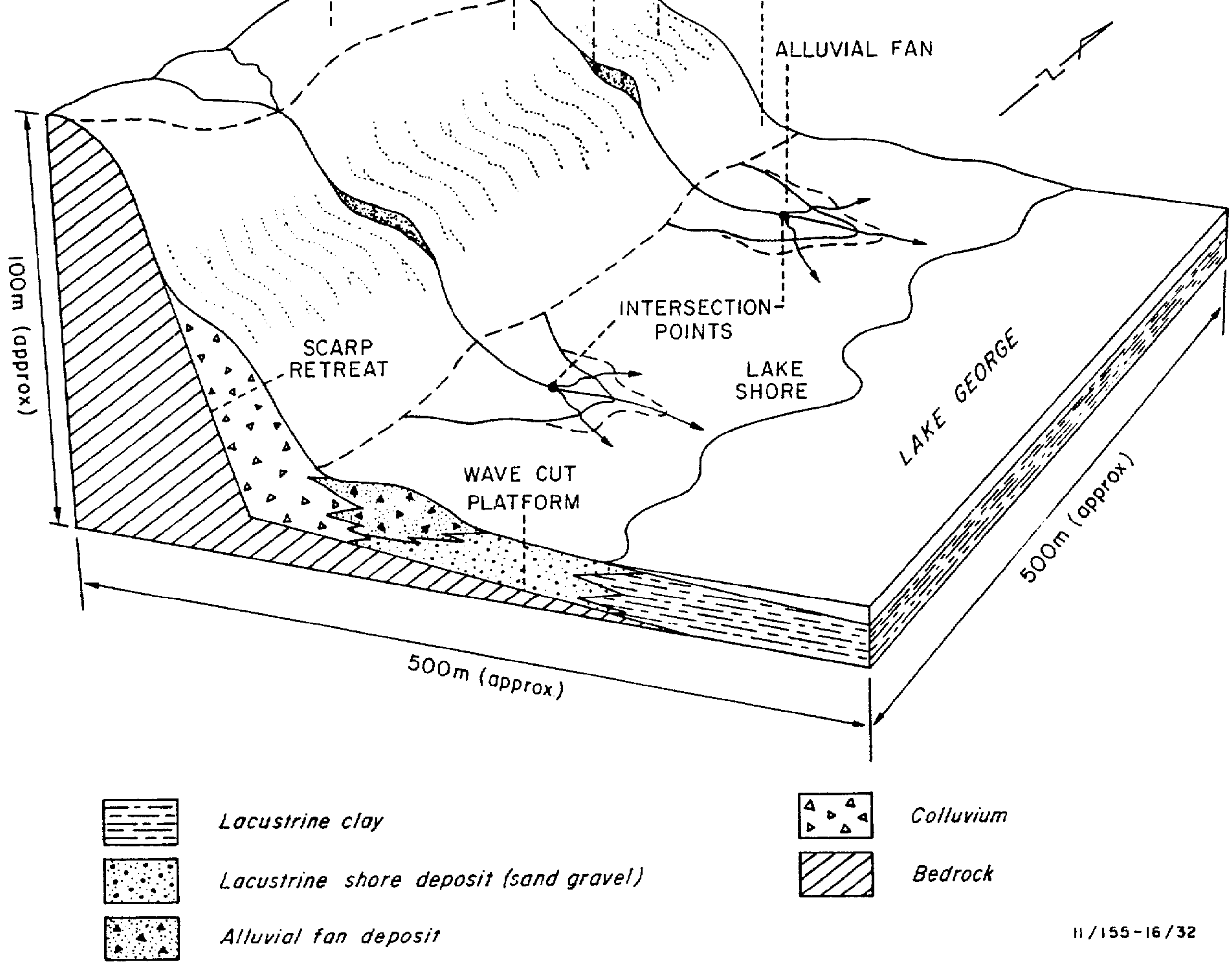
Record 1985/4

Fig. 6 Drillhole logs C343 and C344



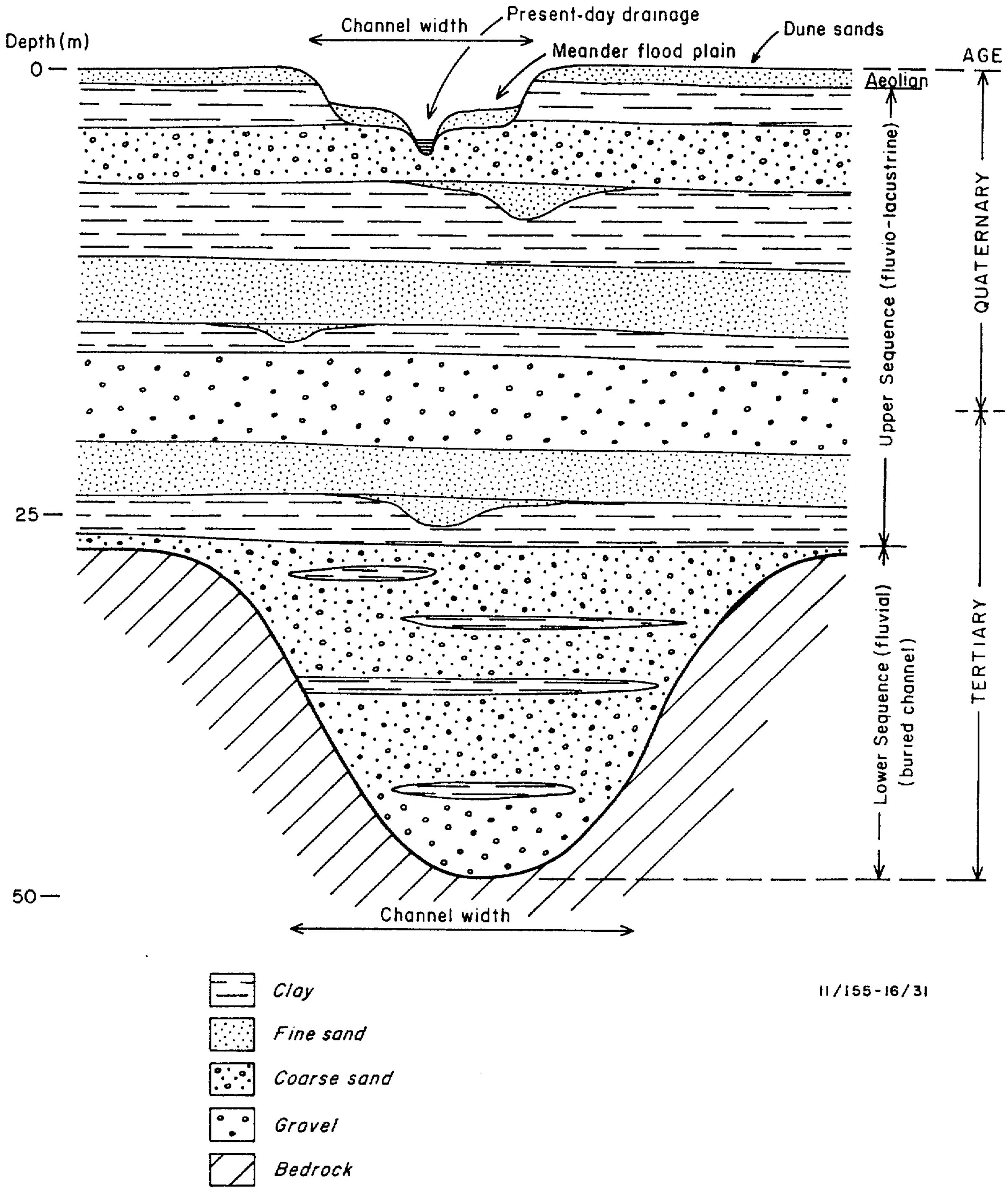
Record 1985/4

Fig. 7 Schematic section across southeastern margin of Lake George Basin showing depositional facies



Record 1985/4

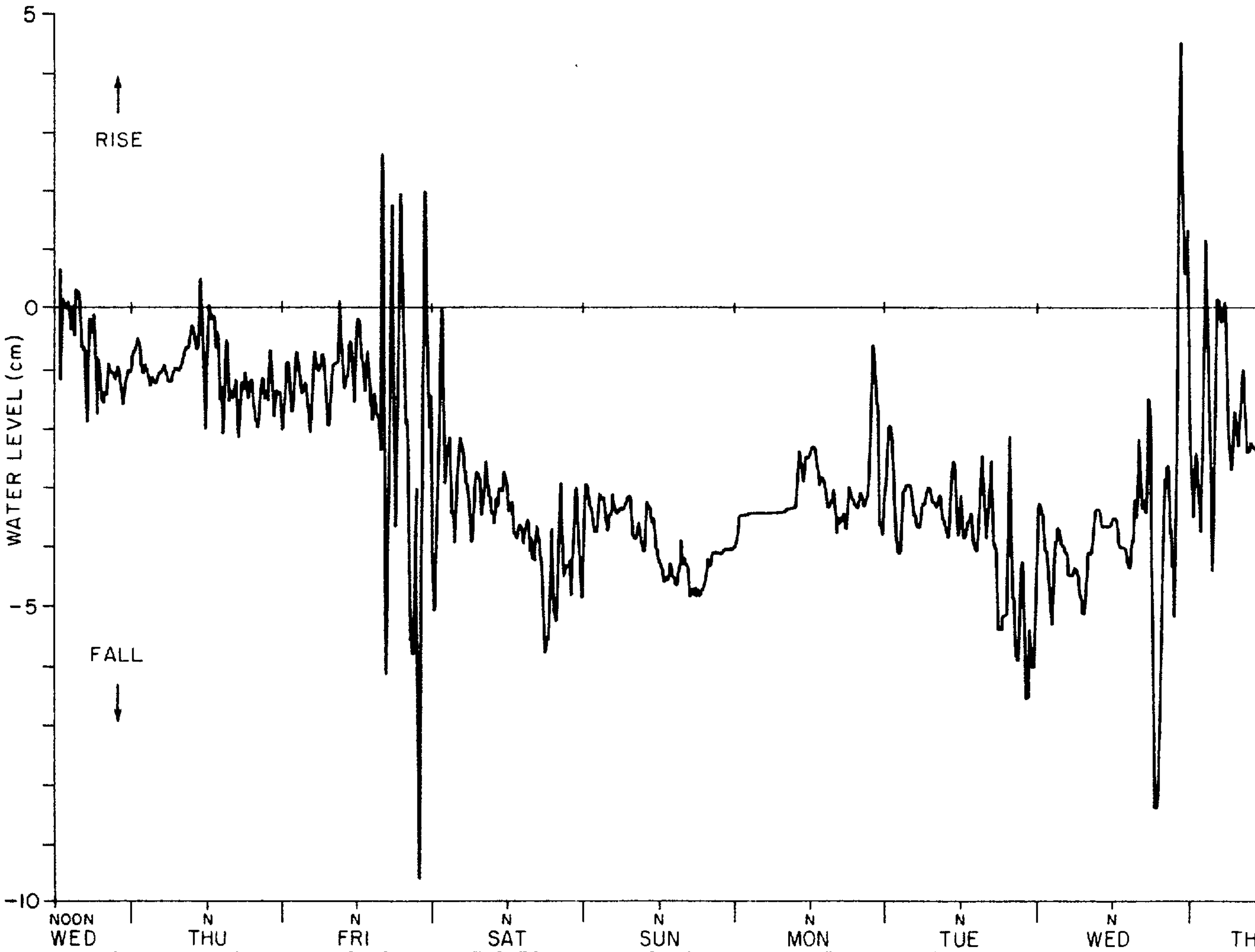
Fig. 8 Schematic block diagram showing sediment facies in the vicinity of the Lake George escarpment (after Coventry 1973)



Record 1985/4

Fig. 9 Schematic sequences of stream channel and floodplain deposits in Lake George Basin

LOCATION	KENNYS POINT
PERIOD OF RECORD	1300 hrs 4·2·70 to 1125 hrs 12·2·70
RAINFALL	44 mm
COMMENTS	Between 6·2·70 and 11·2·70 was a very hot period with light to moderate winds. The slight upward trend of the curve from 11·2·70 caused by considerable rain from thunderstorms.



Record 1985/4

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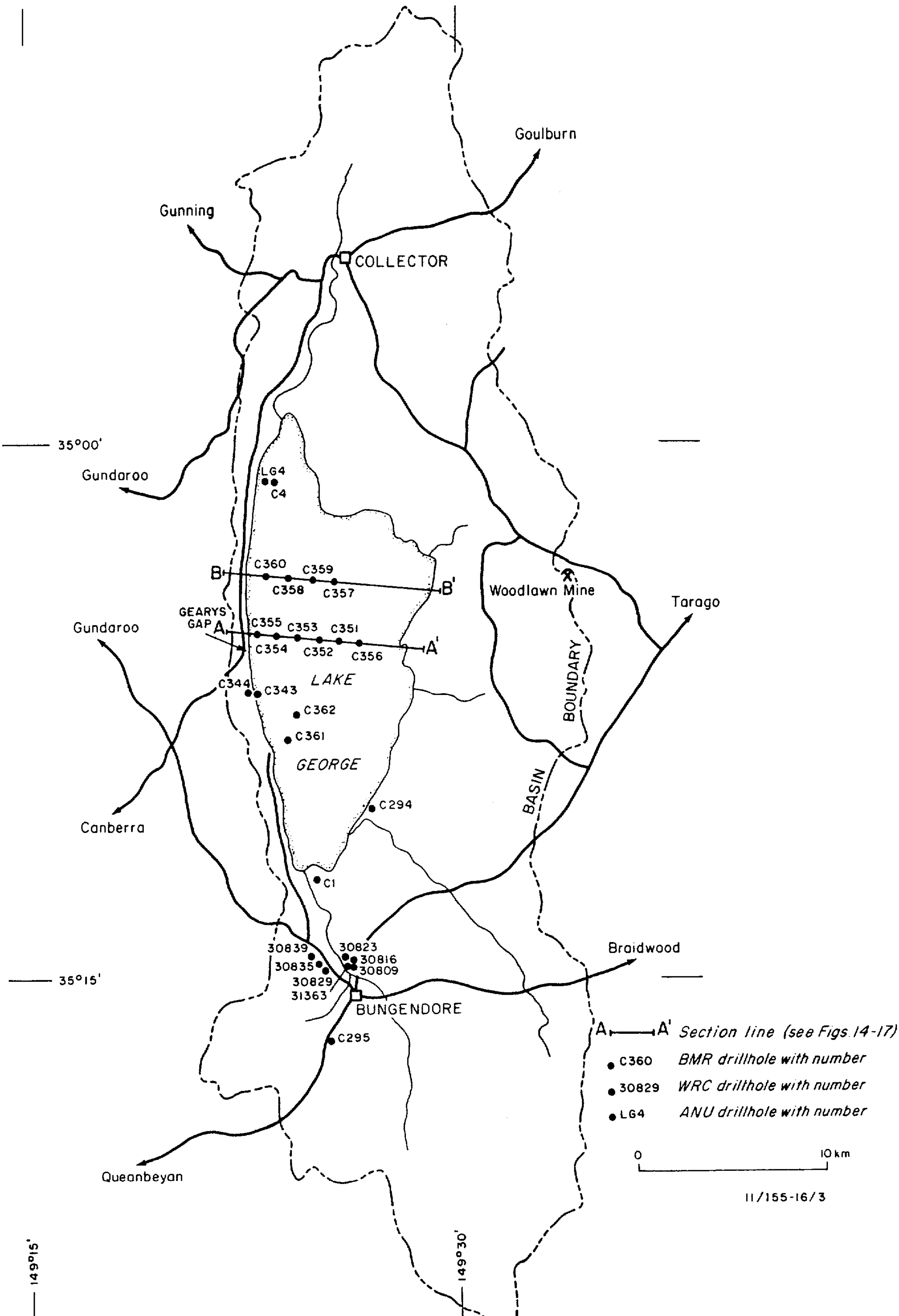
Fig.10 Typical seiche oscillations in a water level record at Lake George



Record 1985/4

Fig. 11 Location and distribution of drillholes

Fig.12 Palaeodrainage lines and structure contours of the bedrock surface

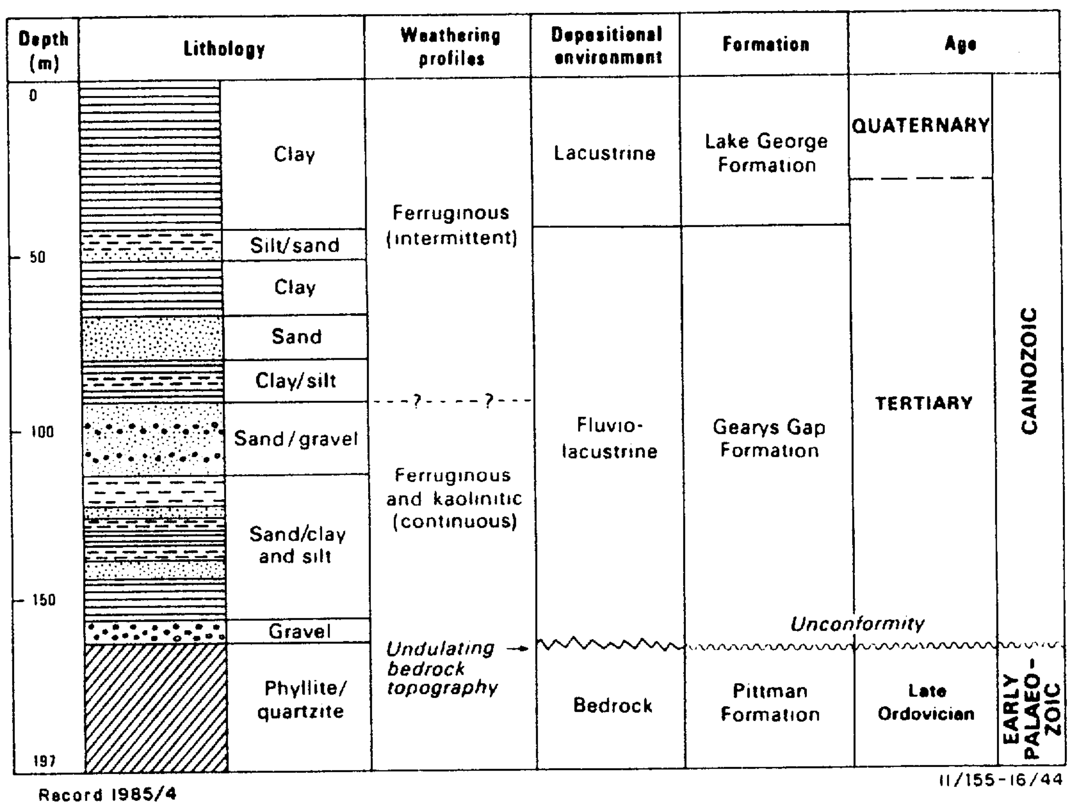


Fig. 13 Summary of Cainozoic stratigraphy

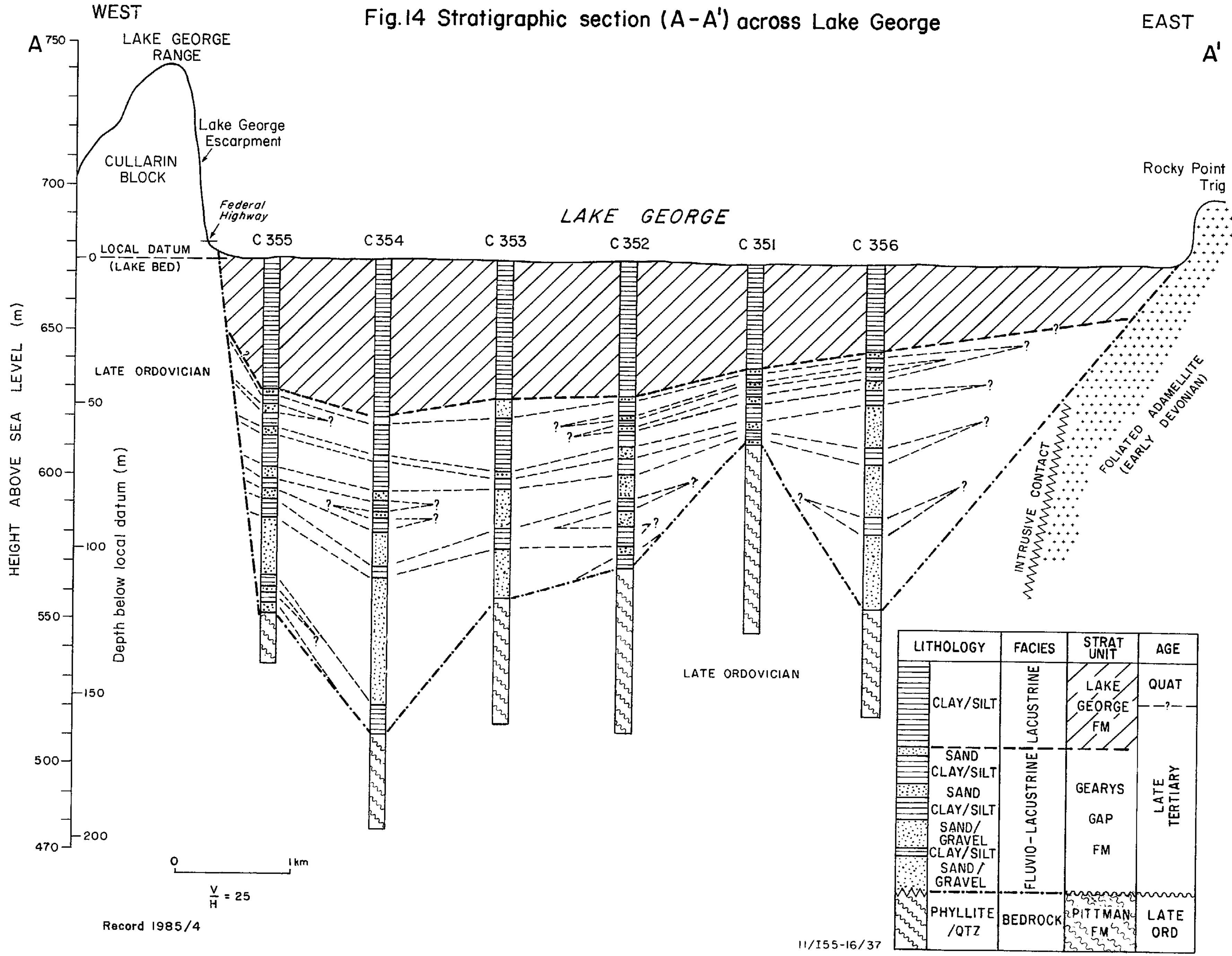


Fig. 14 Stratigraphic section (A-A') across Lake George

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Fig.15 Stratigraphic section (B-B') across Lake George

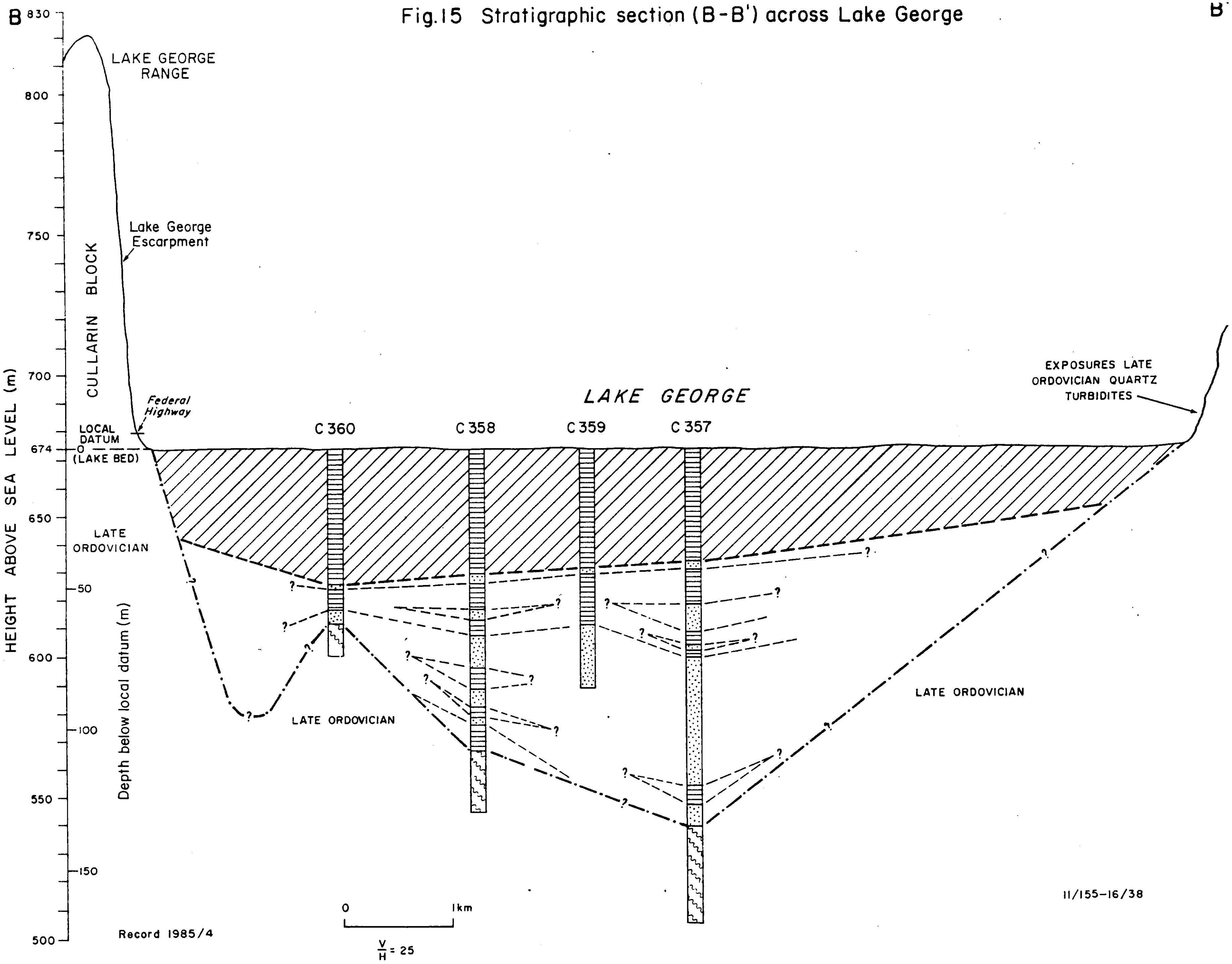
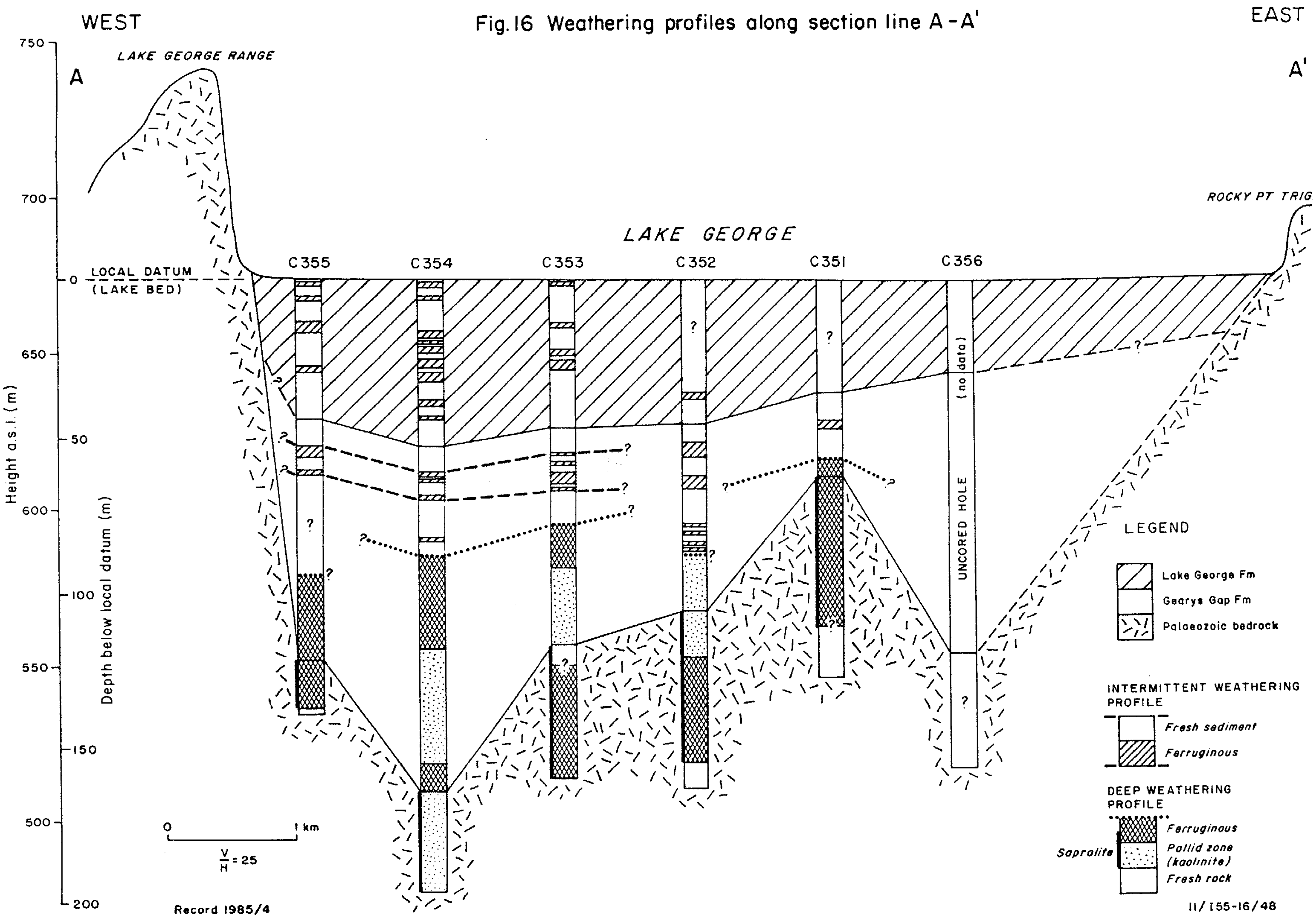


Fig. 16 Weathering profiles along section line A - A'



Record 1985/4

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Fig. 17 Weathering profiles along section line B-B'

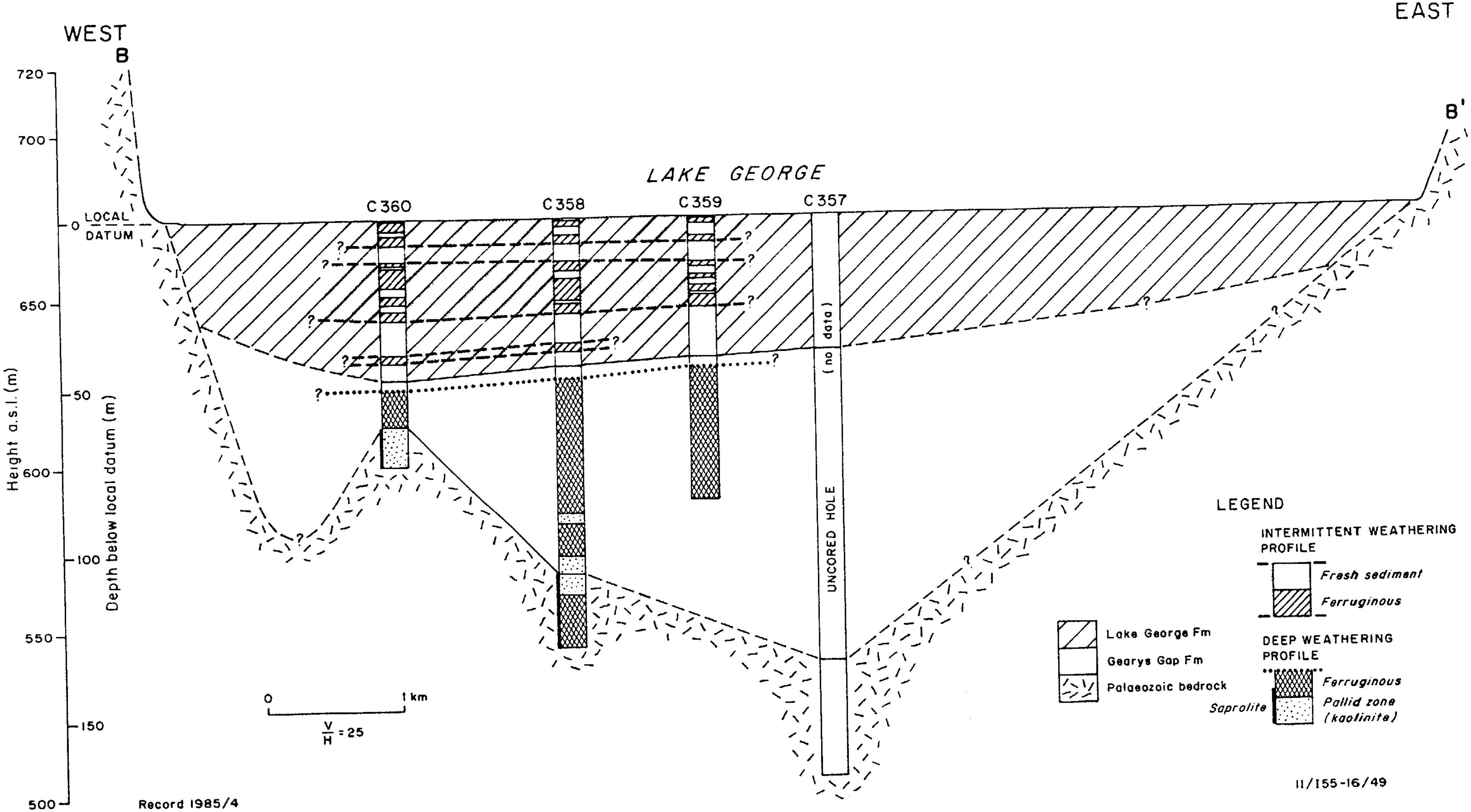

Fig. 18 Structure contours at the top of the deep weathering profile

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Fig. 19 Structure contours at the top of the Gearys Gap Formation

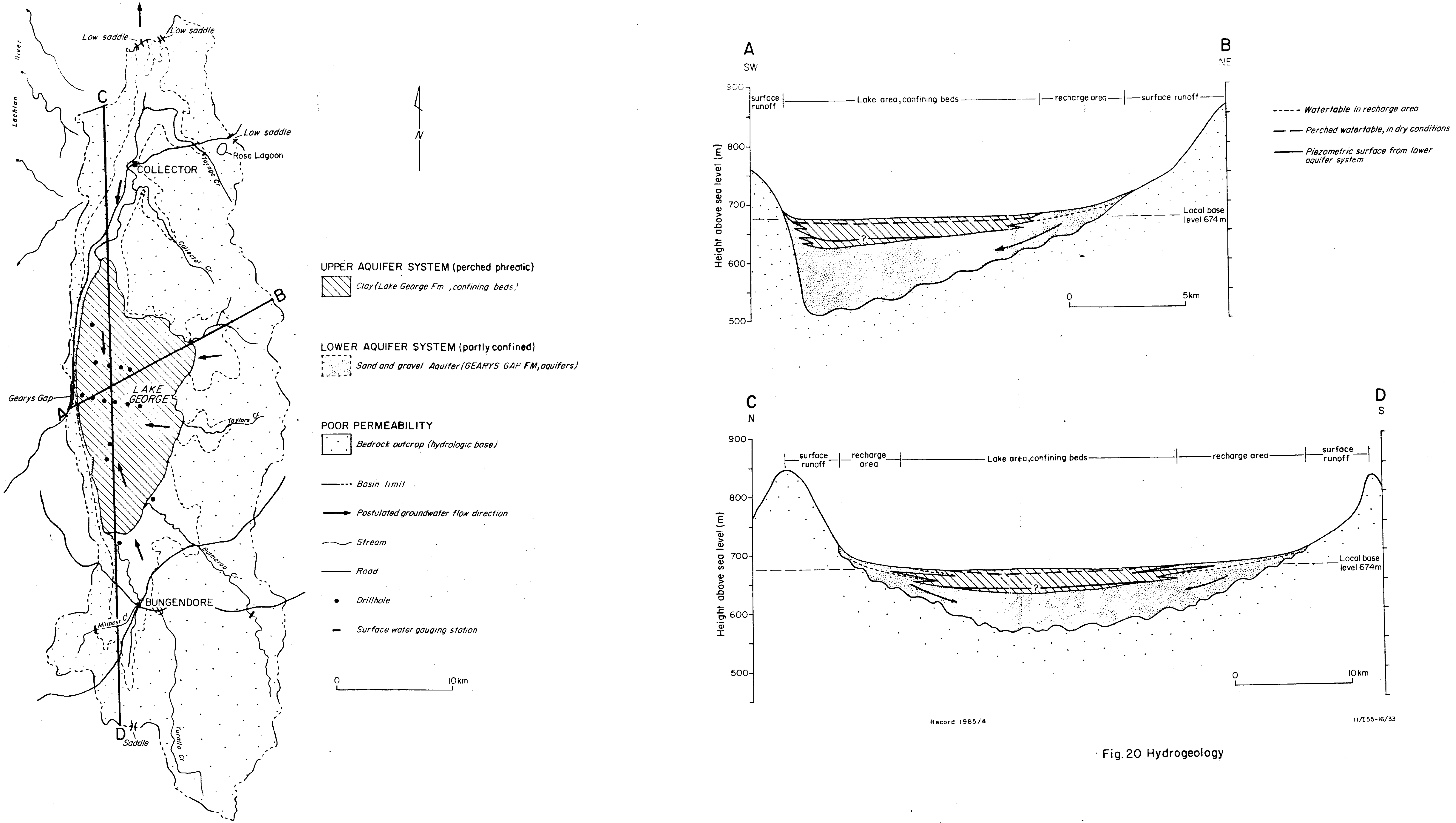

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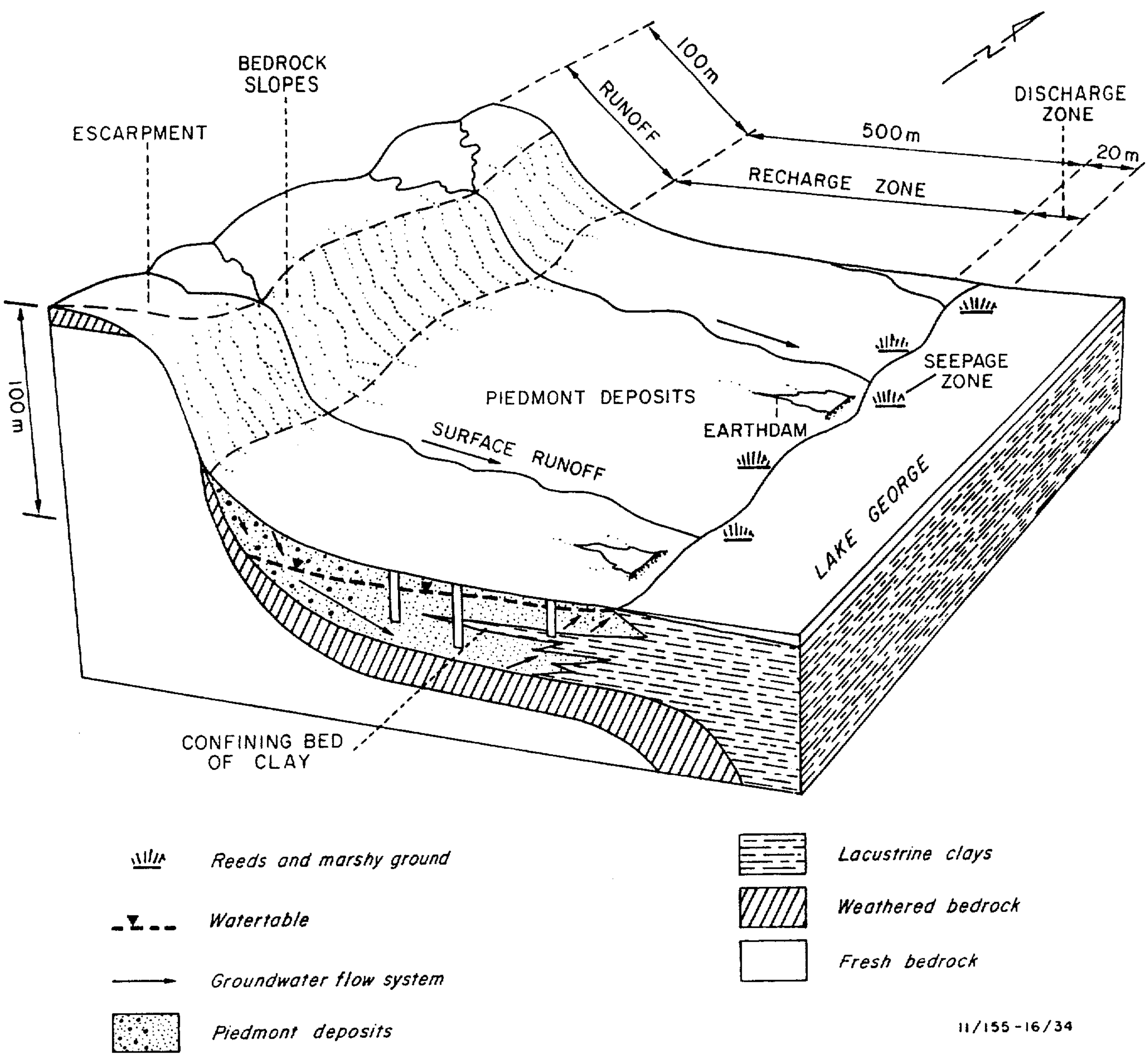
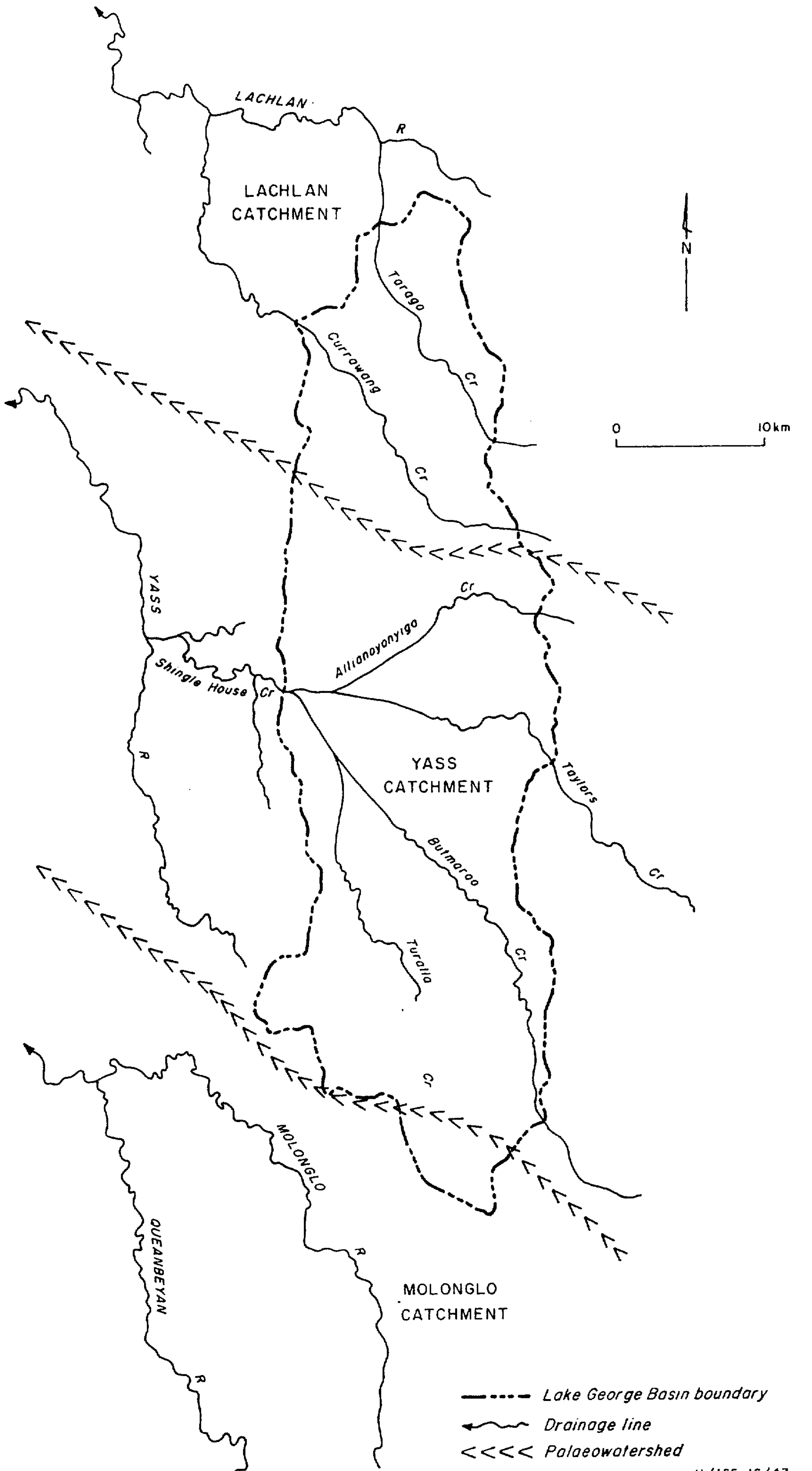
Fig. 20 Hydrogeology



Record 1985/4

Fig. 21 Groundwater occurrence in piedmont deposits along Lake George Escarpment



Record 1985/4

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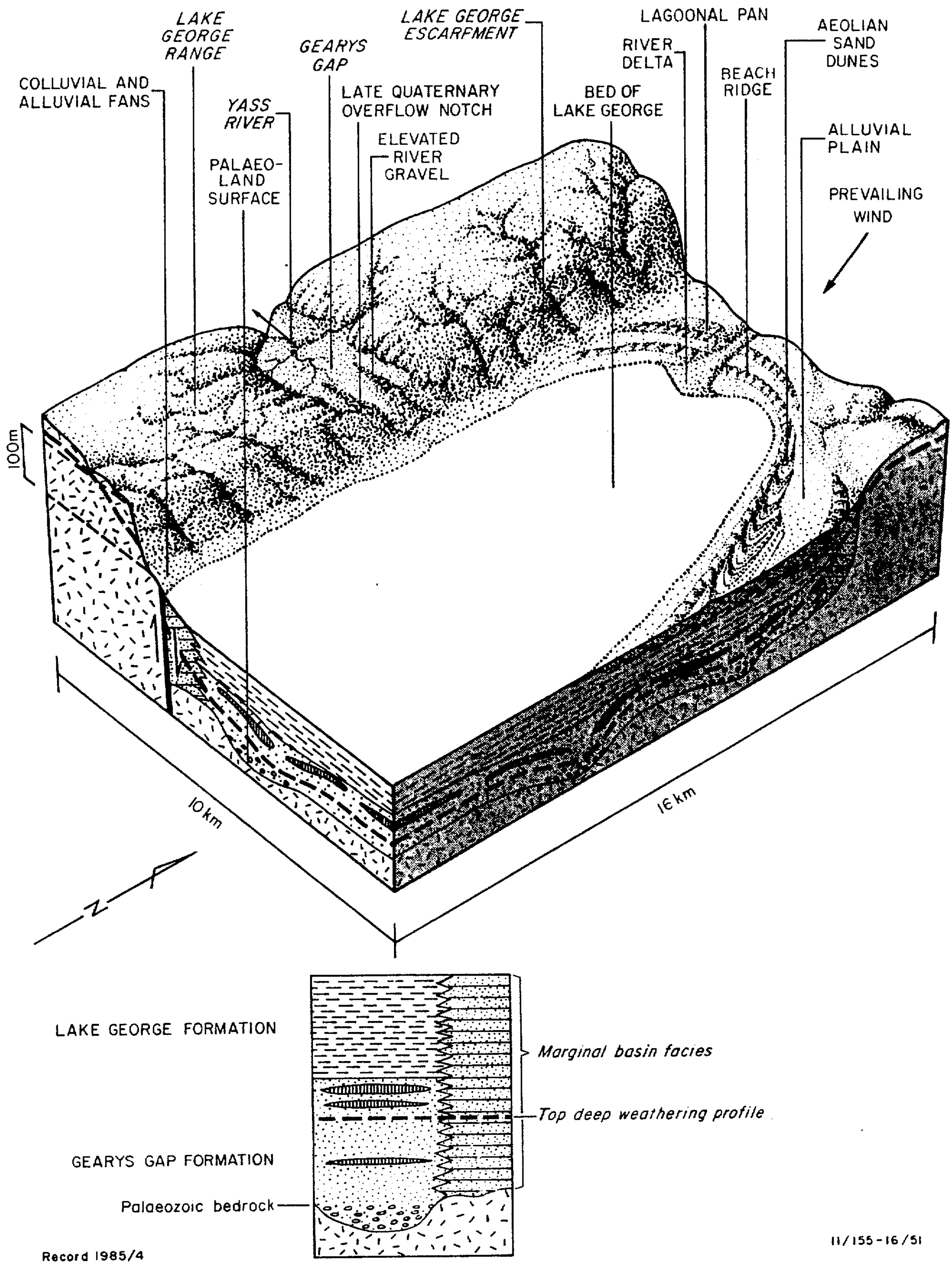
Fig. 22 Pre basin drainage scheme (after Taylor 1907 and Ollier 1978)



Record 1985/4

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Fig. 23 Schematic block diagram showing sedimentation and geomorphology in the central portion of the Lake George Basin

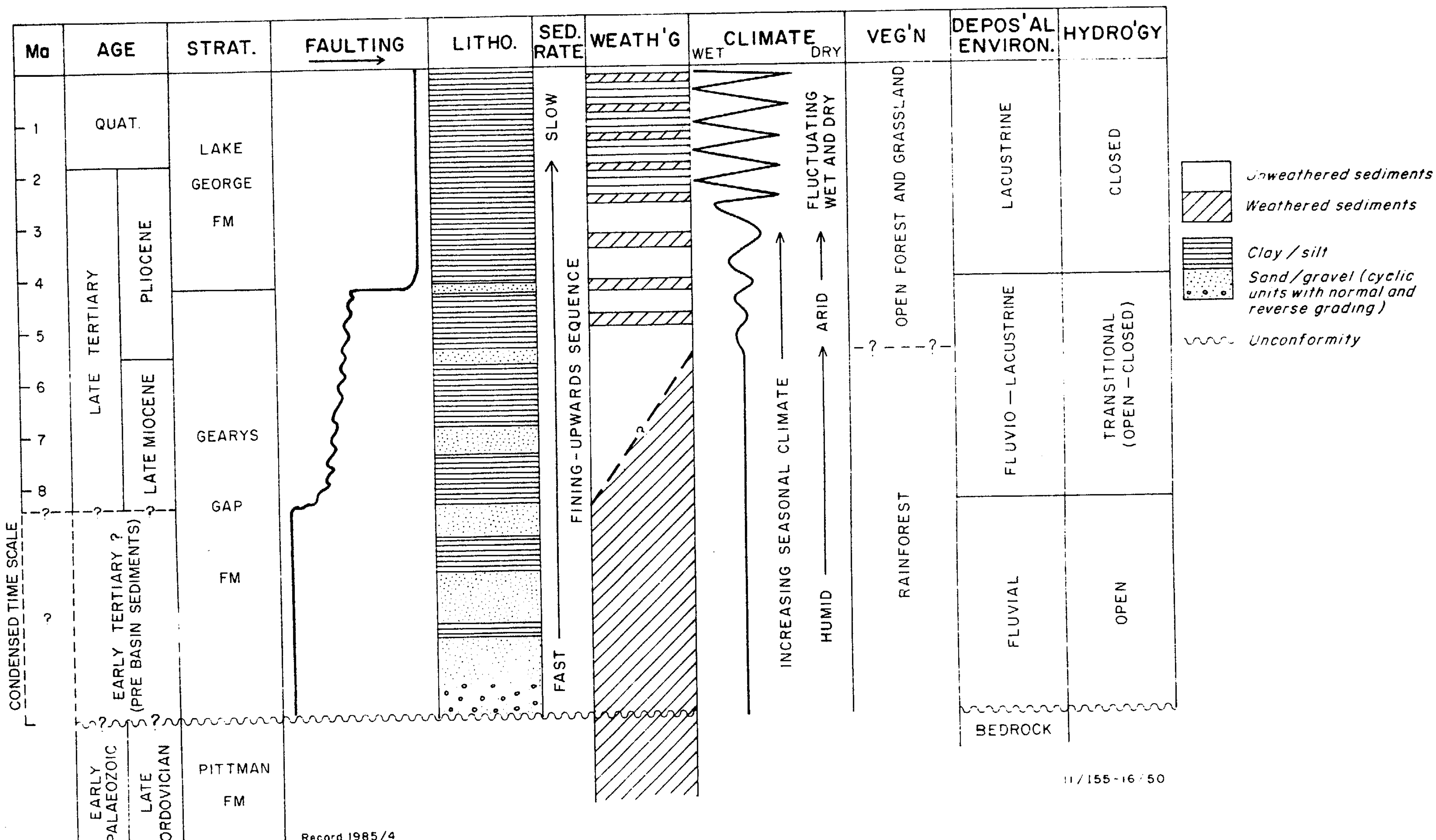


Fig. 24 Summary of the geological and environment history in the Lake George Basin

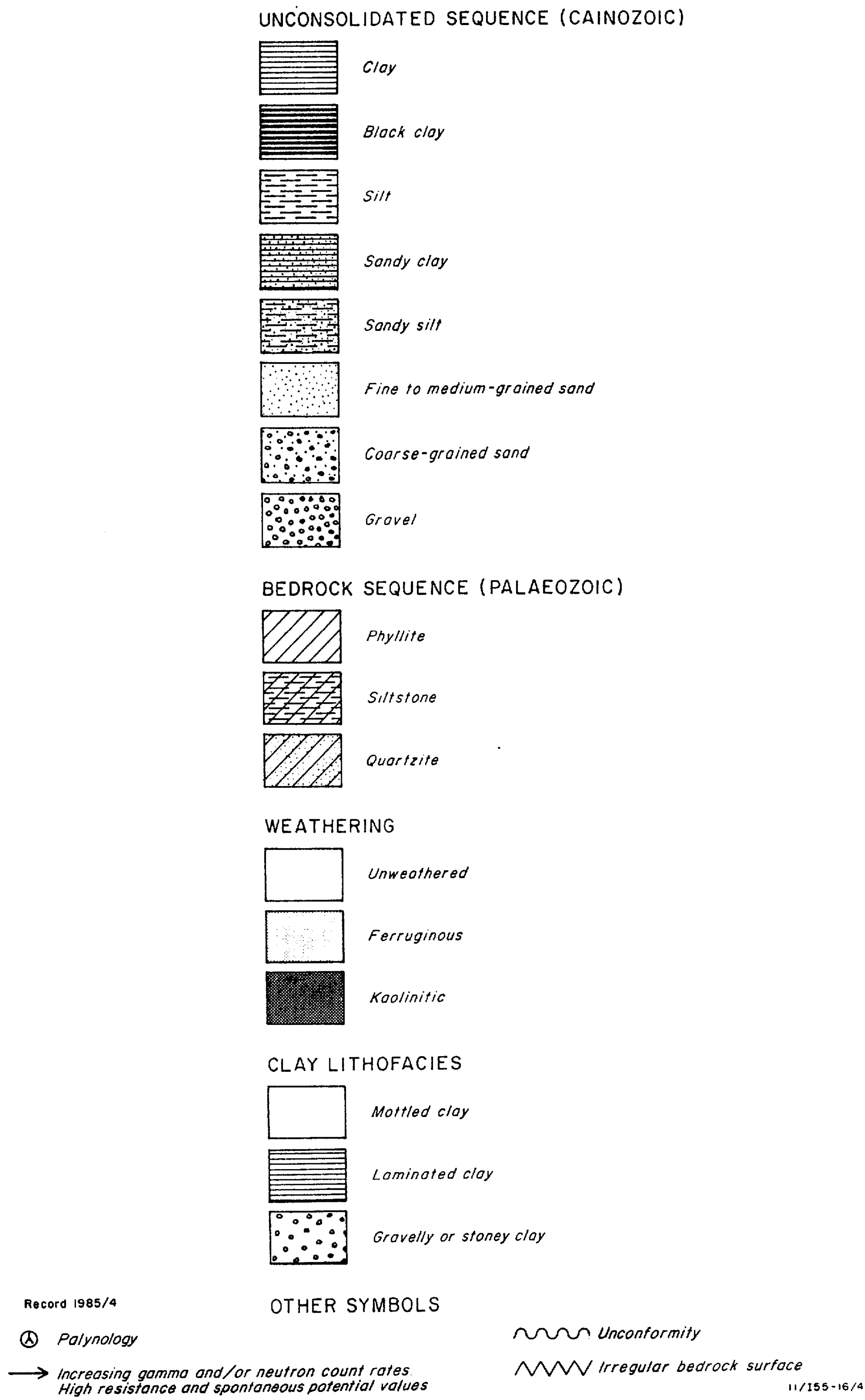
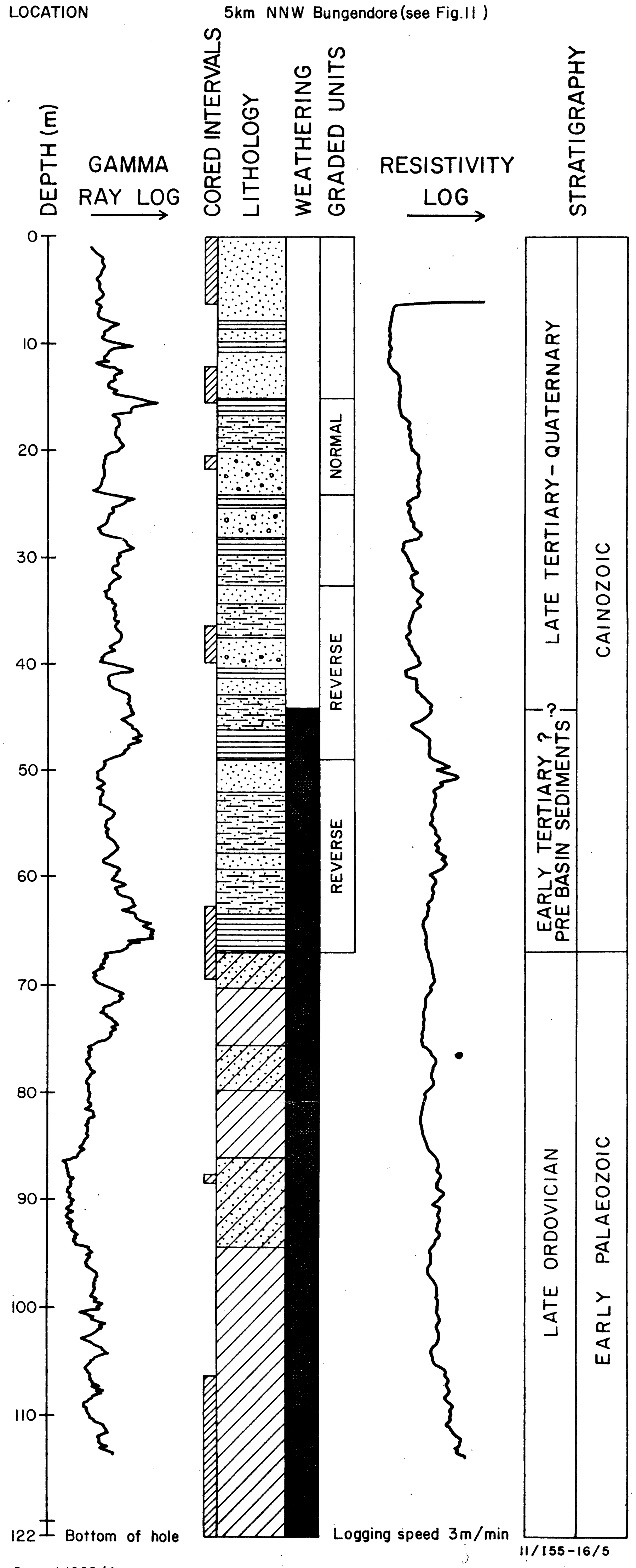


Fig. 25 Legend for drillhole logs (including microfiche logs)

ELEVATION	Approx 680m (Canberra 1:100 000 topo. sheet 8727)
GEOPHYSICAL LOGS	Logged by BMR using a Porta Logger and Probe G10C on 7/2/68
LITHO LOG	Based on (1) geophysical logs (2) drill cuttings and (3) generalised log after Burton (1972)
LOCATION	5km NNW Bungendore (see Fig.11)

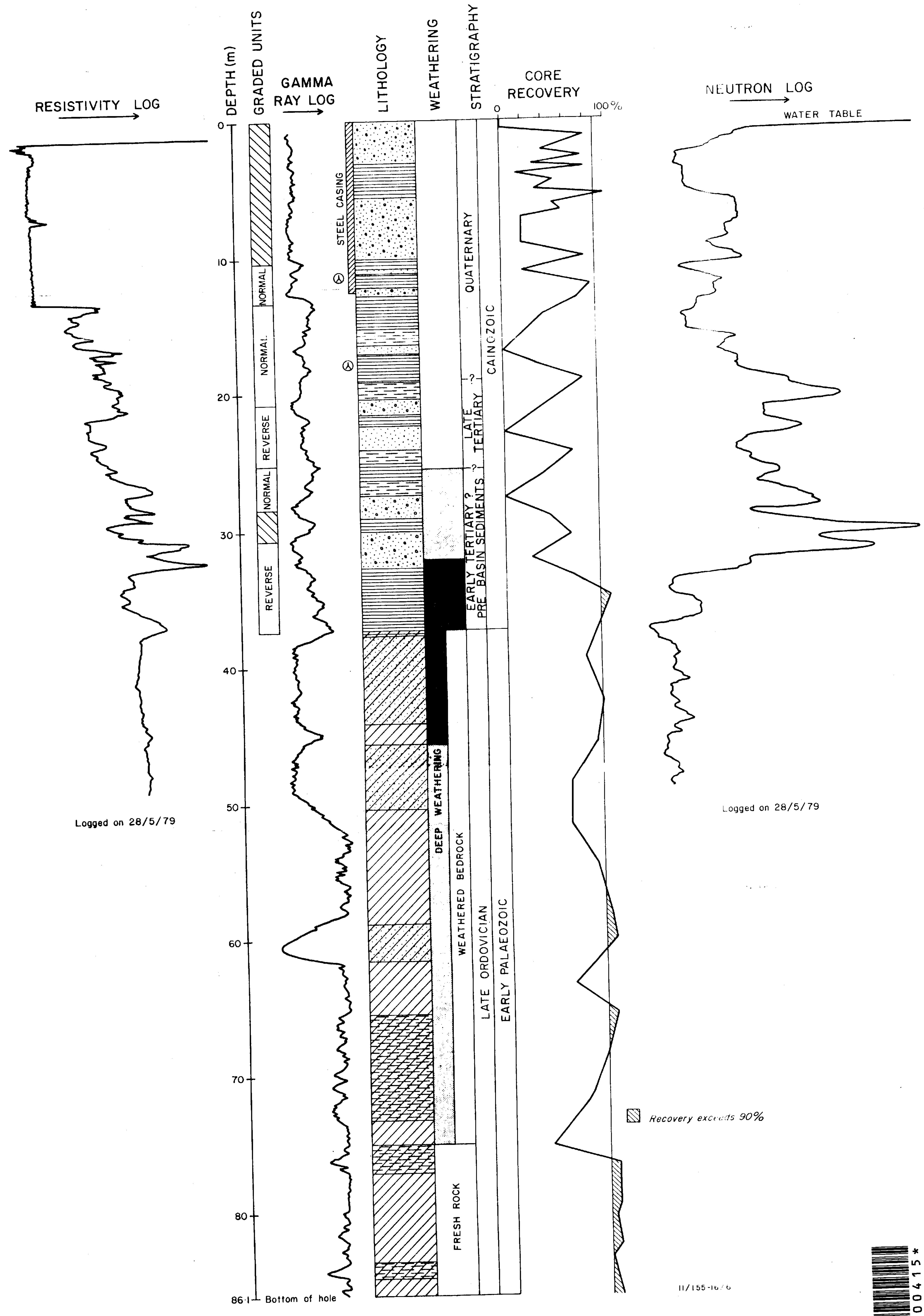


Record 1985/4

Fig.26 Geological and geophysical logs of BMR Scouthole C1

ELEVATION Approx 680m

LOCATION Lakelands property - 0·5km North Butmaroo Creek - approx 9km North Bungendore. Grid ref. 230/050



Drilling commenced 10/4/79, hole completed 4/5/79

Record 1985/4

Fig. 27 Geological and geophysical logs of BMR drillhole C294

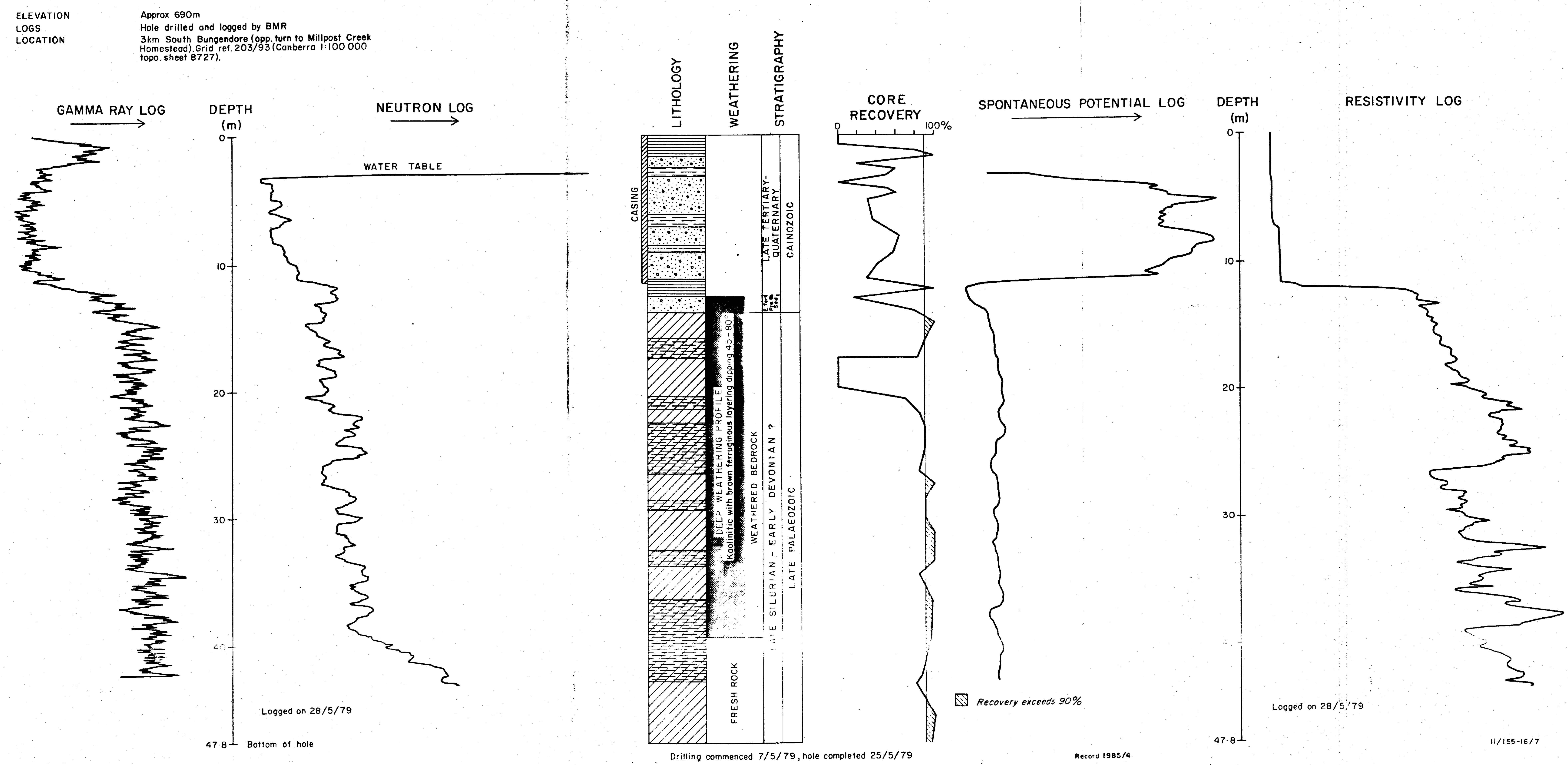
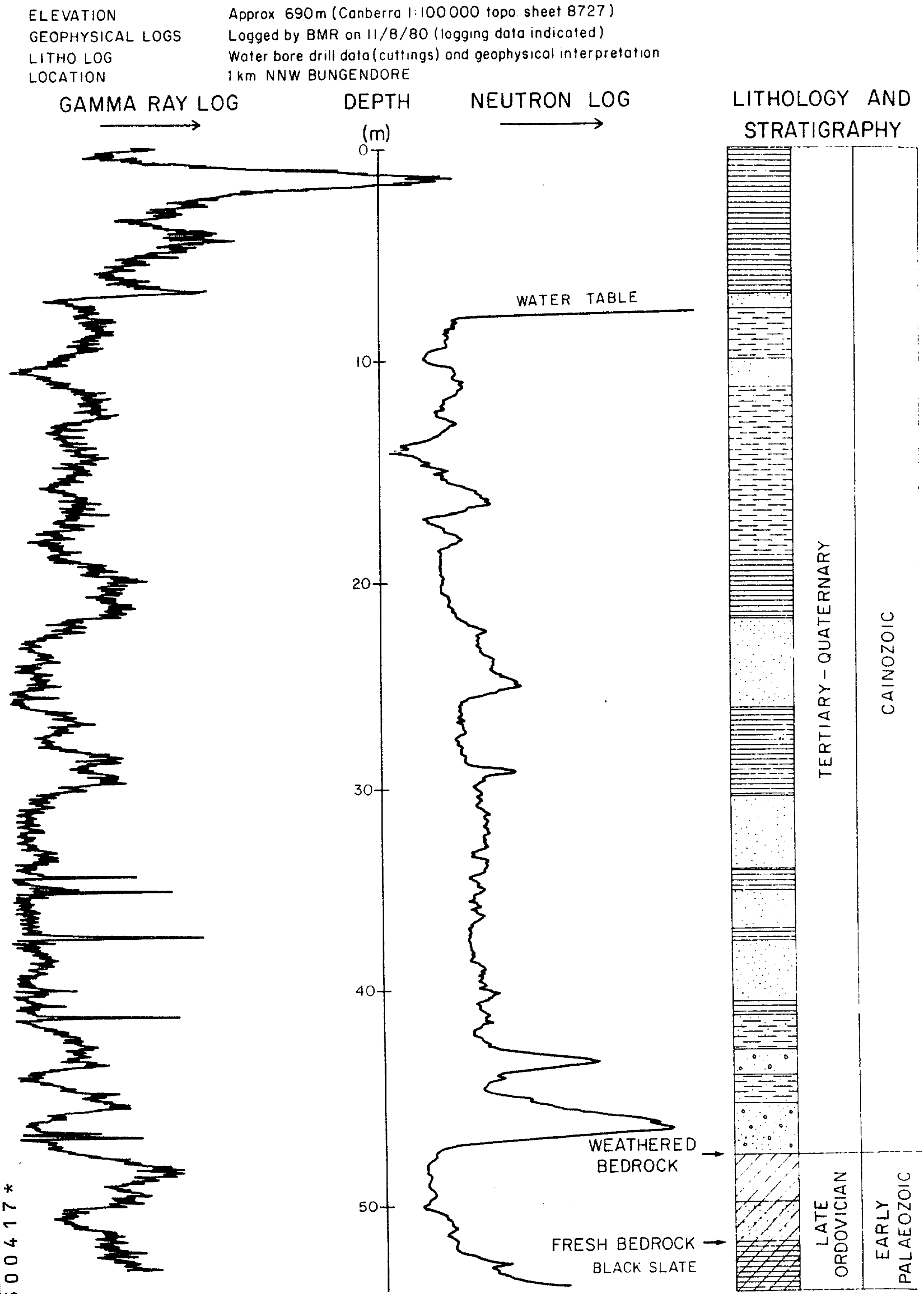


Fig. 28 Geological and geophysical logs of BMR drillhole C295



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Record 1985/4

Fig.29 Geological and geophysical logs of WRC waterbore 30809

ELEVATION — Approx 690m (Canberra 1:100 000 topo. sheet 8727)
GEOPHYSICAL LOGS — Logged by BMR on 24/7/80 (logging data indicated)
LITHO LOG — Water bore drill data (cuttings) and geophysical interpretion
LOCATION — 1km NNW BUNGENDORE

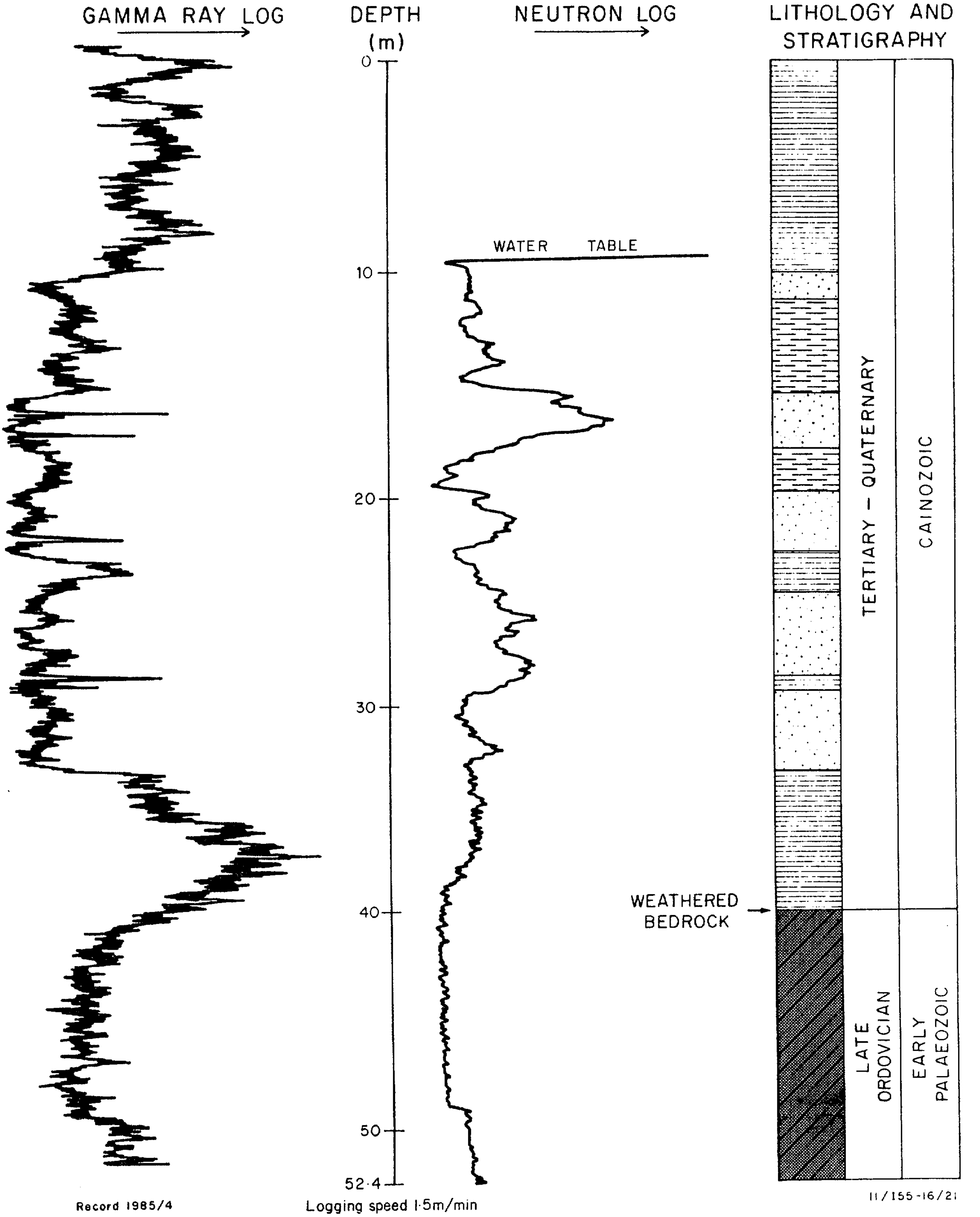


Fig. 30 Geological and geophysical logs of WRC waterbore 30816

ELEVATION Approx 690m (Canberra 1:100 000 topo. sheet 8727)
GEOPHYSICAL LOGS Logged by BMR on 24/7/80 (logging data indicated)
LITHO LOG Water bore drill data (cuttings) and geophysical interpretation
LOCATION 1km NNW BUNGENDORE

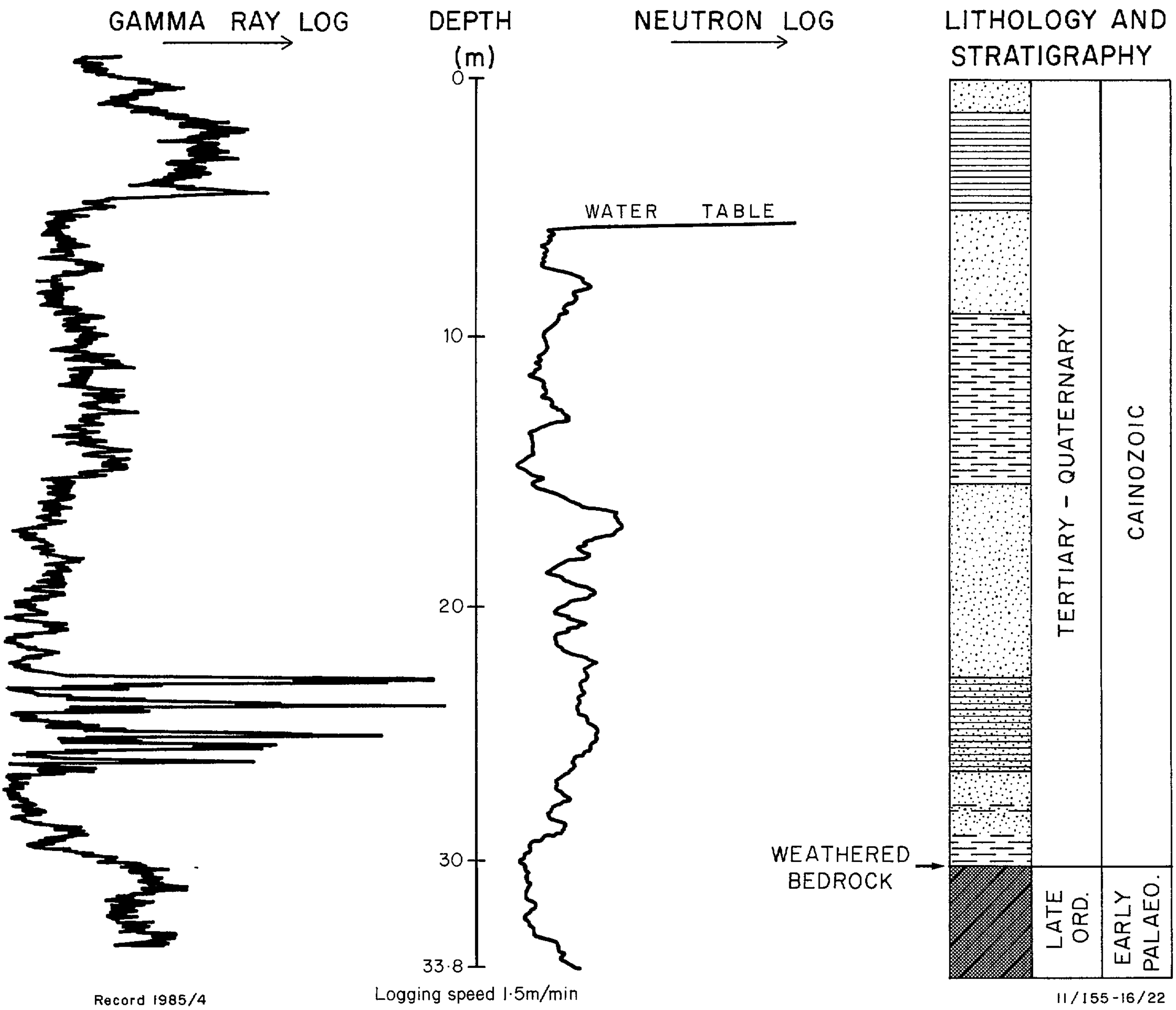
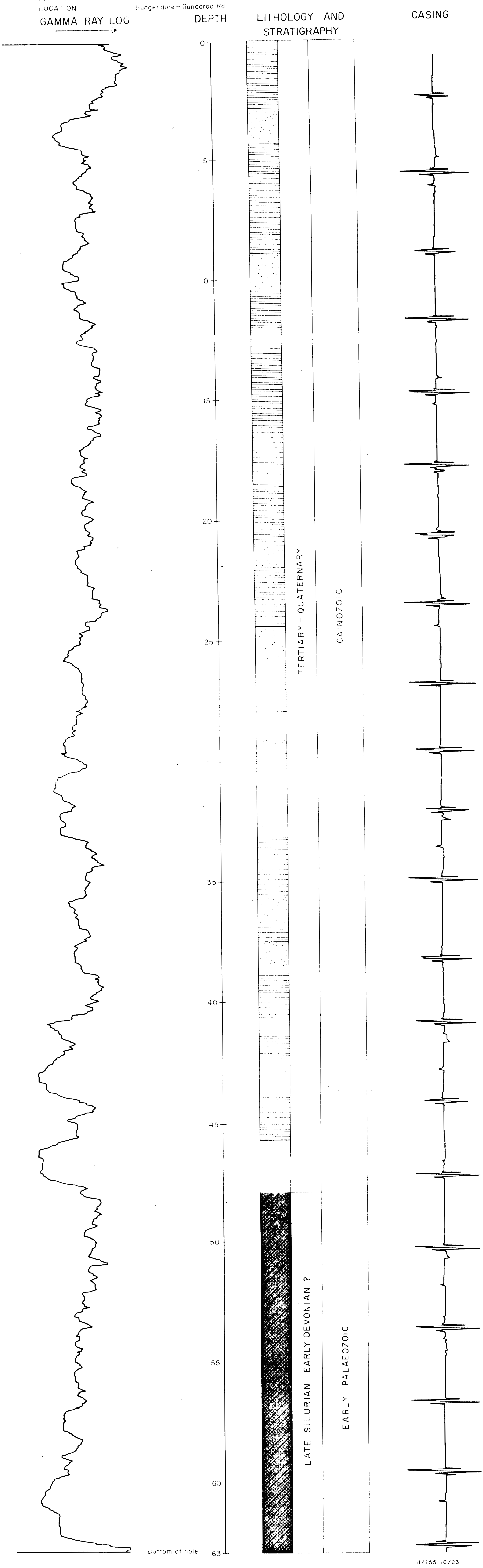


Fig. 31 Geological and geophysical logs of WRC waterbore 30823

ELEVATION	Approx 690 m (Canberra 1:100 000 topo. sheet 8727)
GEOPHYSICAL LOG	Logged by BMR on 28/8/80 using portable WIDCO logger
LITHO LOG	Water bore drill data (cuttings) and geophysical interpretation
LOCATION	Bungendore – Gundaroo Rd

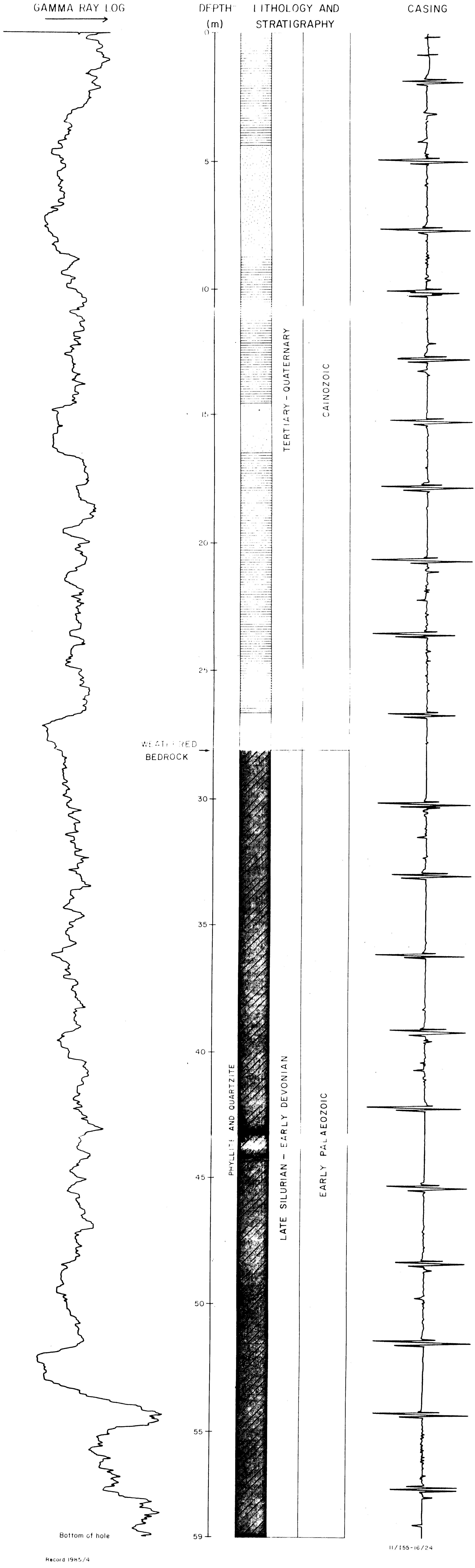


Record 1985/4

11/155-16/23

Fig. 32 Geological and geophysical logs of WRC waterbore 30829

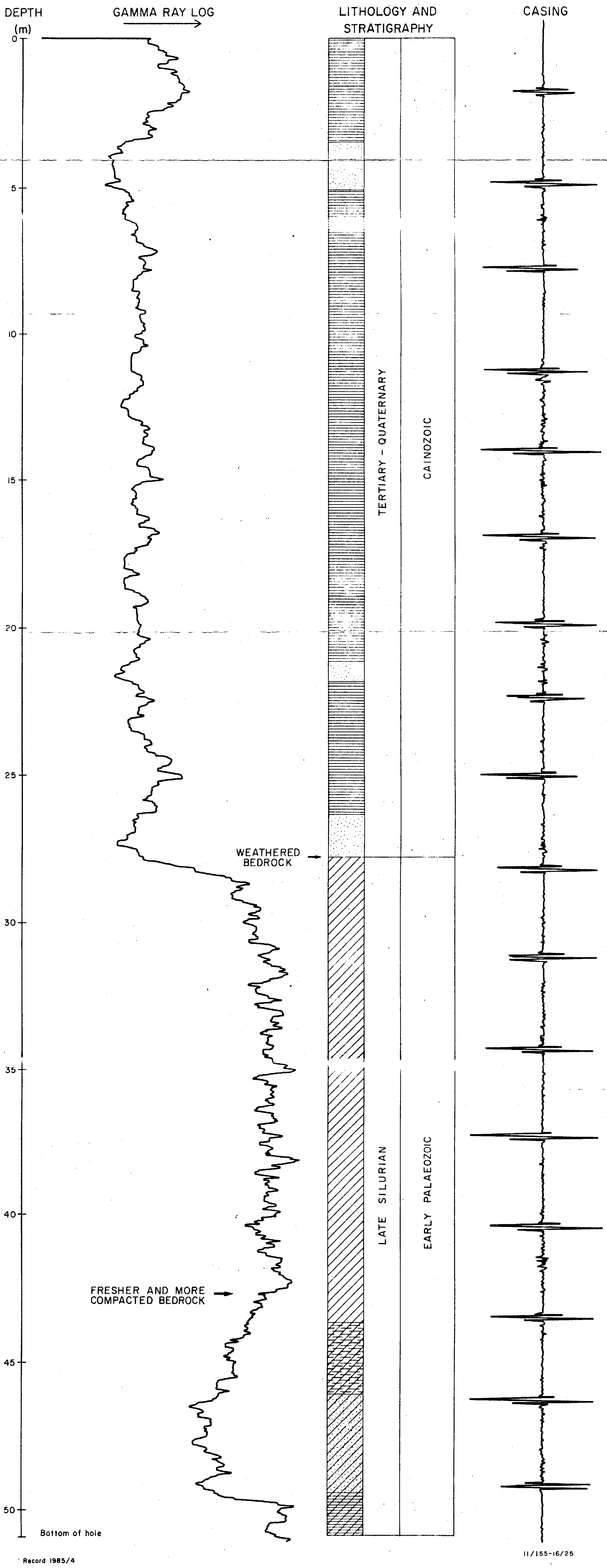
ELEVATION	Approx 690m (Canberra 1:100 000 topo sheet 8727)
GEOPHYSICAL LOG	Logged by BMR on 12/9/80 using portable WIDCO logger
LITHO LOG	Water bore drill data (cuttings) and geophysical interpretation
LOCATION	Bungendore – Gundaroo Rd



Record 1985/4

Fig. 33 Geological and geophysical logs of WRC waterbore 30835

ELEVATION	Approx 690m (Canberra 1:100 000 topo. sheet 8727)
GEOPHYSICAL LOGS	Logged by BMR on 25/9/80 using portable WIDCO logger
LITHO LOG	Water bore drill data (cuttings) and geophysical interpretation
LOCATION	Bungendore – Gundaroo Rd.



Record 1985/4

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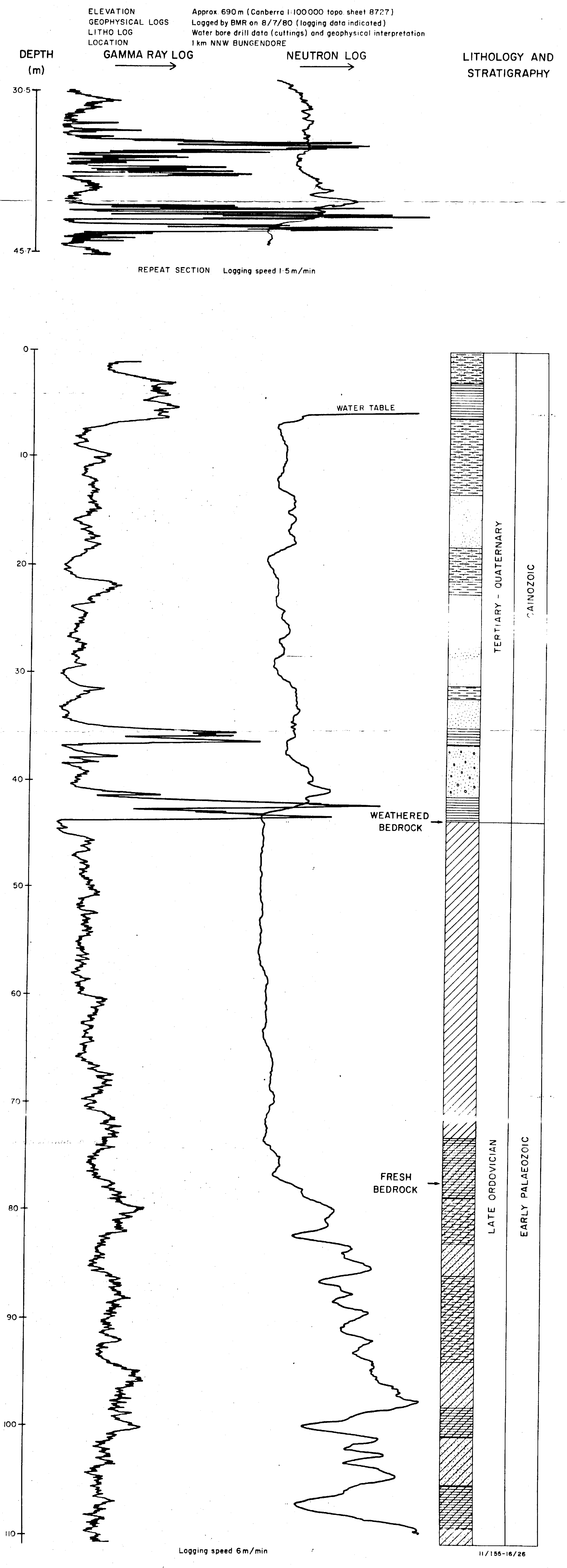
Fig. 34 Geological and geophysical logs of WRC waterbore 30839



Record 1985/4

Fig. 35 Geology and geophysical logs of WRC waterbore 31363

Record 1985/4

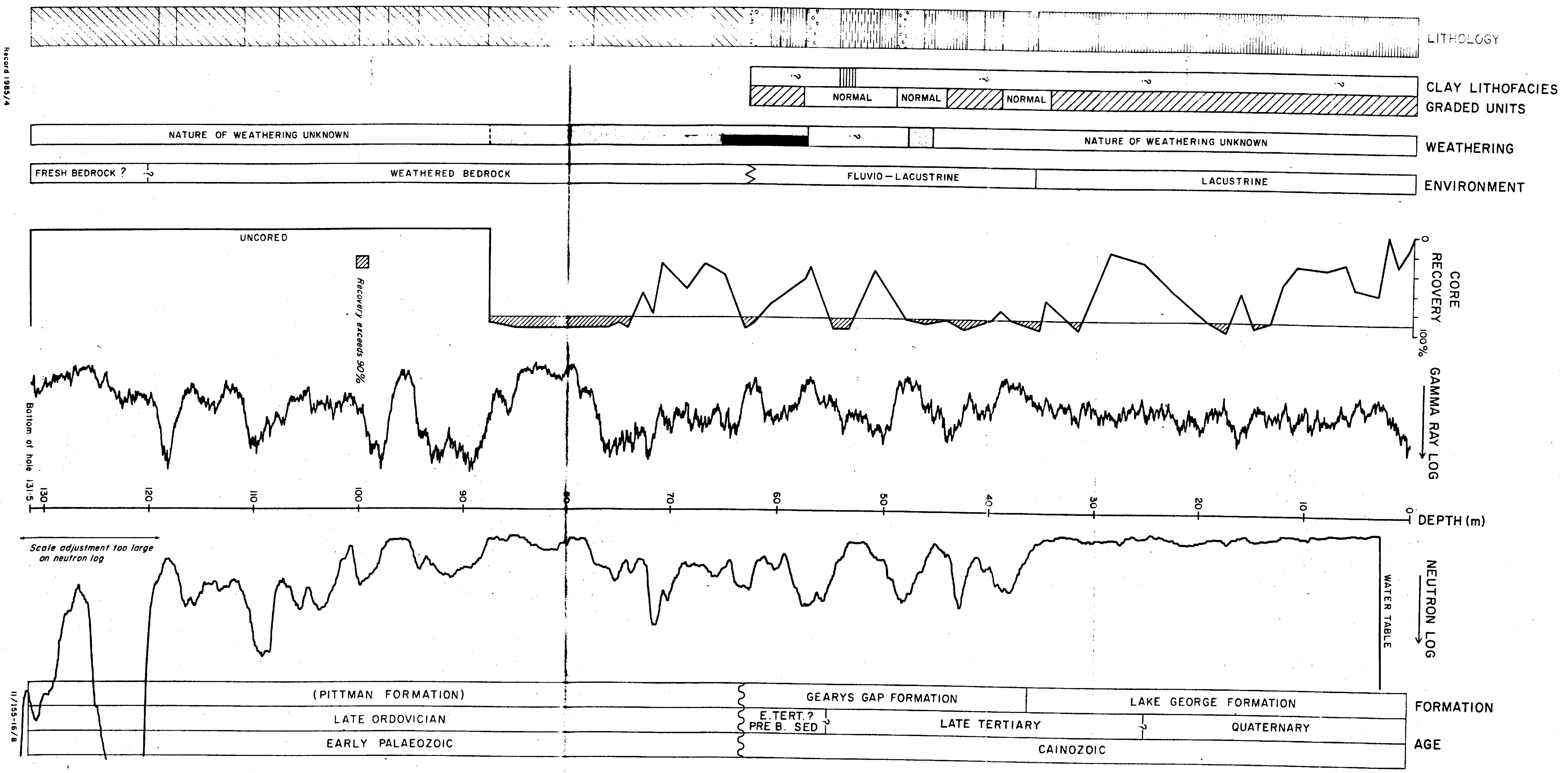
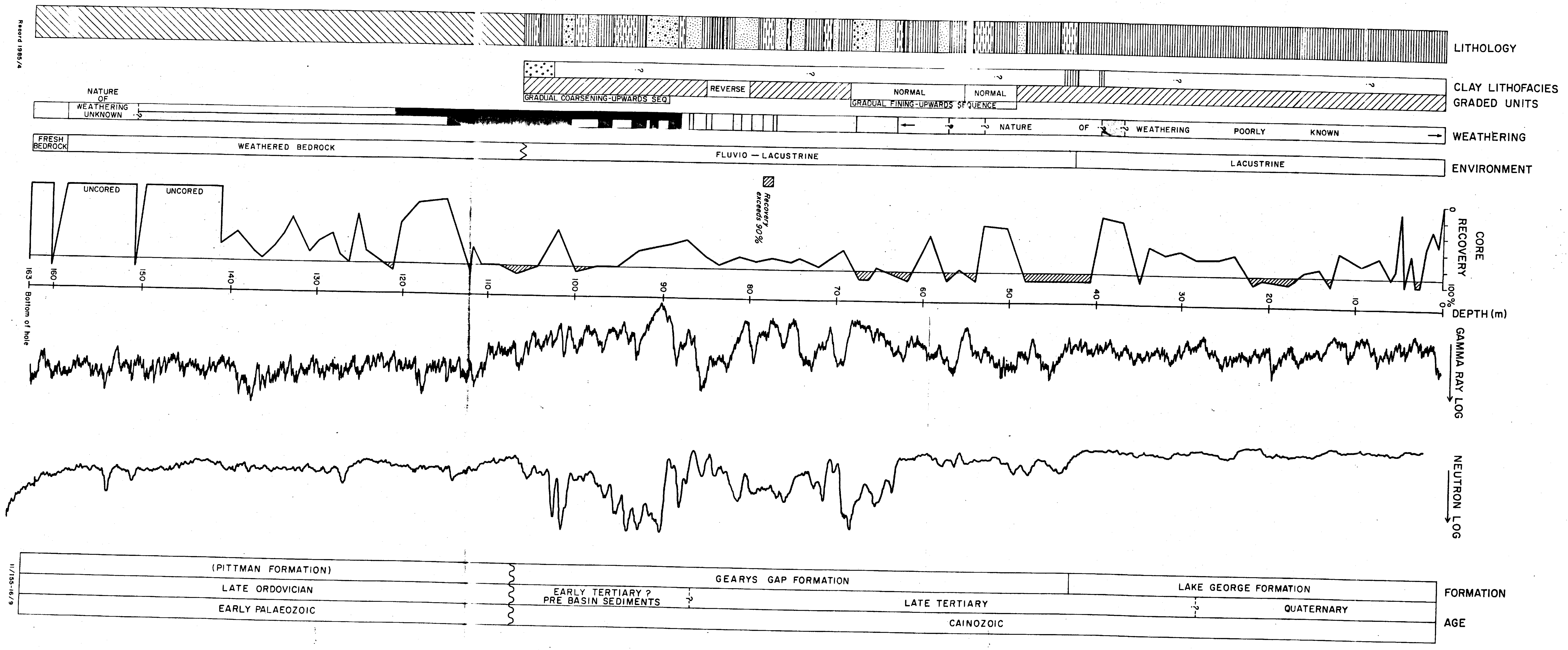


Fig. 36 Geological and geophysical logs of BMR drillhole C351

Record 1985/4



11/155-16/9

Fig. 37 Geological and geophysical logs of BMR drillhole C352

Record 1985/4

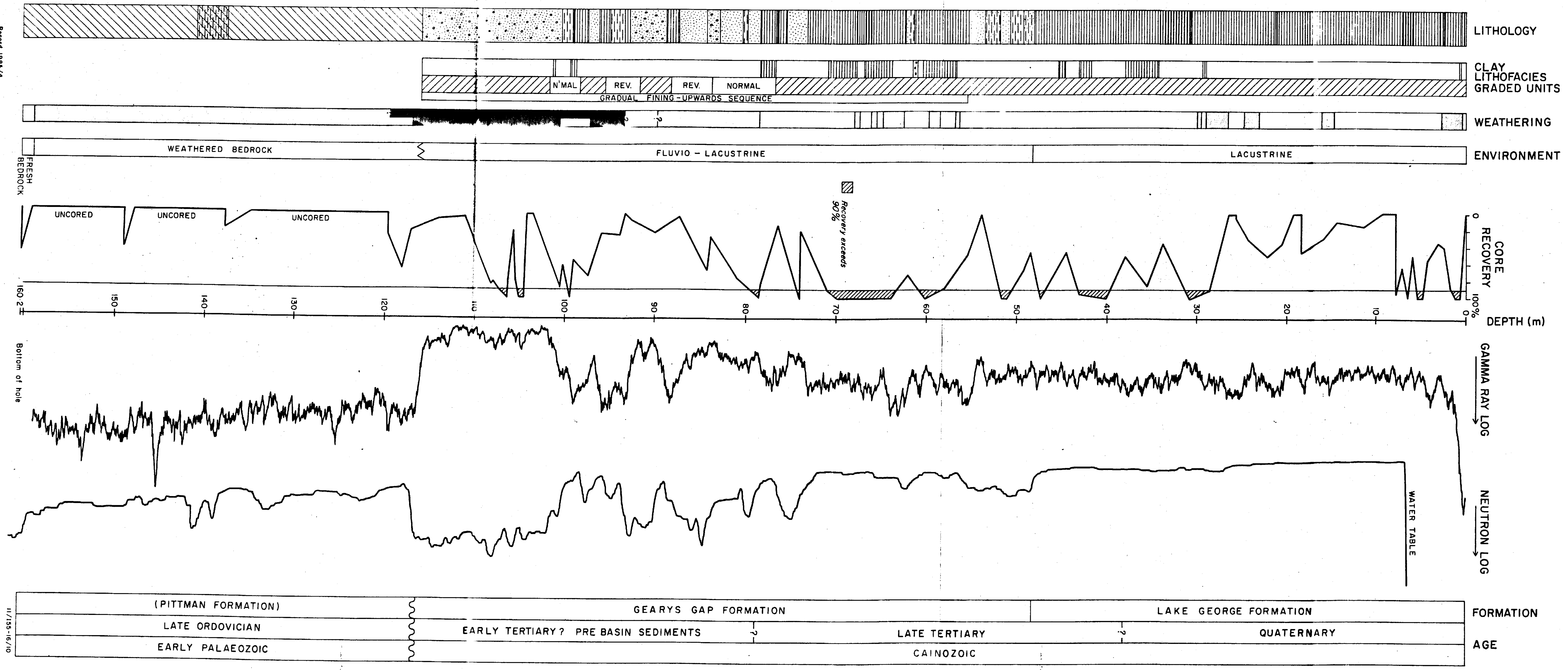
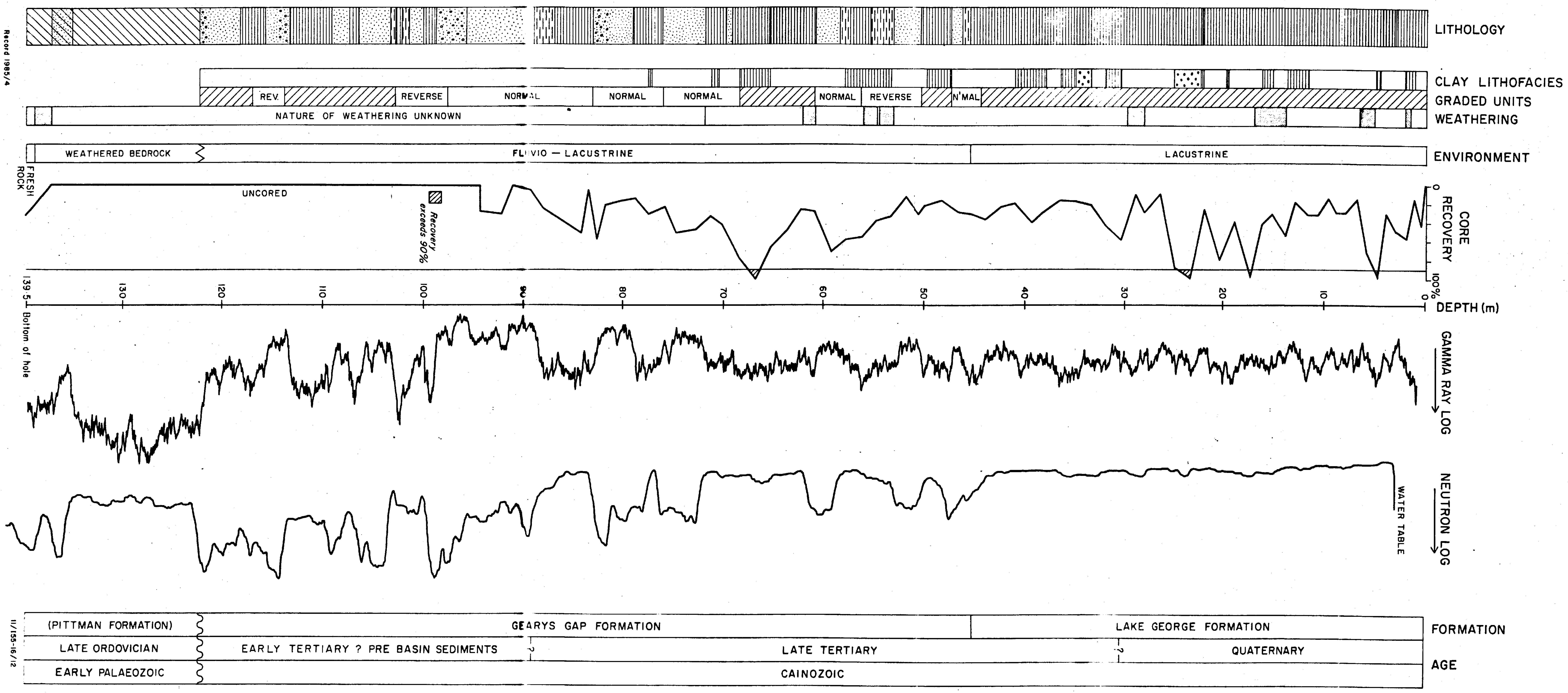


Fig 38 Geological and geophysical logs of BMR drillhole C353

Record 1985/4

Fig 39 Geological and geophysical logs of BMR drillhole C354

Record 1985/4



11/155-16/12

Fig. 40 Geological and geophysical logs of BMR drillhole C355

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Record 1985/4

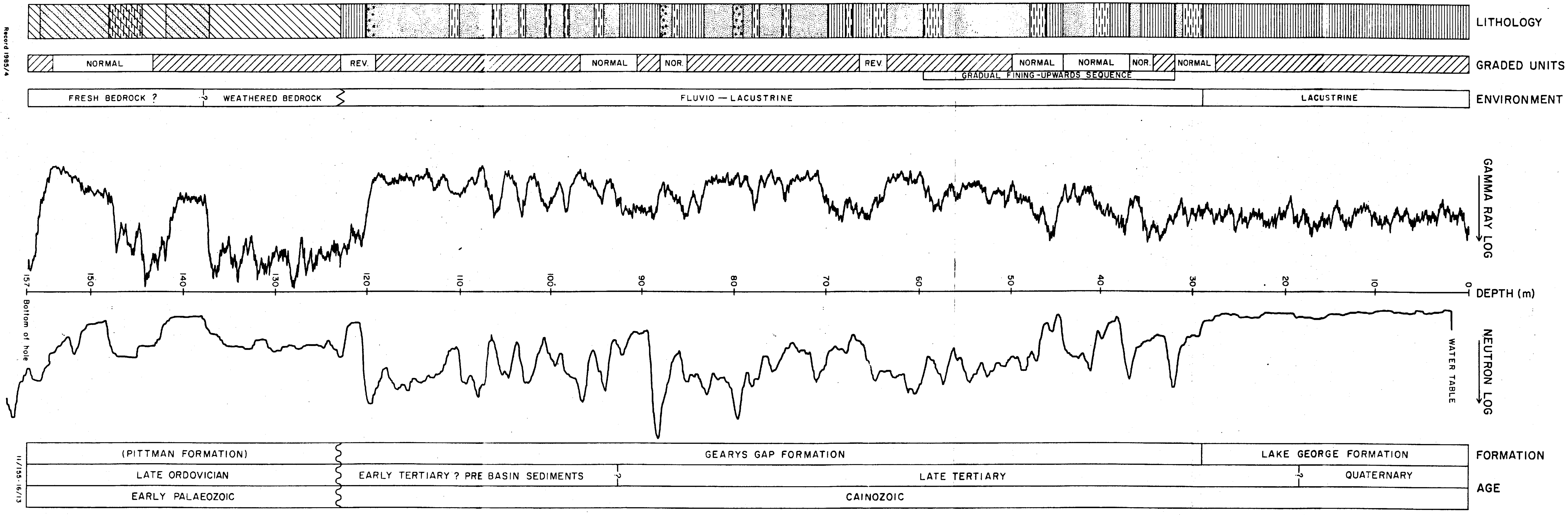


Fig. 41 Geological and geophysical logs of BMR drillhole C356

Record 1985/4

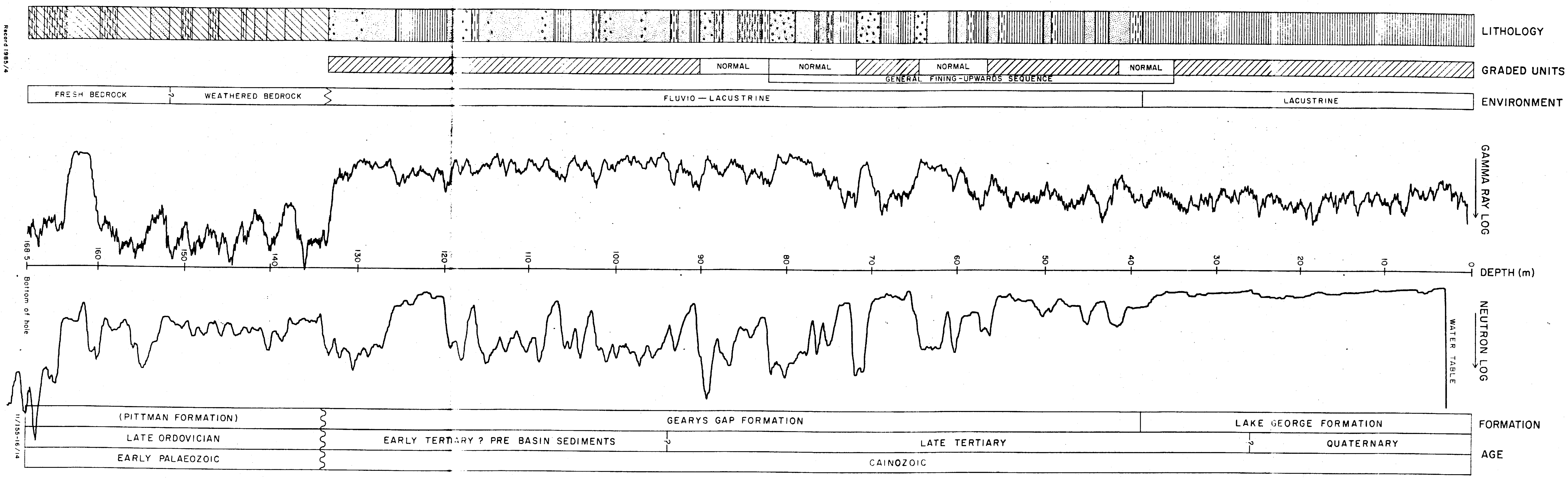


Fig. 42 Geological and geophysical logs of BMR drillhole C 357

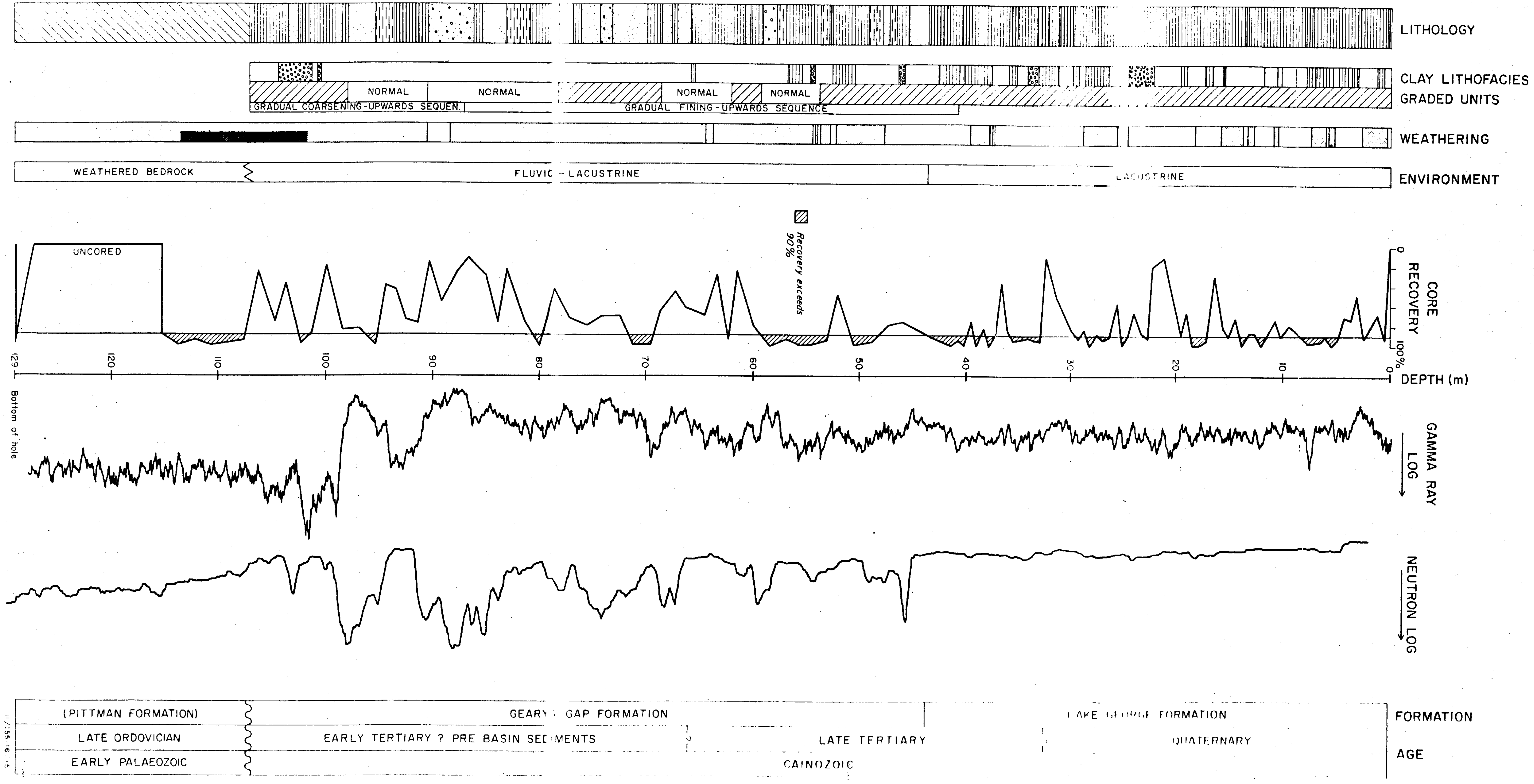
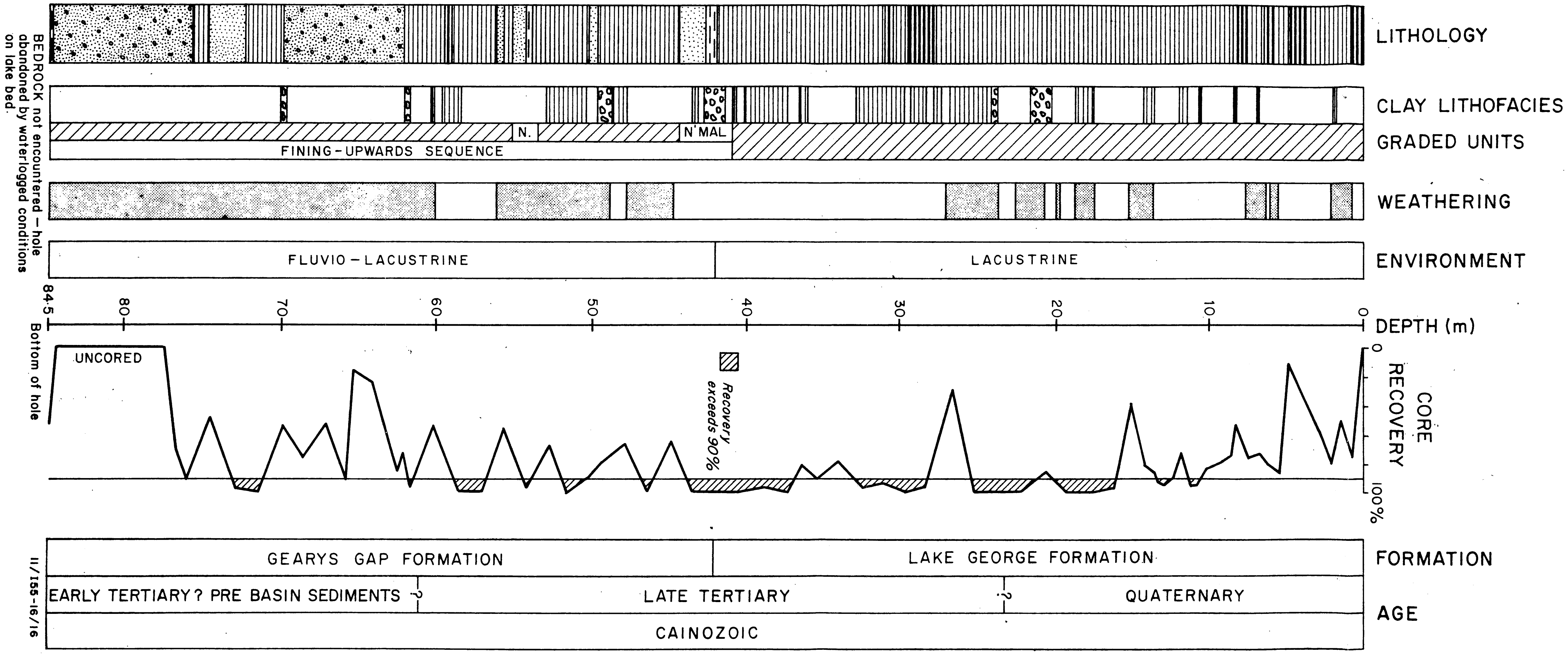


Fig.43 Geological and geophysical logs of BMR drillhole C358



Record 1985/4

Fig. 44 Geological and geophysical logs of BMR drillhole C359

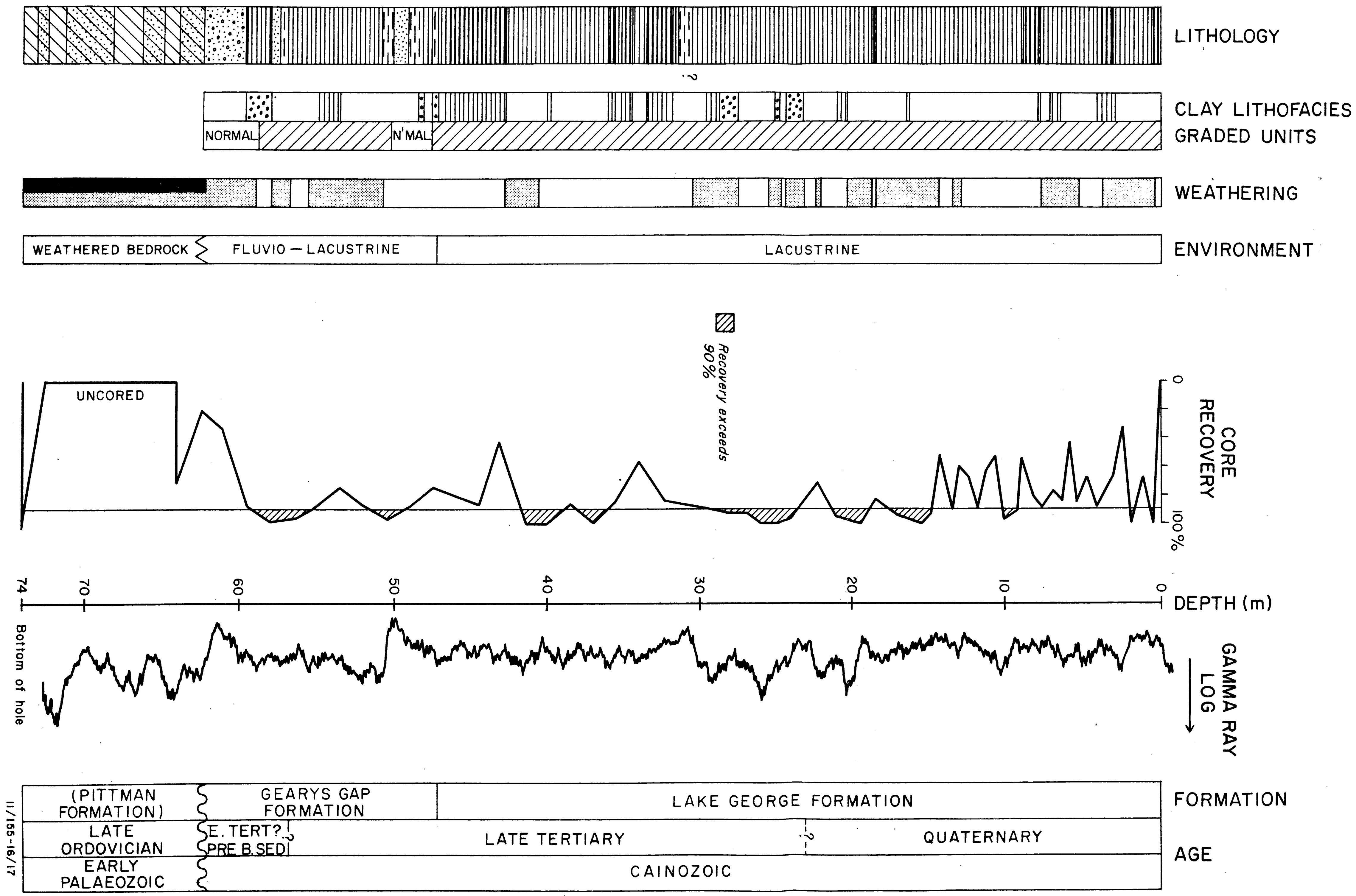


Fig.45 Geological and geophysical logs of BMR drillhole C360

Record 1985/4

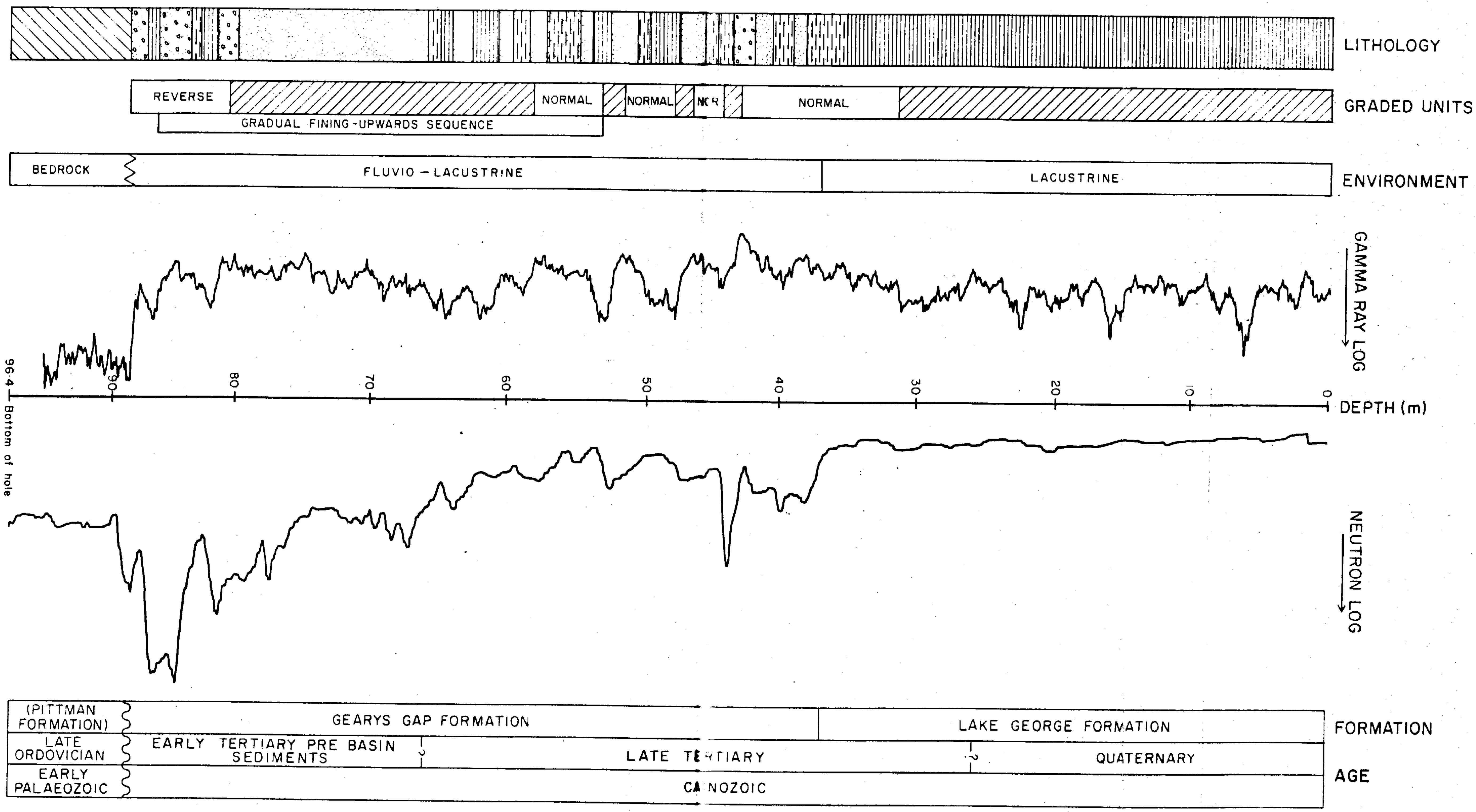
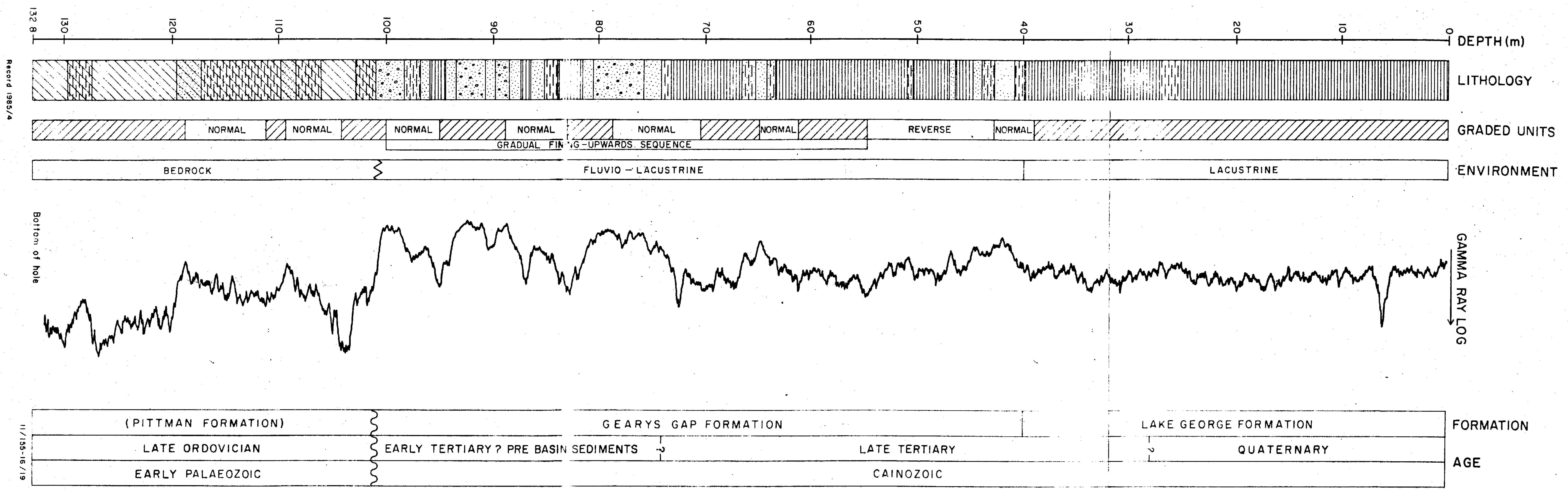


Fig. 46 Geological and geophysical logs of BMR drillhole C 361



Record 1985/4

Fig. 47 Geological and geophysical logs of BMR drillhole C362