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ALLUVIAL TERRACES IN THE MARIBYRNONG VALLEY NEAR KEILOR, VICTORIA

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Abstract

Examination of alluvial stratigraphy from soil pit exposures, excavations, and cores has been combined with a topographic survey, textural and radiocarbon analyses to provide a detailed account of the late Pleistocene to Holocene river terraces and the climatic environments which controlled them.

Sediments of the Keilor terrace in which human remains were located at Green Gully are fine-textured throughout. This, combined with evidence of horizontal ground-surface development through most of the terrace history, points to vertical flood-plain aggradation by deposition from overbank flow in a suspended load regime, rather than from bed-load or point-bar deposits. The stratigraphic relationships between terrace contacts are considerably more complex than a normal cut-and-fill sequence. Where channel incision has occurred into older terrace sediments, slumping and colluviation have formed an additional sedimentary unit with soil developed on it, separating the older from the younger alluvial fill. In the case of the Keilor terrace, younger alluvium has overtopped it, depositing a thin cover of sediment, burying the terrace soil and the colluvial deposit at the terrace margin.

Radiocarbon analyses place the deposition of the Arundel alluvium before 31,000 B.P. This terrace was eroded from 31,000 to about 16,000 B.P. corresponding to the main temperature lowering during the last glacial maximum. Major aggradation of the Keilor terrace extended from approximately 15,000 B.P. to about 12,000 B.P. when floodplain sedimentation became infrequent permitting soil formation to begin. These conditions continued until after the burial (about 6,500 B.P.) with occasional overbank deposition during infrequent high stage flow. During this period, the Keilor terrace chernozemic soil was actively forming with carbonate segregation and intense biotic activity, simultaneously with floodplain erosion by lateral stream incision. Later floodplain aggradation started about 4,500 B.P., depositing a thin cover of alluvium over the Keilor floodplain, burying the grave and forming the younger alluvial deposits including the Maribyrnong terrace.

Following the climatic-hydrologic relationships of Schumm and Langbein, the major phases of deposition are tentatively correlated with low discharge and rising temperature regimes; erosion and soil formation are attributed to high discharge and low temperature environments. Erosion during cold glacial conditions was followed by aggradation of the Keilor floodplain which accompanied rising temperatures and increased evaporation after 15,000 B.P. Red-brown earth soils formed on Arundel terrace alluvium from before 31,000 to about 15,000 B.P. corresponding to the minimal ages postulated for the formation of similar soils on the Riverine Plain in N. Victoria. The chernozemic soil of the Keilor terrace is a polygenetic profile formed by the burial of an older profile beneath younger alluvium. Black alluvial soils with minimal profile development occur on the Maribyrnong terrace the upper surface of which is approximately 2,000 years old.

The terrace stratigraphy, sediments, soils and radiocarbon data from this valley provide a detailed basis for comparison with other fluviatile sequences, and demonstrate the important effects of late Quaternary climates on the soils and surficial deposits in this non-glaciated region of SE Australia.

PART I

Introduction

The discovery of human remains in a soil pit near Keilor in August 1965 initiated an intensive archaeological and stratigraphic study of the area. Previous investigation of human occupation near Keilor had emphasized the importance of the Quaternary stratigraphy and depositional environments in this, one of the best developed river terrace sequences in Victoria. The skeletal remains were discovered by Mr D. Mahon in a soil pit near the junction between the Maribyrnong River and one of its W. tributaries, Green Gully. The pit had been excavated in terrace silts one mile downstream from the township of Keilor and two miles from the site of the Keilor cranium discovered in a similar terrace in 1940. The circumstances of the present discovery have been described elsewhere (Bowler *et al.* 1967, Casey and Darragh, *this volume*).

The site lay in a complex topographic setting in which much of the original terrace detail had been altered or destroyed by soil pit operations. To provide an understanding of the formation, chronology, and environment of human occupation of the terraces, it was necessary to reconstruct the stratigraphic detail both within the limits of the soil pit area and, in the broader context, within this part of the valley. Following a request from the Director of the National Museum of Victoria, the author agreed to undertake this aspect of the investigation in conjunction with archaeologists from the National Museum and the Australian National University.

In the interests of clarity and accessibility of data, this paper is presented in three parts. Following the Introduction (Part I), the second part is limited to those aspects of the investigation specifically related to the burial site and the context of the archaeological excavations carried out in the soil pit region. The third brings together details of the terrace sequence beyond those of immediate archaeological interest, and from a detailed chronologic and stratigraphic account, presents a discussion on the origin and environmental significance of the sequence.

Regional description

Near Keilor, the Maribyrnong River has incised its valley some 200 ft below the level of the late Tertiary to early Quaternary basalts which form the plains. It has cut through a sequence of sub-basaltic Tertiary sands, Lower Tertiary Older Basalt, to Silurian sandstones, greywackes and shales which form the basement throughout the Melbourne area. Where it is restricted by resistant lithologies, the river runs in a narrow valley with steep sides, as near the highway bridge at Keilor. Upstream from such constrictions, the river has excavated a wide valley by lateral erosion. These areas have been extensively alluviated and in them the best terrace sequences are preserved. The cranium discovered in 1940 was located within one such area upstream from Keilor. The present burial site is located in a similar section of the valley upstream from another narrow reach (Fig. 1).

Previous work and terrace identification

Following the discovery of the Keilor cranium, three main terraces were traced through the Maribyrnong Valley by Keble and Macpherson (1946) which they named in descending altitude Keilor, Braybrook and Maribyrnong. At Green Gully, a W. tributary of the Maribyrnong River (Saltwater Creek in Fig. 5, Keble and Macpherson), they recorded a fourth unnamed terrace between the Braybrook and Maribyrnong levels. A higher and older terrace, the Arundel, was subsequently recognized by Gill (1957) on the basis of topographic, soil and sedimentary characteristics. Gill reinterpreted the Braybrook terrace of Keble and Macpherson, by suggesting that the surface so identified was an erosion surface cut into sediments constituting the Keilor terrace, which he termed the Doutta Galla Silt (Gill 1953, 1957, 1962).

In the present study, the terrace levels for approximately ½ mile upstream and downstream from the soil pit have been determined by tacheometer survey based on a Melbourne and Metropolitan Board of Works datum referred to low water at Williamstown. In Table 1, the terrace levels recognized in this survey are compared with those recorded by Keble and Macpherson.

Near Green Gully, three paired and two unpaired terraces are preserved. That in which the burial was located is developed on both sides of the river between R.L. 64-58 ft and is correlated with the Keilor terrace in which the Keilor cranium was found (Mahony 1943). This correlation is based on topographic levels and continuity of the terrace between sites, similar sediments and a characteristic soil profile developed on the terrace at both localities. The correlation has been confirmed by radiocarbon dating. Near Mahon's soil pit, three terraces are distinguished below the Keilor terrace between R.L. 53-49 ft, 47-44 ft, and 44-42 ft respectively. Two additional levels occur higher than the Keilor terrace but are not considered here in detail.

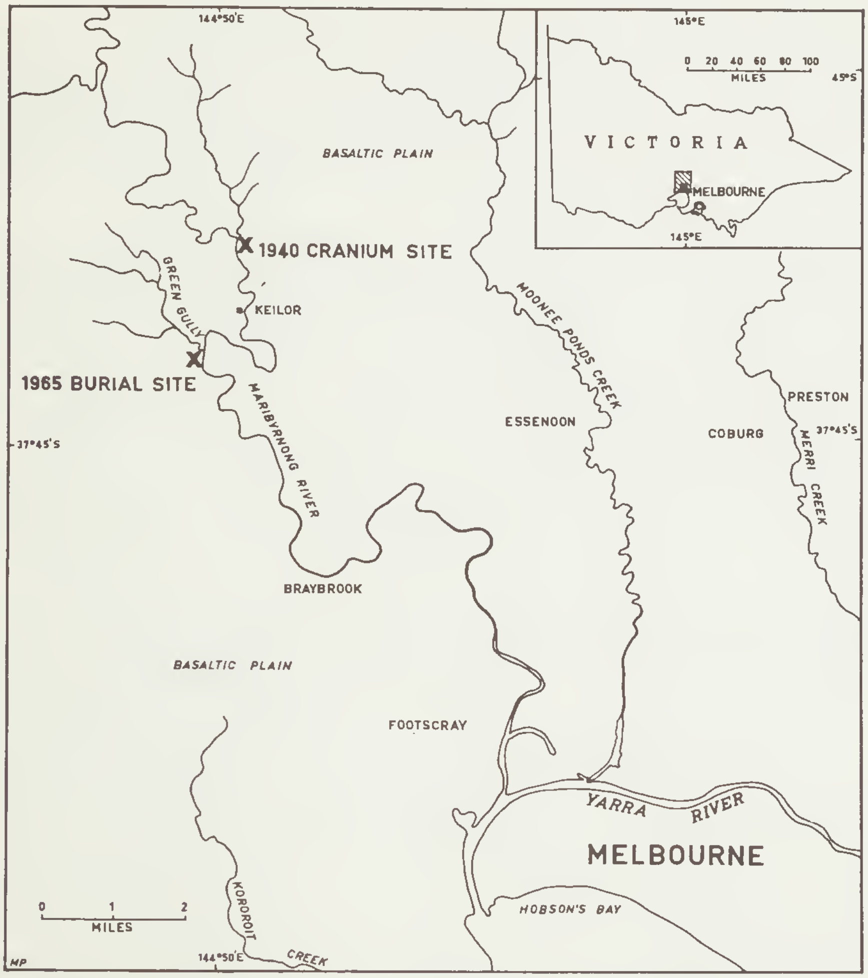

Fig. 1—Location of Maribyrnong River (incised into the Western Victorian basaltic plain near Melbourne), and of the two main archaeological sites near Keilor.

TABLE 1

Elevation of terrace levels in Maribyrnong River at junction with Green Gully

From Keble and MacPherson, Fig. 5, 1946		Present tacheometer survey	
Terrace	approx RL (ft)	Terrace	Average RL (ft)
River bed	24	River bed	23
Maribyrnong	44	GGM	44
Unnamed	54	GGL	48
Braybrook	64	GGJ	52
Keilor	72	Keilor	63
		Arundel A	76
		Arundel B	96

To avoid unwarranted assumptions in correlating with sequences previously described, an informal nomenclature has been adopted for those levels below that of the Keilor terrace. The following names have been allocated to these terraces in order from highest to lowest: Green Gully J (GGJ), Green Gully L (GGL), and Green Gully M (GGM).

Since the Keilor terrace identified in the present survey is in reality equivalent to the type locality of that terrace defined by Keble and Macpherson at the original skull site, these authors appear to have surveyed the Arundel level (near 76 ft) at Green Gully and correlated this with the Keilor terrace. Their Braybrook level is therefore equivalent to Keilor, and their unnamed terrace equates with the Braybrook. These levels are identical, within the limits of accuracy, with those surveyed near Mahon's soil pit.

In the present survey, the level GGL is more extensively developed than GGM. In all probability it was the GGL surface which was levelled by Keble and Macpherson and would be equivalent to their Maribyrnong terrace even though this involves a difference of four feet between the surveyed levels. The surface of GGM is represented by a small area on the right bank of the river near the soil pit, and was not recorded by Keble and Macpherson, or if surveyed by them, it was included with the Maribyrnong terrace. However, different soils and sediments establish these two levels as representing two distinct phases of deposition. This interpretation also removes an apparent anomaly in Keble and Macpherson's figure 5, in which the unnamed terrace begins at Green Gully junction and continues downstream, but which has no upstream extension. On the interpretation above, this terrace would be equivalent to their Braybrook, which they identified further upstream and incorrectly correlated at Green Gully with the Keilor level.

Gill (1953, 1957) has equated the sediments of the Braybrook terrace with those of the Keilor terrace. Both are said to have identical sediments, diastem and soils, although there is a slight difference in elevation (Gill 1957 p. 2). The sediments of these terraces have been formally defined as the Doutta Galla Silt, for which the type locality is located at the Dry Creek section (Gill 1962). The Braybrook terrace of Keble and Macpherson is regarded by Gill as an erosion surface cut into sediments of the Keilor terrace, but since no evidence to vindicate this interpretation has been published it should not be assumed that every surface so named by Keble and Macpherson has in fact originated in this manner. They recognized the continuity of the Braybrook surface along the Maribyrnong Valley at Green Gully although, as indicated above, they miscorrelated the levels at this site. Detailed examination at Green Gully has failed to produce evidence of a terrace surface having been produced by erosion into the Doutta Galla Silts. In fact, the evidence cited below demonstrates that each terrace surface corresponds to a phase of deposition and is separated from its neighbour by an erosional disconformity. While Gill's explanation of the Braybrook terrace may be valid in some parts of the valley, it does not provide a satisfactory working hypothesis in the context of the Green Gully soil pit. All the sediments within the pit would, within Gill's lithological definition, belong to the Doutta Galla Silt despite the soils, disconformities and unconformities developed within them (see p. 28).

To avoid a multiplicity of names in the discussion which follows, a procedure has been adopted in which the sediment relating to any particular terrace is referred to as 'sediment of terrace X' or 'X terrace sediment'. Thus the Keilor terrace sediment may or may not be differentiated from sediment of terrace GGJ depending on their stratigraphic and lithological relationships. This use of informal nomenclature is advocated until such time as the continuity and limitations of the units recognized here have been further defined. A stratigraphic code for the description and erection of formal units in unconsolidated Quaternary alluvial deposits presents additional and difficult problems which will not be dealt with here.

PART II

Stratigraphy of Green Gully Burial Site

The original terrace surfaces had been considerably altered by cultivation on the E. side of the river and by the soil pit operations on the W. These alterations and excavations had in places exposed the stratigraphy to examination, but in so doing had sometimes destroyed the original continuity of stratigraphic horizons. Reconstructions of both the terrace topography and stratigraphic relationships were therefore a necessary first step in deducing the stratigraphic history and chronology of the terrace sequence and the environmental factors controlling it.

Aerial photographs, taken in 1956 before the pit was opened, permitted reconstruction of most of the terrace detail in the immediate vicinity of the pit and on the opposite side of the river, later altered by cultivation. In addition, a survey of the soil pit area was carried out by Garner and Associates in 1962, before bulldozing commenced. Garner's original pegs were relocated and, with the original plan and sections, these facilitated the reconstructions of the topographic surface. One surveyed line passed almost directly over the burial site, allowing its position to be fixed relative to the original contact between terrace surfaces. By using these independent lines of evidence, the plan and levels of the undisturbed terrace surfaces have been reconstructed as shown in Figs. 2 and 3.

Stratigraphic units

The August 1965 outline of the soil pit at the contact between the terraces is shown in Fig. 4. Sediments of the Keilor terrace were exposed on the W. and SW. sides while the NW. sides were cut in sediments of terrace GGJ. Five soil-sedimentary zones were differentiated:

1. Sediment of Keilor terrace unaltered by soil profile development
2. The soil profile zone of the Keilor terrace (top 9-10 ft)
3. Sediments of terrace GGJ unaltered by pedogenesis
4. The soil profile zone of terrace GGJ (top 6-7 ft)
5. An indeterminate zone exhibiting both pedological and sedimentary features, and located between 1 and 3 above. This is referred to here as the *intermediate zone.*

The approximate distribution of the zones is indicated in the block diagram (Fig. 4).

Keilor terrace sediment

Basal gravels three to four feet thick (basalt, sandstone, quartzite and mudstone) passed up through two to three feet of medium to fine quartz sands to 20 ft of yellowish brown to dark grey very fine sands and silts which form the main body of the terrace. Primary depositional structures were virtually absent but traces of original depositional surfaces were preserved in the lower zone of the terrace sediment. At R.L. 42 ft a band of pink oxidized silt two to four inches thick with pellets of charcoal was traced in excavation, in auger holes, and in outcrop on the pit floor, varying in elevation only six inches over a lateral distance of 30-40 ft. This indicated a grass or forest fire of high intensity on a near-horizontal floodplain surface later sealed beneath younger alluvium.

Overlying this at R.L. 44 ft, a second horizontal surface was evident as a zone of yellowish brown silts with weakly developed prismatic cleavage. It main-

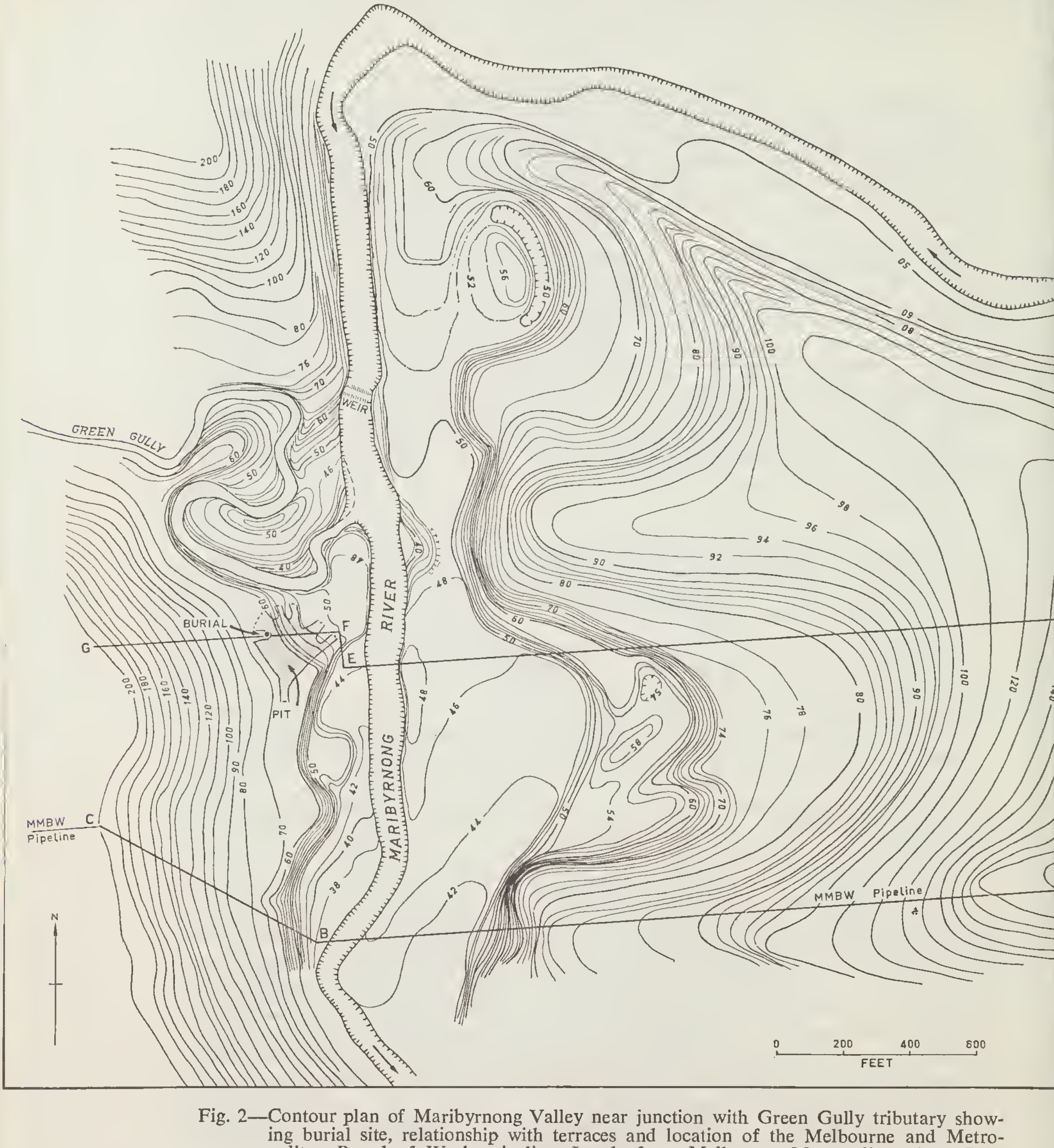

Fig. 2—Contour plan of Maribyrnong Valley near junction with Green Gully tributary showing burial site, relationship with terraces and location of the Melbourne and Metropolitan Board of Works pipeline. Levels from Melbourne Metropolitan Area Base Map Series, sheet 146, and from detailed tacheometer survey of terrace surfaces by author, August 1965. The contour interval changes from 2 ft below 100 ft to 5 ft above 100 ft. All levels in figures and text are referred to Low Water Mean at Williamstown.

tained an E-W horizontal attitude for more than 20 ft and coincided with a weak textural change, being overlain by medium to fine sands slightly coarser than the silts in which cleavage had developed. This weakly developed soil registered a

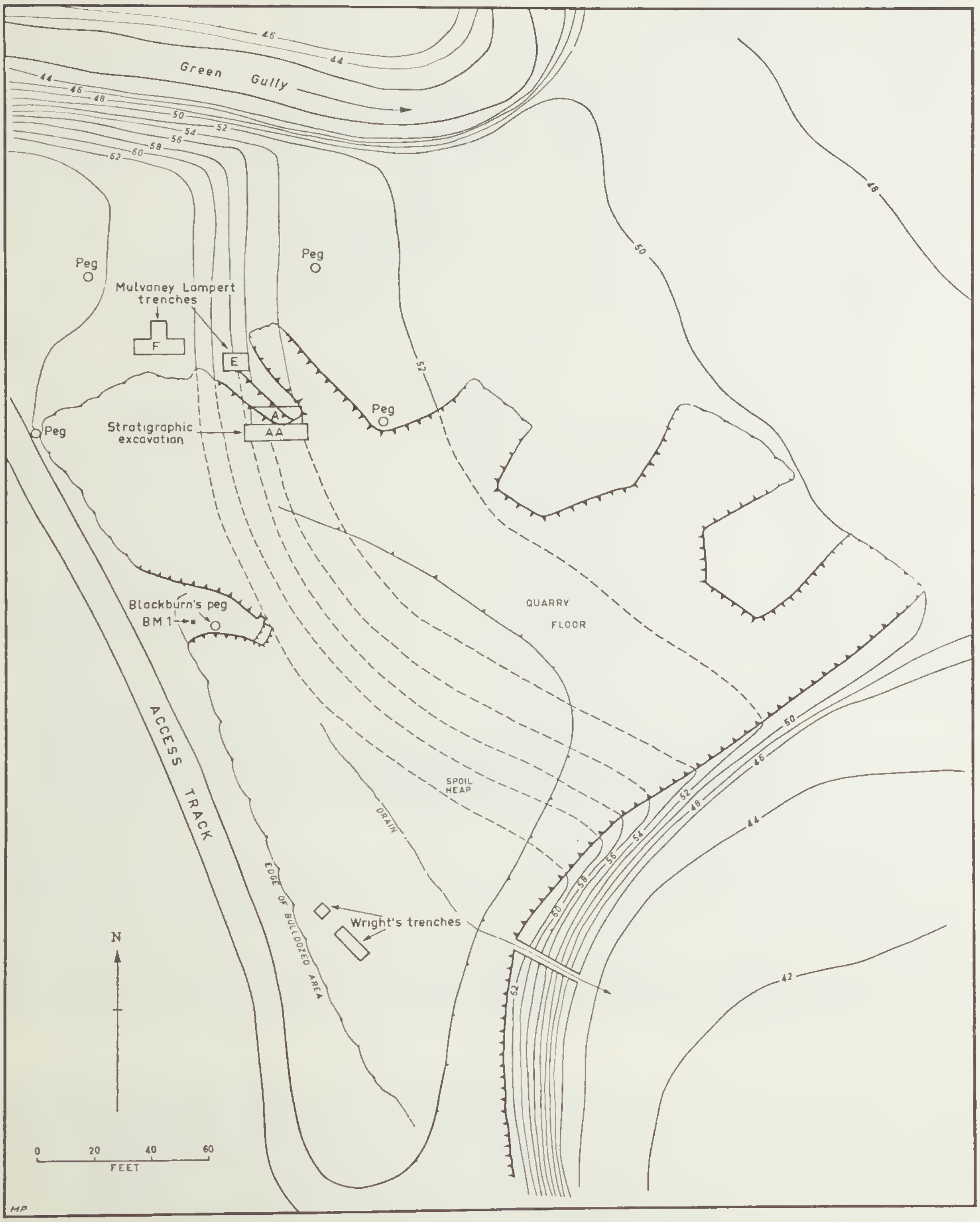

Fig. 3—Contour plan and outlines of Mahon's soil pit showing location of excavations in December 1965. Contours of original terrace surface (dashed lines), reconstructed from aerial photographs and survey by Garner and Associates, demonstrate proximity of burial to undisturbed terrace contacts.

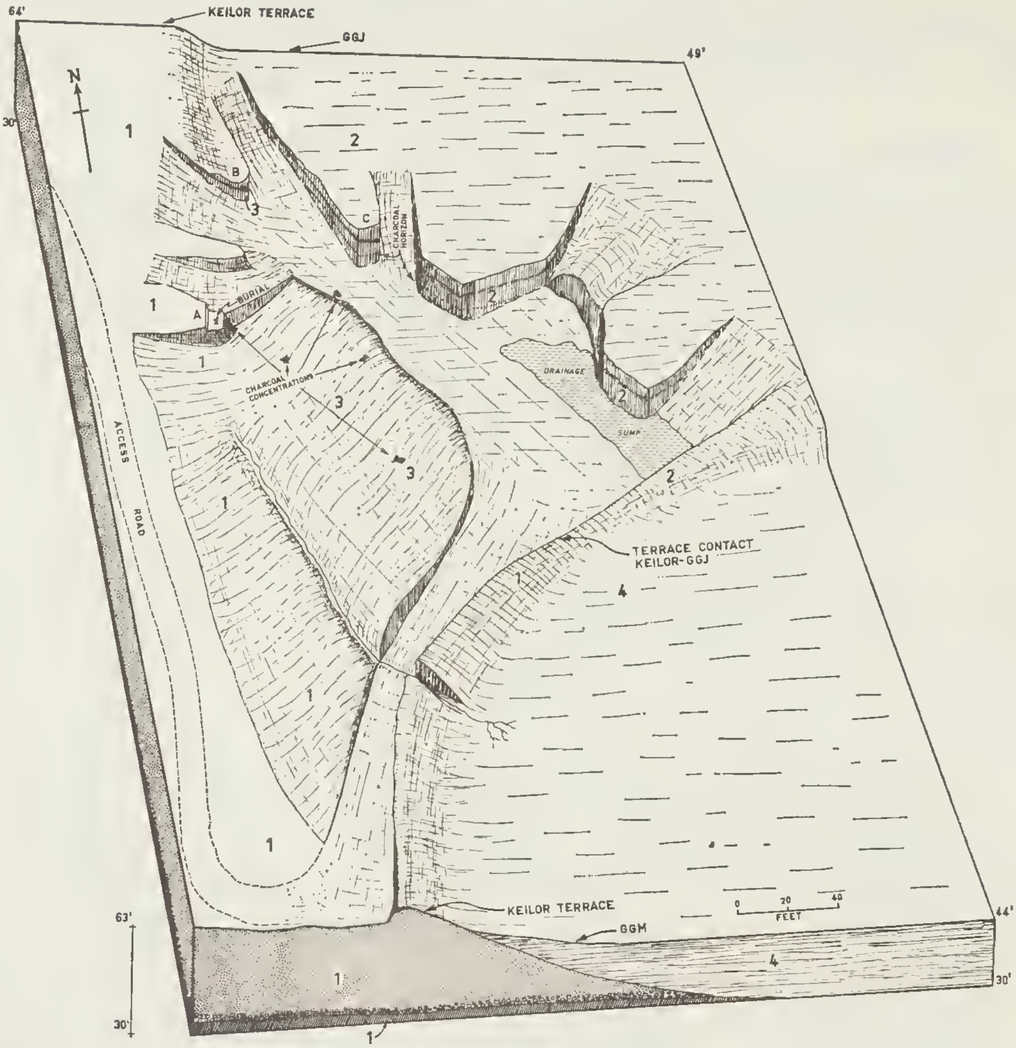

Fig. 4—Block diagram showing the outlines of Mahon's soil pit in August, 1965. Numerals 1 to 4 refer to Keilor terrace, terrace GGJ, intermediate zone and terrace GGM respectively.

hiatus in the deposition of the terrace only six feet above the level of the basal gravel. These examples provided evidence of the early groundsurface configuration and assisted in reconstructing the depositional processes.

Keilor terrace soil

A deeply differentiated soil has developed on silts of the Keilor terrace with profile features extending 9-10 ft below the surface. Although undifferentiated in terms of texture and colour, changes in degree of organization and carbonate accumulation through the profile help divide it into two main zones—an upper non-calcareous, weakly organized zone, extending down to approximately 30 in., over a lower calcareous and more highly organized zone with biotic casts and tubules. Carbonate occurs from approximately 40 in. to near 9 ft in the profile both as fine filaments (pseudo-mycelia) or linings on the surface of peds, voids and tubules, and also as near-vertical pencil-thick concretions.

Infilled worm tubes or biotic casts occur from 30 in. to approximately eight feet. These are approximately ¼ in. diameter and rarely extend in depth for more than 10 in. They are associated with a second type of larger casts of unknown origin. The latter occur as internal infillings of dark grey silts and form weakly cemented cylindrical concretions, nearly vertical in attitude and more indurated than the sediment in which they occur. They are approximately 0·7-1 in. in diameter and have been traced continuously in the profile for up to 2 ft but are usually approximately 10-13 in. long. From their orientation and the absence of branching or bifurcating structure, they are regarded as infilled burrows rather than traces of roots. They are absent in terrace sediments younger than the Keilor terrace although some were observed in the marginal or intermediate zone between the deposits of the Keilor terrace and GGJ. In size and attitude, they resemble structures formed by the infilling of holes excavated by fresh-water crustacea. They are referred to here as *large biotic casts.*

In its general profile characteristics, dark colour, alkaline pH, carbonate concretions, prismatic cleavage and depth of organization, the Keilor terrace soil resembles a chernozem—a soil type rarely found in Australia.

Sediments of terrace GGJ

Basal gravels of this terrace (basalt, quartzite and mudstone) were located in auger holes approximately five feet below the floor of the pit and in outcrop on the S. side of Green Gully some 50 ft N. of the pit. These grade up through four to five feet of medium coarse sands often containing charcoal, to an upper 10-12 ft of fine sands and silts. Although texturally they resemble the Keilor terrace sediment, they differ significantly by containing more coarse sand.

Within this terrace, horizons one to two feet thick of dark grey to yellowish brown fine sands and silts sometimes alternated, forming diffuse bedding or banding. These dipped easterly up to 17° off the contact zone with the Keilor terrace. The bedding, however, was too diffuse to define precisely the stratigraphic relationships between the various units in the irregular exposures of the pit.

Soil profile of terrace GGJ

The upper five to six feet of sediment was affected by weak pedogenesis shown mainly by the dark humic surface soil (black to very dark grey) grading to dark grey and greyish brown in depth. As in the Keilor terrace, soil textures were virtually uniform throughout the profile. Cleavage in the top 3-4 ft produced coarse prisms 2-3 in. in cross-section, in contrast to the fine 'bladed' prisms approximately ½ in. thick which occurred down to depths of 8-9 ft in the Keilor terrace. Evidence of biotic activity occurred as a minor feature only, while the large biotic casts of the Keilor terrace were absent. Carbonate was absent throughout although pH remained alkaline in all but the top few inches. The profile resembles that of a prairie or minimal prairie soil (cf. Stace *et al.* 1968).

Intermediate zone between GGJ and Keilor terrace

On the N. side of the soil pit (peninsula B, Fig. 4) diffuse bedding within sediments of GGJ dipped E., aproximately parallel to the topographic surface at the terrace contacts. One such band of dipping medium to fine sands overlay a darker grey zone in which evidence of weak pedogenesis was shown by:

1. Aggregation of sediments to produce weak pedal structure
2. weakly developed prismatic cleavage and
3. evidence of biotic activity in the presence of both small infilled tubules and large biotic casts similar to those found in the Keilor terrace soil.

This zone resembled the Keilor terrace soil in both colour and texture but occurred at a lower level, being found down to the floor of the pit (R.L. 41 ft).

Dark grey sediment with pedal development, abundant charcoal, and often associated with pink oxidized sediment, outcropped on the floor some 10 yards east of the burial site and continued north to the peninsula B as described above. This appeared as part of the same zone localized near or along the topographic junction between the two terraces. The zone was initially regarded as one of weak pedogenesis developed on a groundsurface formed by erosion in the Keilor terrace before deposition of the younger terrace GGJ. The situation however proved to be more complex than this.

From peninsula B to C (Fig. 4) a thin but extensive horizon of charcoal and pellets of pink oxidized silts were traced laterally for more than 20 ft. These were distributed along an apparent bedding plane within the pedogenetic intermediate zone. The horizon was located approximately 18 in. below the disconformable contact with GGJ, and dipped E. conformably with it suggesting the presence of a bedded unit within what was apparently a zone of soil formation. In addition, while this zone contained no *in situ* carbonate, some concretions were found in horizontal or random orientation indicating deposition following erosion of an older calcareous profile (Fig. 5). Thus, what was regarded initially as a buried soil, contained elements of depositional structures unlike those of either the Keilor or GGJ terrace sediments.

Evidence of fires

Within the pit, concentrations of charcoal enclosed within zones of hard brick-red oxidized silt recorded the effects of oxidation and baking by *in situ* fires. These zones up to five feet across, were usually located near the terrace contacts associated with the dark grey pedogenetic zone with pedal structure and biotic casts. They thus appeared to belong to the intermediate zone described above.

Five concentrations of charcoal and oxidized silt were excavated on the floor of the pit some 20 yards E. and NE. from the burial site. Three of these possessed circular outlines up to 3 ft 6 in. diameter with near-vertical sides extending in depth for more than 3 ft, and sometimes branching laterally in the manner of tree roots. Fibrous structures of charcoal often retained an orientation parallel to the oxidized margins. These zones could only be explained by the burning of large trees in position of growth. Two other such excavated zones had little extension in depth and were formed by burning of horizontal logs.

The downward intrusion of fires into underlying sediment by burning of roots is similar to that known to occur during the burning of stumps in the clearing of eucalypt forests to this day. By covering a burning stump with soil in a process known as 'stoving', farmers commonly keep roots smouldering underground for many days. This produces a partially evacuated zone of ash and charcoal into which soil later collapses. In a case known to the author, a child who fell through surface soil into a space created by recent sub-surface burning of roots, suffered burns up to the waist, indicating an underground zone of burning at least 2 ft 6 in. to 3 ft deep, consistent with the downward extensions of oxidized earth found in the pit. Evidence of similar collapse was found in the disturbance of normally vertical tubules and biotic casts within several of the excavations.

Relationship of burial to soil-sedimentary zones

The burial was located in dark grey silts within the zone of soil profile development of the Keilor terrace. Evidence of pedogenesis in weak pedality, and traces of vertical cleavage in the soil above the remains, confirmed their considerable antiquity. As shown in the detailed report of the burial excavation (Casey and

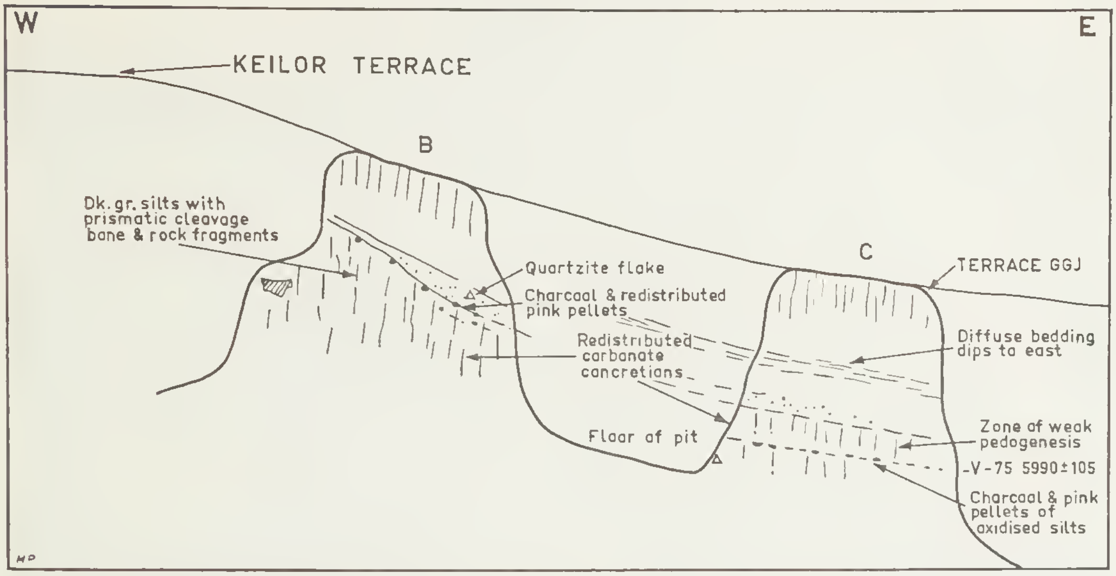

Fig. 5—Section in soil pit showing stratigraphy exposed on peninsulas B and C (Fig. 4) relative to terrace surfaces.

Darragh, *this volume*) the deposits contained little evidence of stratigraphic layering above or near the burial. The archaeological excavation went down through homogeneous deposits of dark grey silts or clayey silts from the surface (R.L. 62·5) down to R.L. 59 ft uncovering occasional quartzite flakes, basaltic fragments and boulders presumably transported by human origin. At R. L. 59 ft, spit 10 in the excavation, a slight change in soil consistency and colour occurred and extended down to the level of the burial. This zone was slightly red in colour due to the admixture of oxidized silts with dark grey unaltered sediment around and above the body. The mixing within the burial zone indicated the use of oxidized earth to partly fill the grave. The bones themselves showed no evidence of burning (Macintosh 1967) and had therefore been interred after the fires which caused the burning, oxidation and local development of charcoal.

Casey and Darragh have established the upper limit of this zone at R.L. 59 ft, i.e., 3 ft 6 in. below the upper level of the terrace surface. This indicates that a grave had been dug from a surface near R.L. 59 ft and later covered by 3 ft 6 in. of alluvium. The fires with which the burial was associated were therefore older than the surface from which the grave was dug. Subsequent excavations by Mulvaney (*this volume*) established the upper limit of *in situ* burnt and oxidized silts in the terrace at about R.L. 58 ft 3 in., i.e., only 9 in. below the burial, and 51 in. below the present topographic surface of the terrace. Almost all the massive concentrations of charcoal and oxidized silts within the soil pit occurred in the pedologically altered intermediate zone, except those below the burial which had extended down into unaltered Keilor terrace silts. In this respect the zone of burning near the burial differed from those described earlier.

Large biotic casts occurred below the level of the human remains but not in the zone above. The zone of maximum carbonate concentration was also located only a few inches below the level of the burial although some carbonate was encrusted on part of the remains (Macintosh 1967). The main period of carbonate mobilization probably occurred before the interment, but some carbonate was still mobile for a short time after the burial.

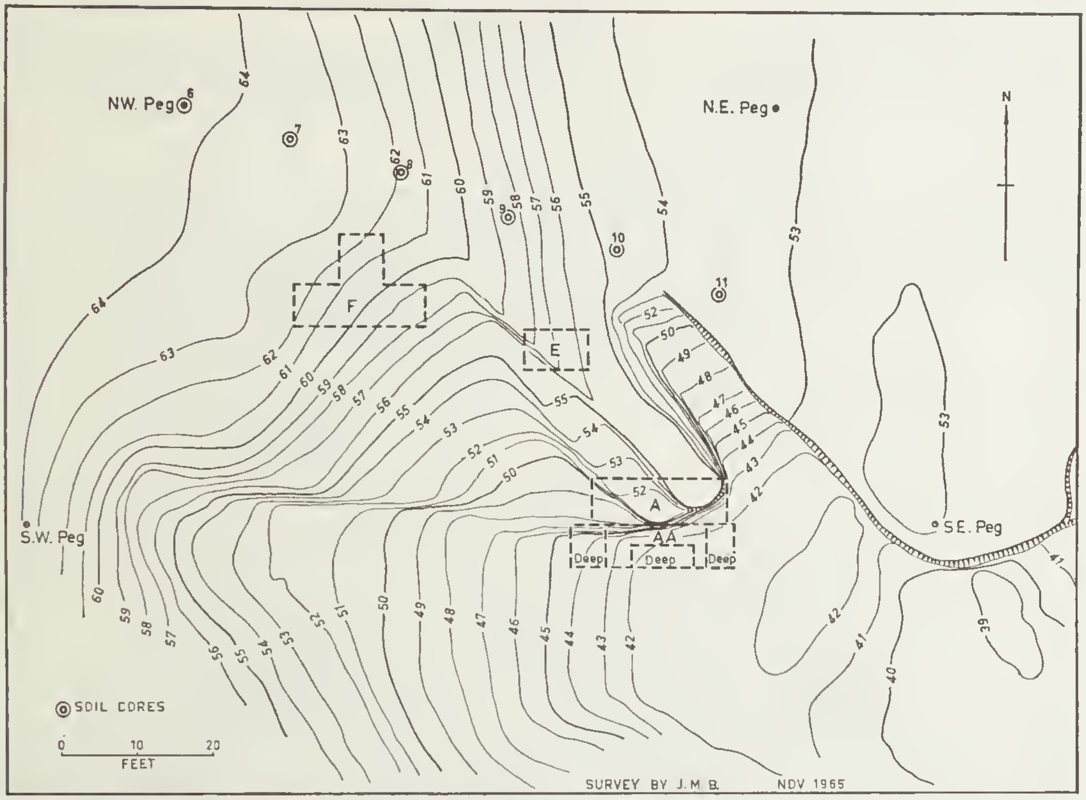

Fig. 6—Detailed plan of N. part of soil pit near peninsula B in December 1965, showing sites and levels of excavation and soil cores.

The dark grey silts of the intermediate zone therefore represented a separate sedimentary unit rather than a simple soil profile. From the similarity in textures and from the spatial distribution of this zone, it could only have originated from erosion and redeposition of Keilor terrace sediment along a steep cliff corresponding to the edge of a channel cut into the older terrace. Sediment which accumulated along the foot of this cliff remained stable long enough to permit a small degree of profile development before the later deposition of alluvium of terrace GGJ. Sediments of this unit comprise the intermediate zone whose presence had been suspected from evidence elsewhere within the soil pit. The recognition of this separate sedimentary unit explained the concentration of flakes, bone and charcoal in the lower levels of the excavation and their relative absence in older sediments of the Keilor terrace at an equivalent level only a few feet to the W.

The lower and upper limits of the intermediate zone were set by (1) the colour change and traces of bedding near the contact between the dark grey silts and the yellowish brown silts in the base of the stratigraphic excavation, and (2) by the upper limit of pedogenetic development between R.L. 49-52 ft as shown in Fig. 7.

The excavation not only established the disconformable relationships between the Keilor and GGJ terraces, but demonstrated the existence of two disconformities where only one had been anticipated. These delineated the zone of redistributed sediment derived by erosion from the Keilor terrace. This further explained the occurrence of reworked carbonate concretions within this zone and at the base of peninsula C, Fig. 5. They were derived by erosion from the soil profile developed earlier within the Keilor terrace.

Stratigraphic Excavation

An understanding of the ages and environmental origins of the soils and sedimentary facies, including those immediately adjacent to the burial area, was essential to clarify both the archaeology and geomorphology of the area. An investigation was therefore undertaken to establish the stratigraphic relationships in an undisturbed area, to evaluate their importance in the environmental history, and to relate them to the history of the human remains.

At the undisturbed contact between terraces on the N. side of the pit, the intermediate zone was represented with other units, and was therefore selected for detailed examination. An excavation here in December 1965 was jointly supervised by the author in co-operation with D. J. Mulvaney and R. J. Lampert of the Australian National University, who took responsibility for the archaeological data. Information on this aspect of the excavation is provided by Mulvaney (*this volume*). Much of the data in this report has been derived from that excavation, which for convenience and to distinguish it from the more specifically archaeological excavations, is hereafter referred to as *the stratigraphic excavation.*

An E-W. base-line 120 ft long was marked out along which a trench 20 ft long and 6 ft wide was opened on the S. end of peninsula B (excavation A in Fig. 6). The floor of the trench was lowered in 3 to 4 inch spits while the spoil was thrown onto the quarry floor and later bulldozed away. The excavation passed through 4 ft of upper fine sandy sediment of terrace GGJ into a zone of dark grey silts with weak pedality and prismatic cleavage. Quartzite flakes, bone and charcoal fragments occurred rarely in the upper GGJ sediment but were more frequent in the underlying pedological zone.

During later cleaning of the spoil from around the end of the peninsula, the bulldozer exposed a concentration of charcoal and oxidized silts with a quartzite flake 5 in. below the quarry floor at R.L. 40·5 ft near the S. side of the excavation. In view of the possible significance of an artifact at this level, 23 ft below the surface of the Keilor terrace, and the need to examine the stratigraphy at a level normally unexposed within the terrace, the excavation was extended by opening a pit (AA in Fig. 6) 24 ft long on the quarry floor 6 ft S. of and adjacent to the level of the first excavation (see Plate 2). Work was concentrated on the lower level below 41 ft, in an attempt to establish the stratigraphic relationship between the artifact found here and those of the Keilor terrace.

In the lower level two different facies or zones were recognized. Dark grey silts with weak soil structure were encountered on the E. end of the trench passing to hard yellowish brown silts of the unaltered Keilor terrace in the W. Occasional artifacts, bone and charcoal occurred in the E. end of the trench in dark grey silts, but only one quartzite flake was found in the W. end in the yellowish brown silts at R.L. 40·5 ft, i.e., 23 ft below the top of the Keilor terrace.

Evidence of fire within the yellowish brown silts was found at 42·5 ft, some 2 ft above the level of the flake. This was the extensive zone of pale pink oxidized silts 2 to 4 in. thick with the fragments of charcoal as described earlier from near the basal part of the terrace. Although continuous to the W. and S. beyond the trench, this horizon did not extend to the E. through the dark grey silts on the N. side of the trench. It could be traced only half way across the face of the section as in Fig. 7.

Traces of bedding throughout the pedogenetic zone dipped to the E. away from a relatively sharp contact between the two facies exposed in the trench. The contact sloped steeply to the E., and was itself immediately overlain by an horizon with a similar E. dip containing pink oxidized silts and redistributed charcoal within the depogenetic zone. Immediately W. of the contact, within the Keilor terrace sediment, traces of original depositional surfaces were horizontal (Fig. 7).

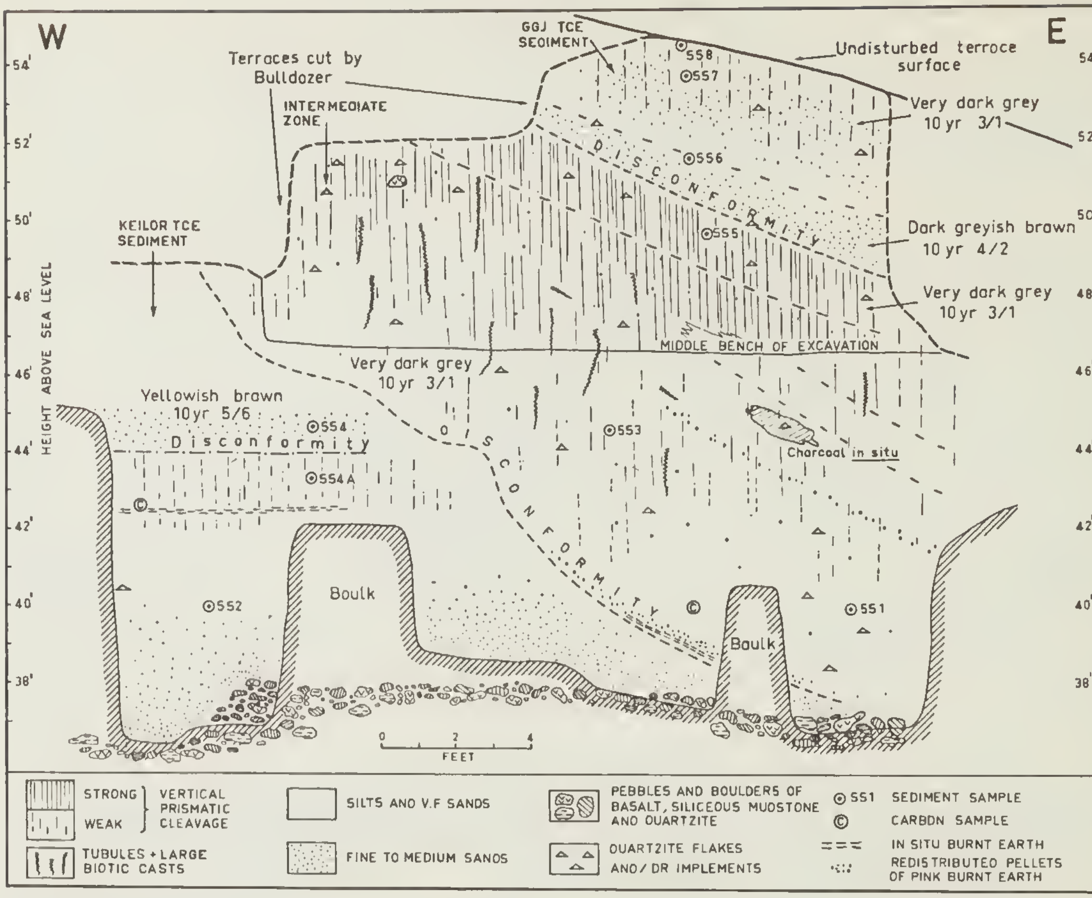

Fig. 7—Detailed section exposed during December 1965 stratigraphic excavation (trenches A and AA, Fig. 6). An intermediate zone with elements of both soil and sedimentary character separates younger dipping deposits of GGJ from older horizontal alluvium of Keilor terrace. Below the middle bench, section projected 6ft N. Section outlines from scale drawing by R. Lampert; stratigraphic details by J.M.B. See Fig. 9 for sediment analyses.

The massive concentrations of charcoal and pink oxidized silts, which occurred at various levels throughout the pit, were now seen to be localized within the intermediate zone of redistributed sediment, and located along the terrace contact. The burial overlay a zone of charcoal and brick-red silts which extended down to R.L. 52 ft and again represented the burning of a tree root in position of growth (Casey and Darragh, *this volume*). An additional excavation near the burial site, by Mulvaney in January 1966, established beyond doubt that the burnt roots intruded into undisturbed Keilor terrace sediment.

In the area affected by burning below the burial, carbonate concretions had developed around pink oxidized silts indicating concretion formation after the fires. At least two separate tree burning phases are therefore implied: one before mobilization of carbonate in the Keilor terrace profile, the other after mobilization. Fires of the latter period were those concentrated along the edge of the channel cut into the Keilor terrace corresponding in place and time to the deposition of the intermediate zone.

Laboratory Analyses

To describe more adequately the sediments and to determine the pattern of variation through the soil-sedimentary column, selected samples were analysed for texture, organic content and pH.

Textural analyses

Standard screening methods were used to size material larger than 62 microns using a BSS nest of screens in a mechanical shaker. The silt distribution (62 to 4 microns) was determined using a settling technique (hydrometer method). Clays (less than 4 microns) were not sized due to the relative unimportance of clay-size distribution for the present study. Analyses of Keilor terrace samples were carried out from three separate sites in or near the soil pit:

1. Samples from N. of the burial were selected from the stratigraphic excavation and from cores, 6, 7 and 8 (Fig. 6);
2. from the burial site and;
3. from Wright's trench S. of the burial as in Fig. 3.

Representative curves plotted on log probability scales are shown in Figs. 12 to 15. Of 42 samples analysed, 88% contained more than 50% silt, 20% contained silt in the range 70-75%, and 30% in the 50-55% silt range. The textural grades present in any one sample extended from very fine sands to clay with the largest primary sediment rarely exceeding 0·30 mm.

Although fine-textured throughout, small lateral variations were recorded between sites. The silt percentage in samples near the stratigraphic excavation averaged 50-55% increasing to 65-70% at the burial site and reaching a maximum of 74% in samples from Wright's trench, thus demonstrating a change in texture from N. to S. in the soil pit area. The apparent coarsening is due more to relative variations in the percentages of clay than to any coarsening of sands, the pattern of which remained the same throughout.

By comparison with fluviatile sediments in other areas (cf. Allen 1965) the Keilor terrace sediments display an unusual degree of vertical uniformity in texture. All samples analysed from core 7 and in the underlying sediment down to 22 ft below the surface (as in Fig. 9) fall within the size ranges—sand 21-29%, silt 47-60% and clay 20-28%. But despite the overall uniformity, small but consistent variations occur in the distribution of the coarser tails of the textural curves, which are particularly sensitive to small changes in depositional regimes (Mason and Folk 1958). These trends are shown in the distribution of material coarser than 0·20 mm, a size which has additional environmental significance for it falls close to the boundary between bedload and suspended load for a wide range of hydrologic conditions (Sundborg 1956). Material finer than 0·20 mm, i.e., almost all sediment of the Keilor terrace, is almost invariably transported as suspended load. Variations in the distribution of this fraction through the column is shown in Figs 8 and 9. SS4 in Fig. 9 represents a thin band (6 in. thick) over the zone of weak pedogenesis near R.L. 44 ft, and may give a false impression of the distribution of the coarse tail in this part of the terrace. In all sections analysed, the top 30 to 36 in. of sediment contains a small but consistently higher percentage of material coarser than 0·20 mm than occurs in sediment immediately below this zone (Figs. 8, 9 and 11).

Sediments of GGJ are likewise fine textured throughout but maintain a higher percentage of fine to medium sand than in the Keilor terrace. The fraction coarser than 0·20 mm resembles that found in the top 30 in. of the Keilor terrace but here the distribution of that fraction remains constant down the profile (Fig. 10). Of 17 samples analysed from this deposit the silt percentage of all fell within the range

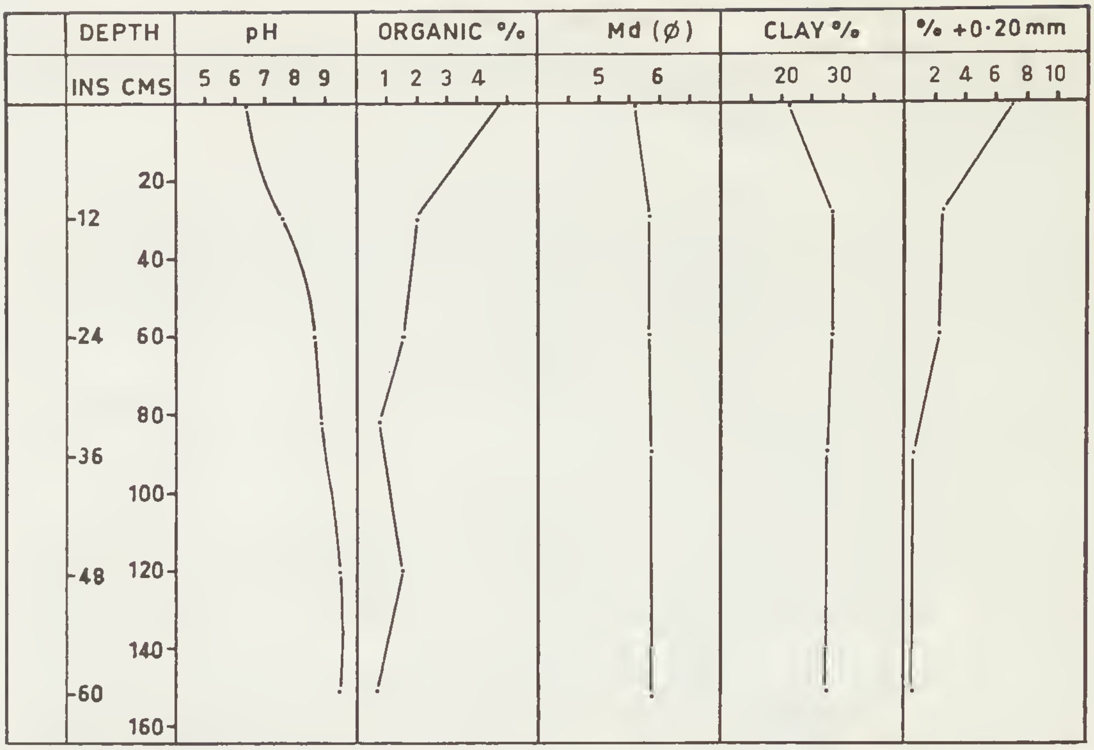

Fig. 8—Fig. 8—Depth function data through top 5 ft of Keilor terrace soil and sediment from samples at one foot intervals through core 6, Fig. 6.

45% to 55%. In the stratigraphic excavation the basal unit of this terrace represented by SS6 is considerably coarser than the overlying sediments SS7 and SS8 (Figs. 7 and 9). The coarse unit here is laterally equivalent to sediment some 10 ft below the surface of terrace GGJ as in Fig. 5. The size distributions of samples at one foot intervals through core 10 are shown in Fig. 10.

Organic content

Organic matter has been determined using hydrogen peroxide as the oxidizing medium, providing a measure of relative organic content. The distributions through Keilor terrace sediment and soil are shown in Figs. 8, 9 and 11. The organic content ranges from 5% in the top 3 in., decreasing with depth below the surface to 0·5% at 3 ft with the important occurrence of a weak buried maximum near 48 in. as shown in cores 6 and 7 (Figs. 8 and 9). The distribution in sediments of GGJ show a similar pattern falling from surface values of 5% to 1% lower in profile at 6 ft, but no secondary maxima are present. The organic content seems mainly controlled in both cases by accumulation or illuviation of material associated with the present terrace surface with the exception of the buried maximum in the Keilor terrace, which may be related to an earlier phase in the terrace history.

pH

Values were determined with a Cambridge pH Meter using a 1:5 soil-water mixture. To reduce drift by interaction with atmospheric carbon dioxide, measurements were carried out in an inert atmosphere obtained by passing a steady stream of nitrogen through the mixture while measurements were made. Values determined

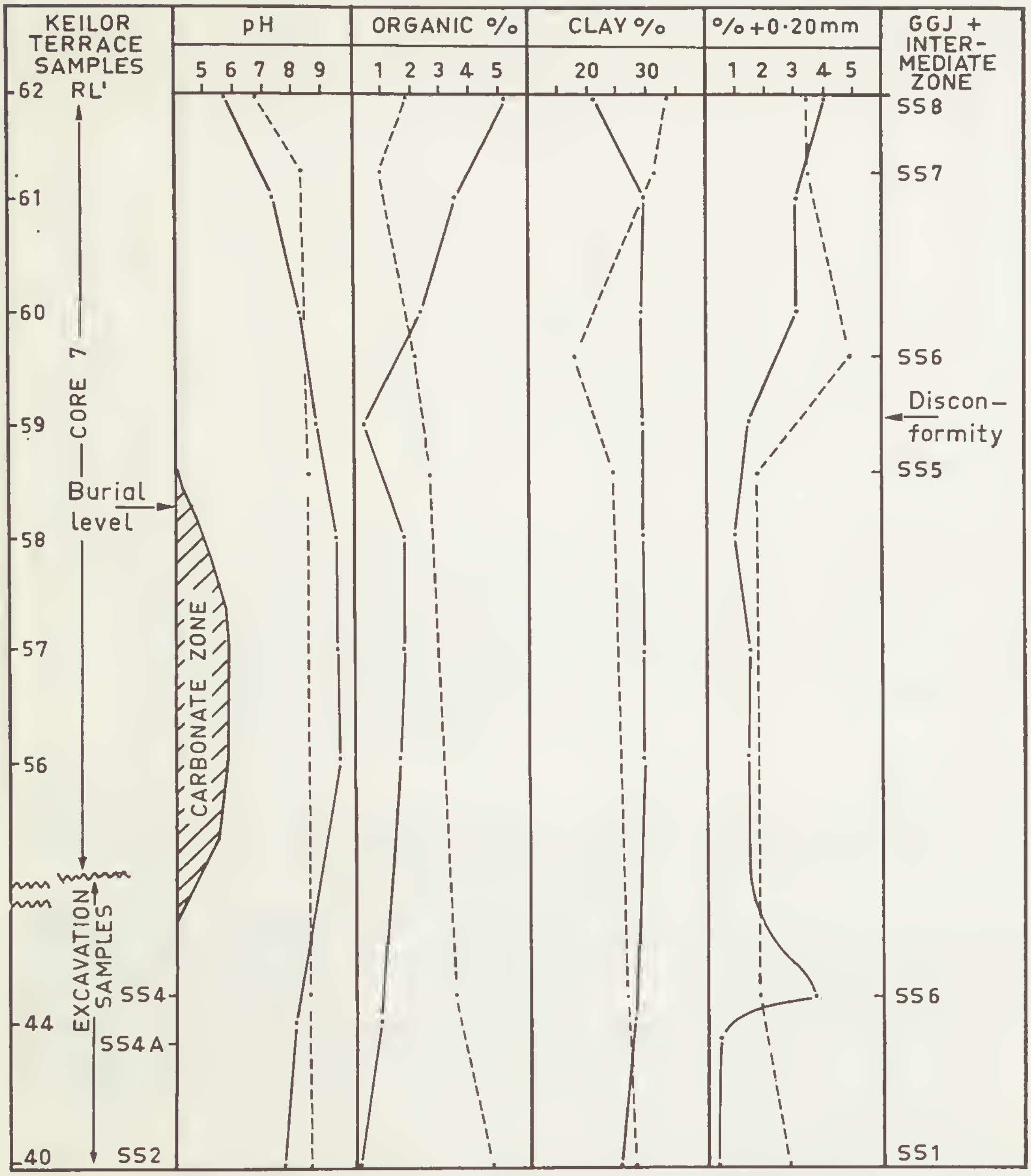

Fig. 9—Composite depth function data through Keilor terrace (full line) and through sediment of GGJ and the intermediate zone (dashed line). Keilor terrace data from core 7 (Fig. 6) and from samples SS2, 4 and 4A. All samples with prefix SS are from the stratigraphic excavation as shown in Fig. 7. Ten feet of homogeneous sediment between RL 45 ft and 55 ft in Keilor terrace are not represented. Disconformity established in field between SS5 and SS6 coincides with textural change as shown in the percentage sand coarser than 0·20 mm. A sympathetic change occurs at equivalent level in core 7 consistent with presence of disconformity also in core. Carbonate which occurs as nodules through 4 ft of core 7 is present in intermediate zone only as fine earth, filaments or redeposited nodules.

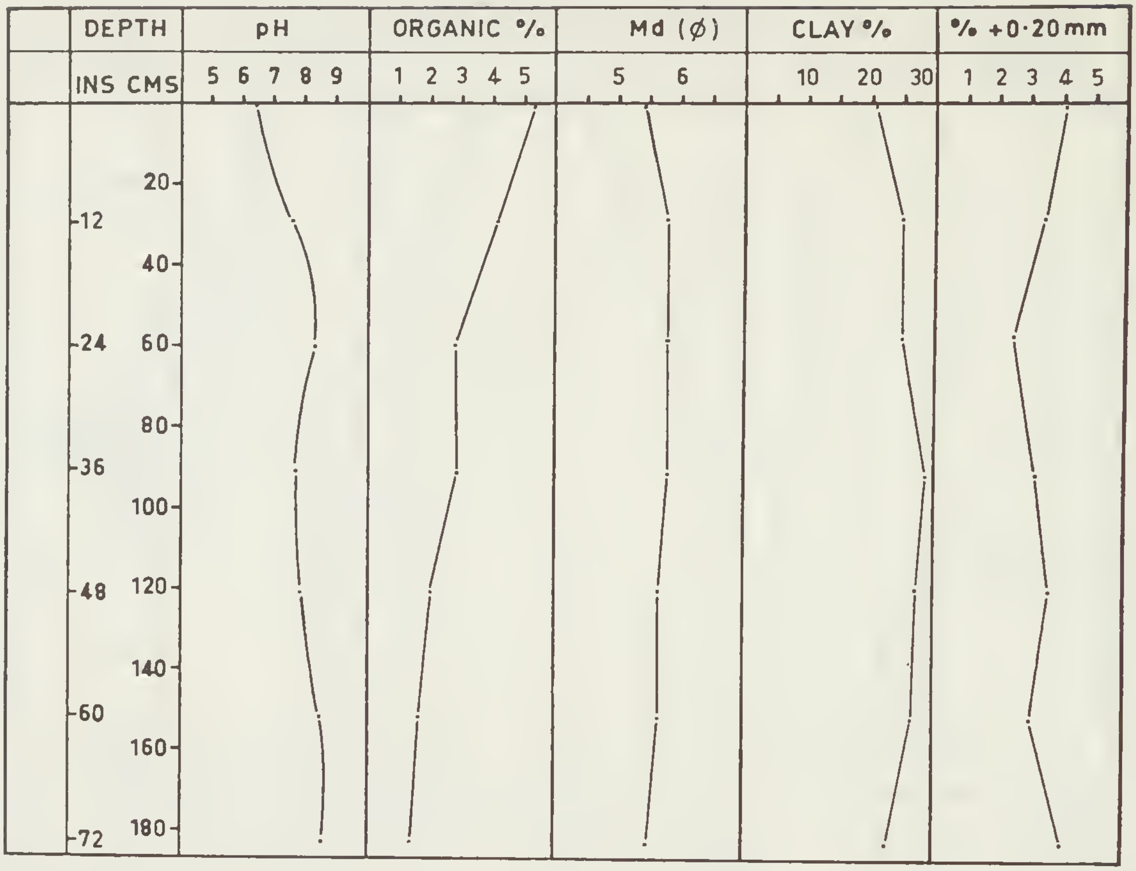

Fig. 10—Depth function data for the top 6 ft or soil and sediment of terrace GGJ from samples at one foot intervals through core 10, Fig. 6.

in this way tend to be a little higher than those made in contact with atmospheric carbon dioxide. In the Keilor terrace, pH varies from weakly acidic values in the top 3 in. increasing to alkaline values near 12 in., and further increasing in depth to values exceeding 9 near 48 in. in the zone of secondary carbonate (Figs. 8, 9, 11 and 17). In GGJ a similar pattern is evident, although the high values in excess of pH 9 are not present, presumably due to the absence of carbonate in sediment and soil of this terrace. Values remain alkaline to considerable depth as shown in Fig. 10.

Comparison between samples from terrace units and intermediate zone

Comparison between the sediments of the two main terrace units and that of the intermediate zone is best shown in the analyses of samples from the stratigraphic excavation Table 2 and Fig. 9. These show the comparison between the Keilor terrace sediment as determined from samples of core 7 and from the basal part of the terrace exposed in the stratigraphic trench with the sediment characteristics of terrace GGJ and the intermediate zone as revealed in the stratigraphic excavation. The relative position of the samples is shown in the section Fig. 7. Here the presence of the three zones separated or bounded by disconformities had been established in the field as described earlier.

The texture of samples from the intermediate zone closely resembles that of the lower part of the Keilor terrace from which it was derived. But the percentage

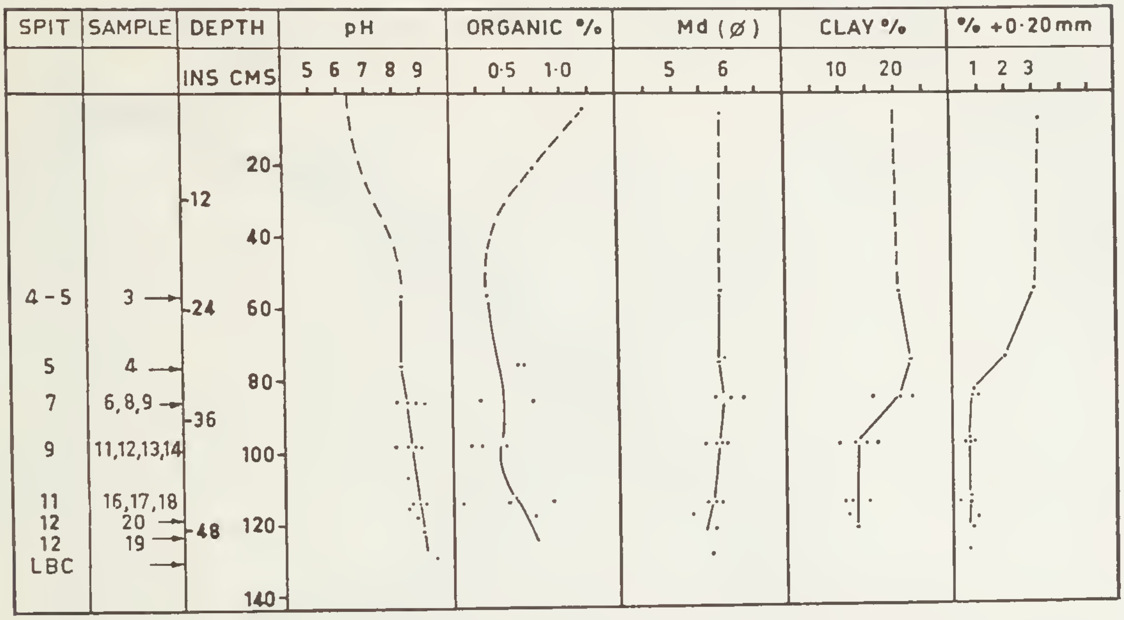

Fig. 11—Depth function data through burial excavation section. Samples are from the spit levels as excavated by Casey and Darragh. Note small but significant change in texture near spit 7 which corresponds to level of suspected disconformity (cf Fig. 17). Analyses of large biotic cast (LBC) from near burial included for comparison; material infilling tubule related to zone below spit 7, suggesting infilled from surface existing before deposition of top 30 in. of terrace sediment. This is consistent with these casts being same age or older than burial.

coarser than 0·20 mm in samples SS6, 7 and 8, representing sediment of GGJ in the stratigraphic excavation, is similar to the upper 30 in. of the Keilor terrace, suggesting a genetic relationship between the two zones. The former samples were deposited on a topographically lower site than those on the upper part of the Keilor terrace, as in the top 30 in. of core 7, and therefore would be expected to contain more sand and less clay than equivalent sediment at a higher level in a regime of overbank deposition. This is consistent with the results shown in Fig. 9 when compared to those of core 7. Thus the disconformity established in the field between samples SS6 and SS5 is also related to the sediment variations near 30 in. in cores 6 and 7.

Sediment of the intermediate zone contains slightly less clay than in core 7 as may be expected; during reworking of the older sediment the clay is most likely to be removed. This zone is also high in organic matter—another aspect of its pedological development. The textures of the intermediate zone are closely related to the analyses of the Keilor terrace below 30 in. from which material of that zone was derived. But the sediments of the overlying GGJ terrace show a consistent contrast with the underlying zones (cf. SS6 with SS5, Fig. 9). Deposition during this later phase started with relatively coarse sands of SS6 (5% material larger than 0·20 mm), and then became finer upwards through SS7 to SS8, with sand percentages ranging from 32% (SS6) through 25·5% (SS7) to 20·7% (SS8).

Carbonate

The presence of carbonate has been estimated visually in the field and checked in the laboratory by reaction to dilute hydrochloric acid. The distribution of car-

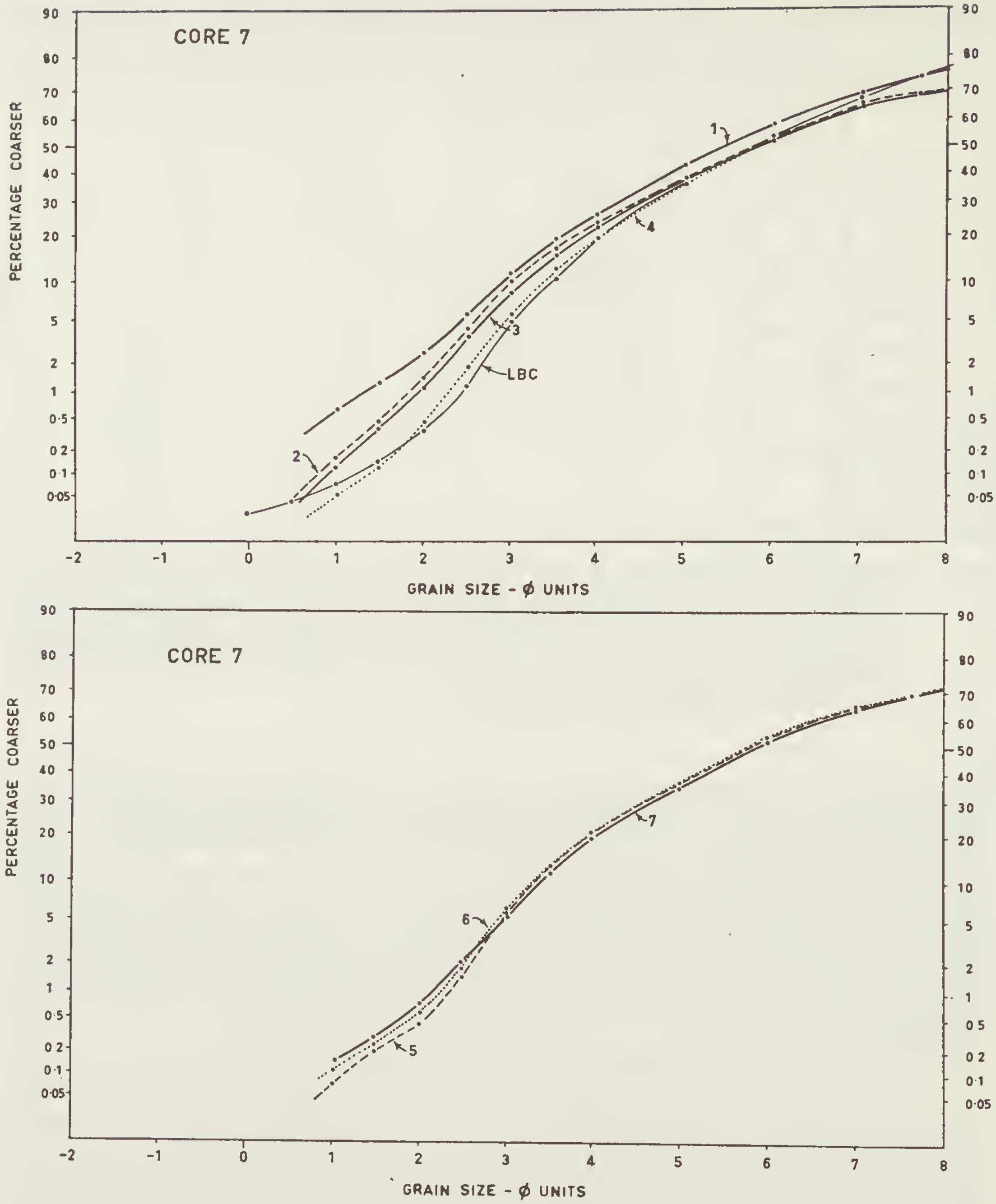

Fig. 12—Textural distribution curves of samples at one foot intervals through core 7 with curves 1 to 7 representing the top and 6 ft in cores respectively. Note homogeneity of curves below 3 ft (curves 4 to 7) and the upward coarsening towards top of core (4 to 1). The sediment infilling large biotic cast is texturally identical with lower zone in which it occurs.

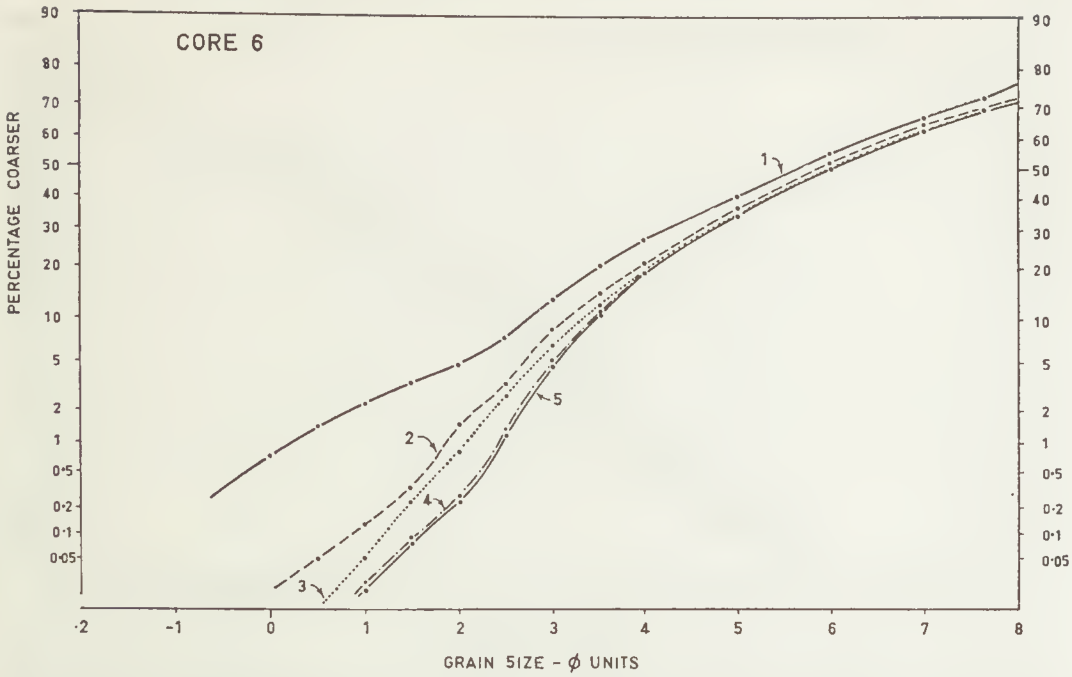

Fig. 13—Textural distribution curves of samples at one foot intervals through core 6 to show features identical with core 7, Fig. 12, emphasising lateral as well as vertical uniformity through Keilor terrace.

Table 2

Comparison between textures through upper 6 ft of Keilor terrace as shown in core 7 with those in section exposed by excavation AA at terrace contact (Fig. 6)

CORE 7							SECTION IN FIG. 7					
Depth (Ft)	Sample	Md ϕ	% Clay	%+0·20 mm	% Organic	pH	Sample	Md ϕ	% Clay	%+0·20 mm	% Organic	pH
0	1	5·4	21·0	4·5	5·2	5·9	SS8	5·8	29	3·2	2·0	6·8
1	2	5·7	29	3·0	3·6	7·4	SS7	5·6	27	3·5	1·0	8·2
2	3	5·7	28	3·0	2·3	8·2	SS6	5·1	16	4·9	2·2	8·3
	. . . disconformity . . . inferred								. . . disconformity . . . established			
3	4	5·7	28	1·2	0·2	8·8	SS5	5·9	22	1·6	2·7	8·7
4	5	5·7	28	0·9	1·7	9·4**						
5	6	5·7	28	1·2	1·7	9·4**						
6	7	5·8	28	1·3	1·6	9·5**						
18·5	SS4*	5·4	22	3·6	1·1	8·1						
20	SS4A	6·0	28	0·25			SS3	5·8	26	1·6	3·0	8·5
23	SS2	5·6	21	0·5	0·2	8·6	SS1	5·8	26	2·9	4·8	8·6

** Free carbonate present.

* SS4 is unusually coarse for this part of the terrace. It represents a slightly coarser band overlying the weakly developed soil horizon at 4 ft.

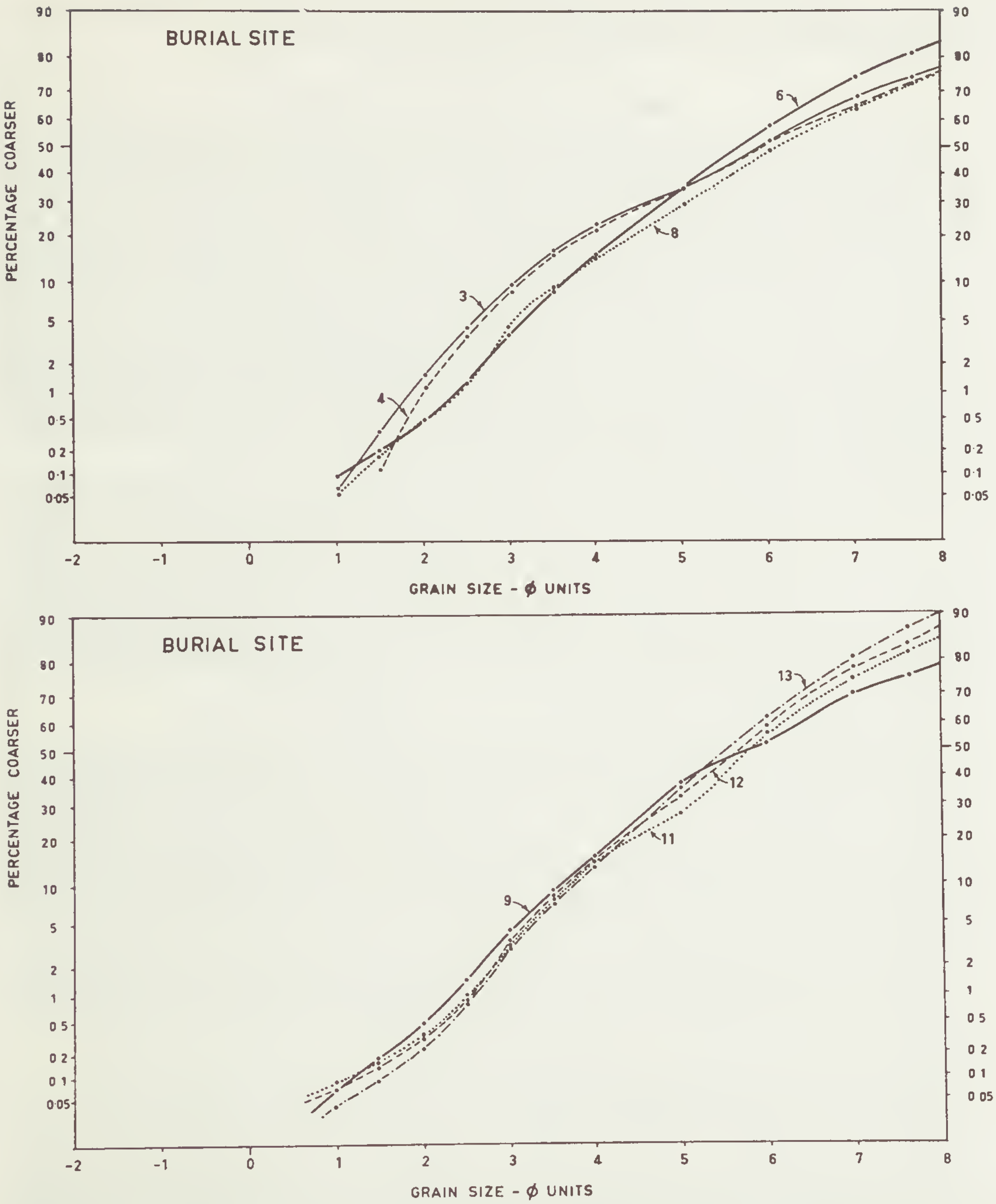

Fig. 15—Textural distribution curves of samples from burial excavation. Sample numbers as in Fig. 11.

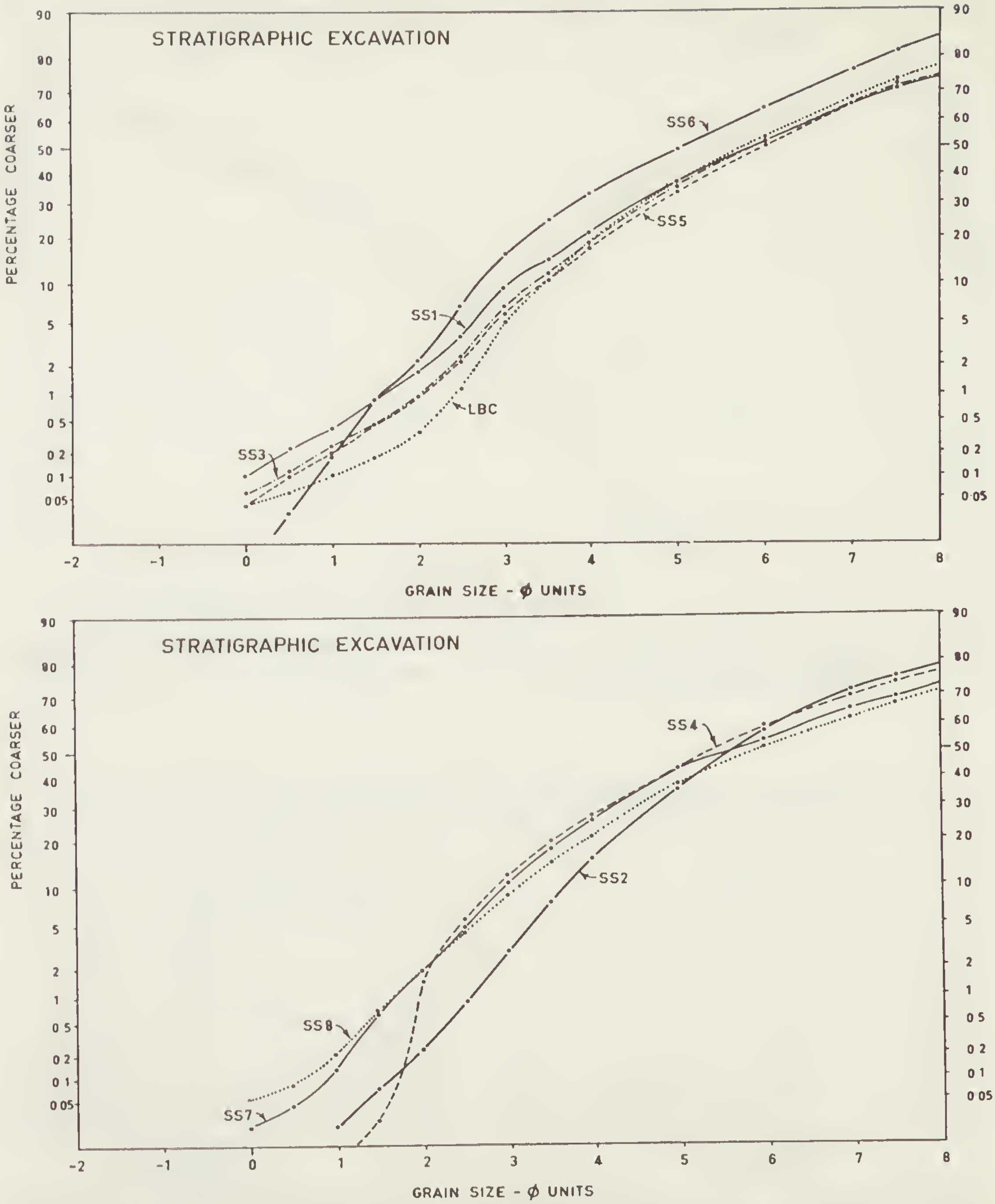

Fig. 14—Textural distribution curves of samples through stratigraphic excavation. Sample numbers as in Fig. 7.

bonate in figures accurately represents the upper and lower limits of its occurrence but should not be used as quantitatively defining its abundance.

Stratigraphy of the Burial Zone

The burial was located in a particularly complex part of the terrace. Reconstruction of the undisturbed topography placed the burial close to the contact between the two main terrace bodies. To determine adequately the age of the burial, it was necessary to establish its relationship in space and time with the soil-sedimentary zones already recognized near the terrace contact. An additional complication lay in the possibility of a stratigraphic discontinuity within the upper 3-4 ft of the Keilor terrace in this region. The presence of an erosional break, accumulation of the intermediate zone and a period of weak pedogenesis, had already been shown to predate deposition of terrace GGJ. The extensive evidence of fires localized within the intermediate zone, and the close proximity of the burial to one such zone of burning, pointed to a close relationship in time between the burial, the intermediate zone, and the period of non-deposition.

In the relationships between the three sedimentary units recognized near the terrace contacts, two possibilities were envisaged as shown in Fig. 16. In the first case, sediments of GGJ are inset into a zone eroded into the Keilor terrace (inset theory). In the second case (Fig. 16B), sediment of GGJ is inset and also overtopped onto the higher level depositing the upper 30 in. of the Keilor terrace (overbank theory). The consecutive lettering in the figures show the different orders of deposition implied in the two alternatives. Independent discriminating lines of evidence were therefore sought as outlined below.

Evidence from spatial relationships

The topography of the terrace contacts was accurately reconstructed using levels from the undisturbed surface 20 ft N. of the stratigraphic excavation. Information from this excavation and the burial site was then projected onto the topographic profile to represent the original spatial relationships as they existed in the undisturbed terrace. Thus the burial was located close to the topographic and sedimentary contact between the terraces, and both to the intermediate zone and to the disconformities which delimited it (Fig. 16). Unfortunately, the upward or W. continuation of bedding in the dipping sediment of GGJ (Fig. 7) merged a few feet W. of the stratigraphic excavation into soil where all trace of bedding was destroyed. Thus the lateral continuity of bedding could not be used to resolve the problem.

Evidence from textures and organic content

The information established in the stratigraphic excavation has been presented alongside that of core 7 (Table 2, Fig. 9). Discrimination between the overbank or inset theory depends on the presence or absence of the disconformity within the profile represented by that core. Two features in particular point to its presence. The first is the rise in organic content near 48 in. and above 36 in. consistent with the deep pedogenesis representing in part a buried soil profile. Secondly, the presence of a textural change in the upper 36 in. shown by the consistent increase in sands coarser than 0·20 mm relates this zone with that of GGJ sediment rather than with uninterrupted deposition during a single phase of Keilor terrace aggradation. Similar trends are apparent in the depth function of core 6 (Fig. 8). But the general significance of this evidence could only be confirmed by its consistency over larger areas and especially near the burial zone.

Textural analyses were therefore carried out on samples from the burial ex-

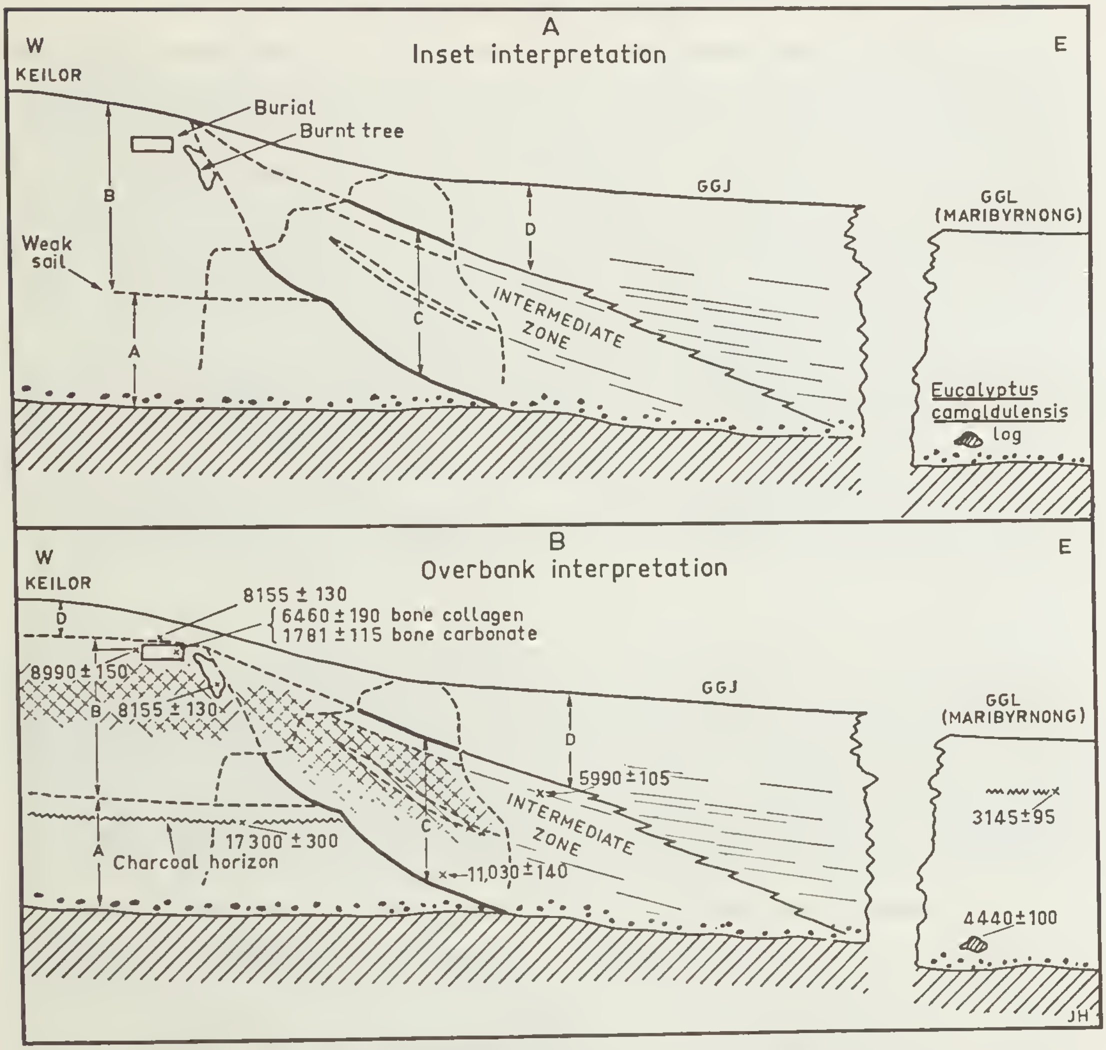

Fig. 16—W. to E. stratigraphic sections across terrace contacts to show alternative explanations possible to explain stratigraphy exposed in excavation, Fig. 7, the outlines of which are shown in dashed lines. The different sequences of deposition implied in these alternative hypotheses are illustrated by consecutive lettering of sedimentary units A to D from oldest to youngest. Radiocarbon dates from sequence are shown in their relative stratigraphic positions. The hachured area indicates occurrence of pedogenetic carbonate.

cavation site (Figs. 11 and 15). These show a markedly uniform textural distribution in sediment in and near the grave, but change significantly approximately 12 in. above the burial. This is best seen in the variation of sand coarser than 0·20 mm (Fig. 11). Samples below 30 in. (R.L. 59 ft) possess a uniform sand percentage coarser than 0·20 mm (near 1%), but at 24 and 18 inches in the profile, this rises to 2% and 3% respectively resembling the sediment of GGJ in the upper part of the stratigraphic excavation and in cores 10 and 11.

This regular pattern suggests a change in environment consistent with a pause in deposition near R.L. 59 ft followed by commencement of aggradation of terrace GGJ with overbank deposition burying the earlier sediments of the Keilor terrace.

Evidence from biotic casts

The large casts, which occur below R.L. 60 ft near the burial, were infilled by material derived from the surface which existed at the time of their formation. Analyses of the internal infillings should therefore relate to the horizon from which they were formed. Fig. 11 shows the results of textural analysis from one such infilling compared to sediment above and below R.L. 59 ft near the burial. The similarity of the infilling texture to that of sediment below R.L. 59 ft (cf. also the lower samples of cores 6 and 7, Figs. 8, 9, 12 and 13) supports the claim that the original burrows were formed before the deposition of the upper 3 ft of terrace sediment, probably during a phase of slow deposition or complete hiatus. It is significant that occasional casts occur in the intermediate zone (Fig. 7) but none have been found in either the top 30 in. of the Keilor terrace or in terrace GGJ. Moreover, had this burrowing and admixing of soil materials been operative after the deposition of the upper 30 in., the small textural changes evident at this level would have been removed by homogenization.

In addition, no evidence of such casts was found above the burial. The skeletal remains were therefore interred after the cessation of biotic activity, but before the next phase of aggradation which deposited the upper 30 in. and the lower terrace GGJ.

Evidence from soil carbonate

Secondary carbonate concentration is restricted to the Keilor terrace profile below 36 in. and to the intermediate zone, where both weak carbonate organization (filament and surface coatings) and reworked nodules were recorded. No additional carbonate deposition has occurred in the Maribyrnong Valley in sediments younger than the intermediate zone. The slight carbonate accumulation on the bones of the burial lowest in the grave (Macintosh 1967) was due to the burial being dug into a calcareous soil already in existence at that time. Carbonate organization therefore mainly predated the burial, as pointed out by Macintosh.

Evidence from burnt tree remains

The occurrence of thick concentrations of charcoal and oxidized silt corresponding to the burning of *in situ* trees and horizontal logs, described earlier, is similarly restricted to the Keilor terrace below the burial and to the intermediate zone. No large fire-burnt zones were recorded within either the upper 30 in. of the Keilor terrace and only one in sediments of GGJ. Redistributed pellets of pink oxidized silts to ¼ in. diameter occurred from 30 to 49 inches in the Keilor terrace and in the intermediate zone. But they too were absent from the top 30 in. of the Keilor terrace and sediments of GGJ, thus reinforcing the depositional relationship postulated between these two units. Two periods of burning were involved—one near the grave before carbonate deposition and a later period synchronous with deposition of the intermediate zone as described earlier.

In summary, the occurrence of carbonate, large biotic casts, and burnt tree remains, relate the intermediate zone to the lower part of the Keilor terrace soil profile. Moreover, the evidence from spatial relationships together with the textural trends and similarities between the top 30 in. of the Keilor terrace with sediment of GGJ, are all consistent with the theory of overbank deposition rather than the inset theory (Fig. 16). This hypothesis was advanced earlier (Bowler *et al.*, 1967) on the basis of the field and radiocarbon evidence then available. Since then, additional laboratory and radiocarbon evidence has reinforced this interpretation. The Keilor terrace soil at this locality is therefore a polygenetic profile with a paleosol overlain by 24-30 in. of sediment texturally and mineralogically little different from the underlying alluvium.

Chronology of the Burial Zone

Radiocarbon evidence

Radiocarbon dates obtained from the Green Gully region are set out in table 3, and their positions in the stratigraphic sequence are shown in Figs. 5, 16 and 18.

Of the two dates initially obtained (Bowler *et al.*, 1967) one was from charcoal in a root zone below the burial at R.L. 54 ft 5 in. (V-65) while the other (V-63) was from pellets of redistributed charcoal above the upper level of the burial at R.L. 59 ft 4 in. Both samples yielded C14 ages of 8155 ± 130 B.P. These provide an estimate of the age of the zone of burning into which the grave was dug rather than the age of the burial itself. The coincidence in the levels of C14 activity have been previously discussed (Bowler *et al.* 1967, Casey and Darragh *this volume*). The remaining charcoal sample from the equivalent level of the burial site (V-64) provides a better estimate of the age of the undisturbed sediment or upper terrace level at R.L. 58 ft 9 in. in which the remains were located. The latter have been dated independently at 6,460 ± 190 B.P. from analysis of bone collagen (Macintosh 1967).

Two additional samples from the intermediate zone (V-74 and V-75), indicate that the channel was already present before 11,000 B.P. and that the accumulation of the intermediate zone extended from 11,000 until after 6,000 B.P. This period corresponds to one of slow deposition and soil formation on the surface of the Keilor terrace with simultaneous erosion along the channel margin corresponding to accumulation or deposition of the intermediate zone. From the occurrence of reworked carbonate concretions and biotic casts or tubules, this episode continued until after pedogenesis had produced these features in the Keilor terrace soil. Pedogenesis was initiated near 11,000 B.P. under conditions of slow deposition, and continued until after 8,000 B.P. when fragments of reworked soil material began to find their way into the accumulating intermediate zone. When the burial occurred, again under stable conditions, the intermediate zone had developed a stable slope and was itself subject to pedogenesis simultaneously with continued carbonate mobilization on the higher Keilor terrace. This situation ended when aggradation recommenced soon after 5,000 B.P.

PART 3

Stratigraphy and Interpretation of the Terrace Sequence

In addition to the study of stratigraphic detail in the immediate vicinity of the burial zone, restricted to the upper levels of the Keilor terrace, data were collected from other terrace deposits and from lower levels of the Keilor terrace. Although not directly related to the burial, these data are included to provide a more adequate basis for understanding the stratigraphy and chronology of the entire sequence in the valley.

Arundel terrace and associated sediments

In the M.M.B.W. trench section on the right side of the river, a complex stratigraphic sequence was exposed (Fig. 19). Here some 15 ft of Keilor terrace silts were inset into eroded calcareous sandy clays of the Arundel terrace, a small remnant of which was preserved near R.L. 80 ft. Along the zone of contact between the Keilor and Arundel units, a zone of red calcareous clay marked the disconformity. This showed evidence of soil organization, in the segregation of carbonate into soft concretions, and in the development of prismatic or columnar structure with waxy clay cutans lining the prism surfaces. Approximately 3 ft below the surface of this zone, a layer of soft charcoal was traced for more than 20 ft following the general

TABLE 3

Radiocarbon dates from near Green Gully, Maribyrnong River

Lab. No.	Age Years BP	Description
Samples from Green Gully		
V-78	3,145 ± 95	Charcoal fragments from horizontal fire-burnt surface 8 ft beneath surface of Maribyrnong terrace in trench on left bank of Maribyrnong River near Green Gully. R.L. 36 ft. Collected J. M. Bowler.
V-77	4,440 ± 100	Fragment of red gum log (*Eucalyptus camaldulensis*) 22 ft below surface of Maribyrnong terrace in M.M.B.W. trench on left bank near Green Gully R.L. 22 ft. Coll. J.M.B.
V-75	5,990 ± 105	Charcoal from section exposed in Mahon's soil pit. Sample from near top of intermediate zone located 2 ft 6 in. beneath upper surface of soil buried by sediment of terrace GGJ. Coll. J.M.B.
V-63	8,155 ± 130	Redistributed charcoal fragments from few inches above top of burial. R.L. 59 ft 4 in. Coll. D. A. Casey and T. A. Darragh.
V-65	8,155 ± 130	Charcoal from zone of *in situ* burning of tree root 4 ft 9 in. below V-63 and approximately 3 ft below floor of grave. Root intruded from a surface near level of grave. R.L. 54 ft 5 ins. Coll. D.A.C. and T.A.D.
V-64	8,990-± 150	Charcoal fragments from approximately 4 in. below top of grave but outside burial area. Dates sediment into which burial dug. R.L. 58 ft 9 in. Coll. D.A.C. and T.A.D.
V-74	11,030 ± 140	Charcoal from root of tree growing at base of intermediate zone near unconformable contact with Keilor terrace sediment. Provides estimate of lower age limit of intermediate zone developed along channel edge. Coll. J.M.B. and R. J. Lampert.
V-79	14,940 ± 500	Charcoal associated with *in situ* fire, oxidized silts and bone fragments 15 in. above disconformity near base of section through Keilor terrace at weir, approximately 200 yd upstream from Green Gully. Coll. J.M.B.
V-73	17,300 ± 300	Charcoal fragments from extensive horizontal surface of pink oxidized silts from lower zone of stratigraphic excavation and floor of soil pit RL 42 ft 6 in. Coll. J.M.B.
V-76	30,700 ± 1,850	Charcoal distributed along bedding plane in colluvial red clays in M.M.B.W. trench. Clays were redeposited from higher Arundel terrace after erosion of that surface and were later buried during aggradation of Keilor terrace. Coll. J.M.B., D. J. Mulvaney and A. Bermingham.
Dates from carbonate and skeletal remains		
NZ-676	6,460 ± 190	From bone collagen, determined on fragments of Green Gully human remains (Macintosh 1967).
NZ-675	1,781 ± 115	From bone carbonate fraction of Green Gully remains represented by collagen date above (Macintosh 1967).
	7,360 ± 105	Carbonate from encrustation on original Keilor cranium. (E. D. Gill *pers. comm.*).
Additional dates		
GAK-996	7,700 ± 140	From sections in Keilor terrace upstream from the soil pit at Green Gully.
GAK-985	7,710 ± 150	Stratigraphic relationship to sequence at Green Gully not available. (E. D. Gill *pers. comm.*).

E. slope of the deposit. The zone of red clay with pedogenetic features represented a sedimentary deposit developed by downward movement of calcareous Arundel clays along the slope developed by stream incision into the older terrace. In this respect, it was identical in origin with the intermediate zone in the soil pit as described earlier. The valley slope and colluvial deposit so formed, remained stable long enough to allow the pedogenetic features to develop *in situ* before burial by the later Keilor terrace deposits.

From the radiocarbon analysis of the charcoal horizon (V-76, 30,700 ± 1850 B.P.) the age of the incision into the Arundel terrace is placed at approximately 32,000 B.P. while the accumulation of clay and soil formation occupied the period from approximately 31,000 until the deposition of the Keilor terrace silts at approximately 18,000 B.P. This situation is similar to that reported from the excavations of A. Gallus at the cranium site (Polach *et al.* 1968). The independent radiocarbon data from both sites confirm the validity of the chronological sequence outlined above.

Keilor terrace

Data from the lower levels of the Keilor terrace are available from the soil pit and from a section on the right bank of the river near the weir approximately 200 yards upstream. Charcoal from the extensive horizontal zone of burning exposed near R.L. 42 ft in the stratigraphic excavation (Fig. 7) has provided a radiocarbon age of 17,300 ± 300 B.P. (V-73). This was located only 1 ft 6 in. below the soil disconformity suggesting an age for that surface of approximately 16,500 B.P. Confirmatory evidence is available from the weir section where charcoal distributed on a horizontal surface with burnt bone fragments at R.L. 49 ft, only 1 foot above a break in deposition, yielded an age of 14,940 ± 500 B.P. (V-79). On the basis of the similarity in levels, pedogenetic features and radiocarbon ages, the sedimentary break and weak soil developed at this level can be reliably correlated between sites (Fig. 20). Moveover, the duration of the depositional break would appear to extend

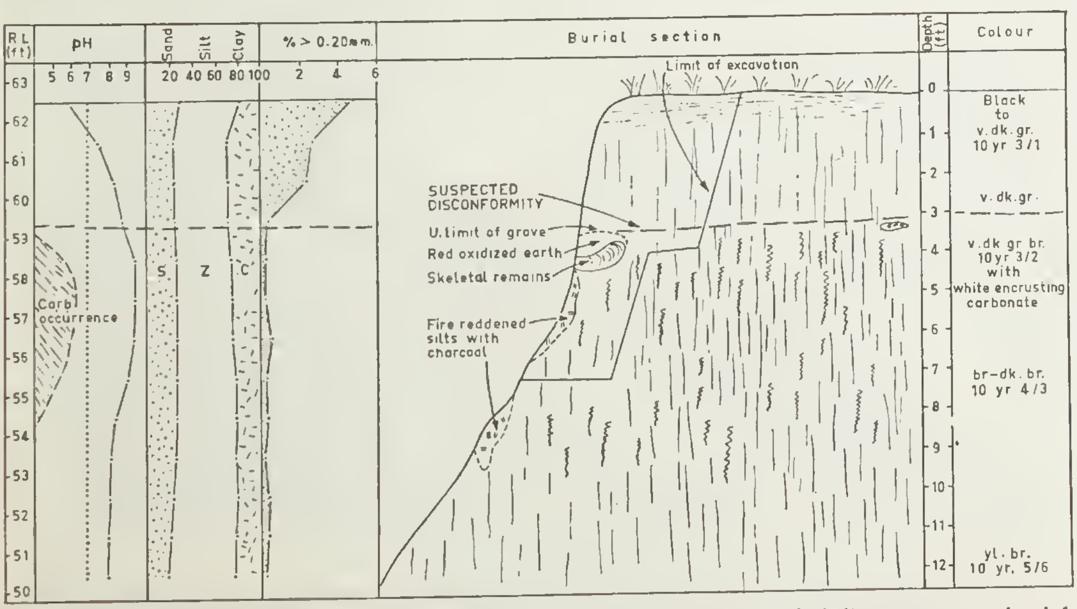

Fig. 17—Section summarizing depth function data through top 12 ft of Keilor terrace at burial site. The deeply organized chernozemic soil is thought to be a polygenetic profile with a disconformity near top of burial zone. The zone below burial contains carbonate and many biotic casts or tubules which are absent in top 30 in. of terrace.

from approximately 16,500 to 15,000 B.P. Depositional details of the higher and younger horizons in the Keilor terrace have been discussed earlier.

Maribyrnong terrace

In the M.M.B.W. trench on the left side of the river, approximately 20 ft of vertical section was available for examination. This consisted of homogeneous sandy silts with a close textural resemblance to those of the Keilor terrace although slightly darker in colour reflecting higher organic content. No bedding traces were preserved. Samples from two levels selected for radiocarbon analysis provided ages of 4,440 ± 100 (V-77) and 3,145 ± 95 (V-78) as outlined in Table 3 and Fig. 16.

Correlation of terrace GGJ

In the sequence described here, the Keilor and Maribyrnong terraces are separated by the terrace GGJ. Although it has not been possible to trace this terrace through the valley, it would appear from its level and stratigraphic position to correlate with the Braybrook terrace of Keble and Macpherson. But as shown earlier, this terrace consists of a body of alluvium separated from the Keilor terrace by an erosional disconformity and a period of soil formation. It must therefore be considered as a separate body of sediment independent from the Keilor terrace and not formed by shallow surface erosion of the latter as postulated for the Braybrook terrace (Gill 1953), with which it seems to be identical at Green Gully. But in terms of its age, it is probably synchronous with the lower part of the Maribyrnong terrace.

Correlation with Keilor cranium site

The stratigraphy of the original cranium site near Dry Creek has been discussed by Keble and Macpherson (1946) and by E. D. Gill in a series of papers (see bibliography p. 57), although no definitive account of the stratigraphy and sediments of the Dry Creek locality is yet available. The chronology of the terrace as known in September 1965 is set out in Table 4.

Gill (1953) showed a section at the skull site with a prominent diastem located 9 ft below the terrace surface. The evidence for the diastem lay firstly, in the tendency for sediment to break away neatly along a horizontal surface producing a notch in vertical section, and secondly, the presence of a zone affected by pedogenesis immediately beneath this level. Below the diastem Gill (1966) recognized a weak duplex soil profile with carbonate and clay accumulation in the buried B horizon. Since the cranium was encrusted with secondary carbonate, this provided evidence of its original position within the terrace which has been estimated at 18 ± 6 in. below the diastem (Gill *op. cit.*). From the evidence available, a reconstructed section of the skull site is shown in Fig. 18 with the radiocarbon chronology as deduced by Gill. In any attempt to compare this with the Green Gully site, the chronology presents some difficulties.

Firstly, the only date above the diastem (W-169) was collected 5 miles downstream from Dry Creek at Braybrook (Fig. 1). Its correlation with the cranium site rests on:

1. Its position 2 ft 6 in. above a diastem at Braybrook, and
2. the lateral continuity of that diastem along the valley between Braybrook and Dry Creek.

If the extrapolation from Braybrook to Dry Creek is accepted, the diastem at the latter locality would fall within the range 15,000 to 8,500 B.P. as postulated by Gill (1966 p. 584).

This chronology cannot readily be correlated with the evidence from Green

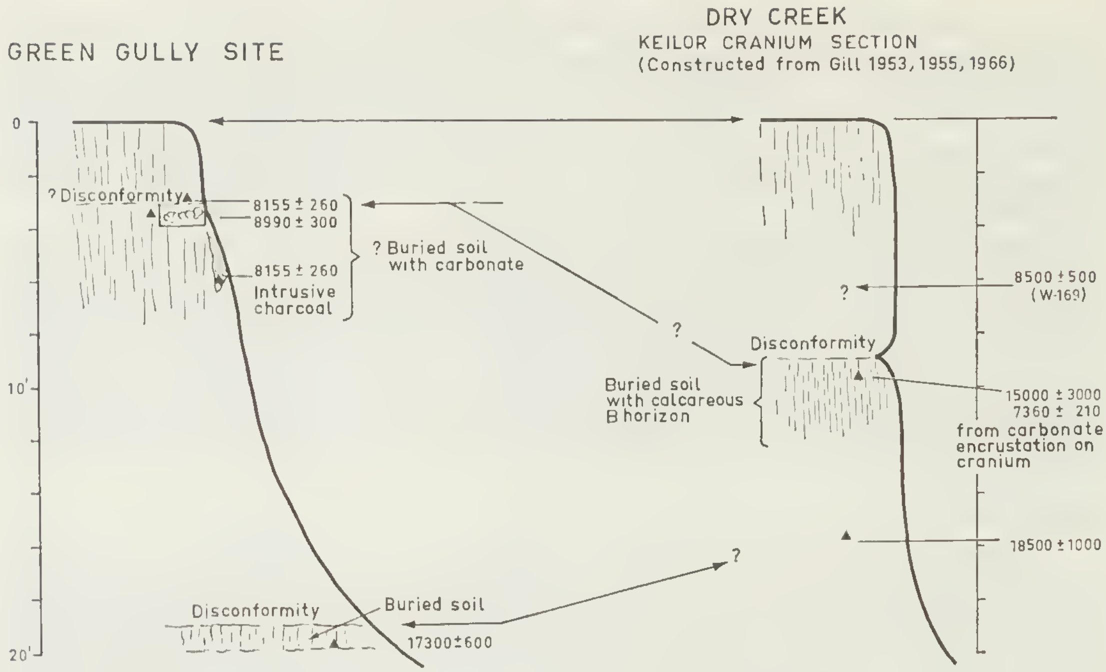

Fig. 18—Diagram showing correlation between composite sections at Green Gully and Keilor cranium site. Radiocarbon sample W-169 collected at Braybrook is shown in position assigned to it by Gill on basis of its promixity to a disconformity at Braybrook which Gill has correlated with that at Dry Creek. Dates are reported with errors of *two standard deviations* to emphasize the relative degrees of uncertainty in chronology at these sites.

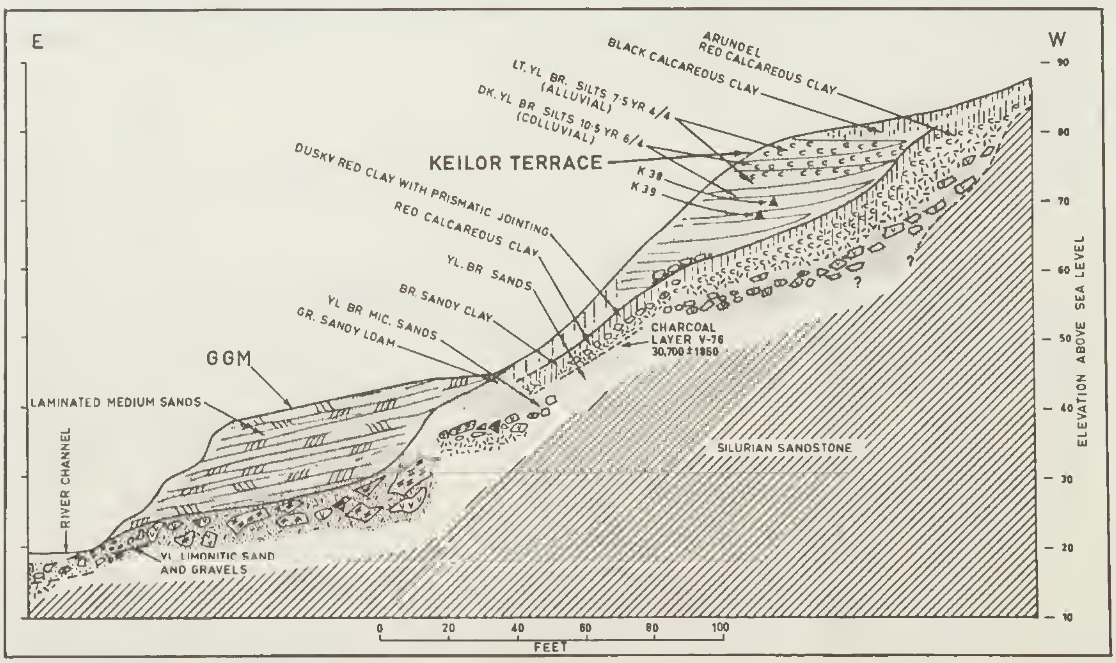

Fig. 19—E-W section through part of MMBW pipeline trench showing silts of Keilor terrace inset into eroded remnant of Arundel terrace. Colluvial silts within the Keilor terrace interfinger with alluvium which was deposited here to near R.L. 78 ft with a low initial dip to E. off valley wall. For line of section see Fig. 2.

TABLE 4

Additional radiocarbon dates from the Maribyrnong Valley

Lab. No.	Age Years BP	References	Comments
GX-O148	1,020 ± 80	Gill 1966	From log of *Eucalyptus* with its upper edge two feet from the surface of Maribyrnong terrace in soil pit on E side of Milleara Rd, Braybrook.
W-125	3,010 ± 160 or 3,100 ± 160	Rubin and Suess 1955 Gill 1955a, p. 50	From Keilor terrace four chains downstream from Medway Golf Links, Braybrook. Date regarded as too young on geological evidence because from a number of hearths in the terrace some deep, and others near the surface (Gill 1955a, p. 49). Rubin and Suess suggest some charcoal may be intrusive.
W-169	8,500 ± 250	Rubin and Suess 1955 Gill 1955a, 1955b	Charcoal from hearth from middle (vertically) of Keilor terrace at the E. end of moulding sand quarry on S. bank of river near Braybrook. Sample was 'from a mass of charcoal and reddened silt' 2 ft 6 in. above the diastem (Gill 1955b). Note the resemblance to features described in this report from near burial.
NZ-366	15,000 ± 1,500	Grant-Taylor and Rafter 1962 Gill 1966	Charcoal from carbonaceous lens below diastem at Keilor cranium site 6 ft 9 in. above NZ-207. Grant-Taylor and Rafter report 'sample was too small to separate carbon and carbonate and the age is therefore an order of magnitude only.'
NZ-207	18,000 ± 500	Grant-Taylor and Rafter 1962	Charcoal from hearth at site of Keilor cranium 5 ft 9 in. below level of cranium i.e. 6 ft 9 in. below the level of the diastem (Gill 1961). This is equivalent to 16 ft. below the surface of terrace from figure 1 of Gill 1953.
All the above samples were collected by E. D. Gill			
ANU-65	31,600 + 1,100 − 1,300	Polach *et al.* 1968	Charcoal from red (reworked Arundel) clay beneath the basal Keilor terrace sediments at Dry Creek cranium site. Coll. A. Gallus.
ANU-81	24,000 + 3,300 − 5,700	Polach *et al.* 1968	Charcoal from same sedimentary unit as ANU-65 buried beneath Keilor terrace sediments. Coll. A. Gallus.

Gully where the main pause in deposition commenced near 11,000 and continued until near 5,000 B.P. While the disconformity at Green Gully has some features in common with that reported from the cranium site, the lateral continuity of the latter and its synchronous development throughout the valley have still to be verified. Therefore its use as a datum to extrapolate radiocarbon data from Braybrook to Dry Creek remains open to question.

The age of main soil profile development at Green Gully determined from the limiting ages of carbonate accumulation can be reliably estimated as lying between 11,000 and 5,000 B.P. A radiocarbon date obtained from carbonate encrustation on the original Keilor cranium of 7,360 ± 305 (Gill *pers. comm.*) is in agreement

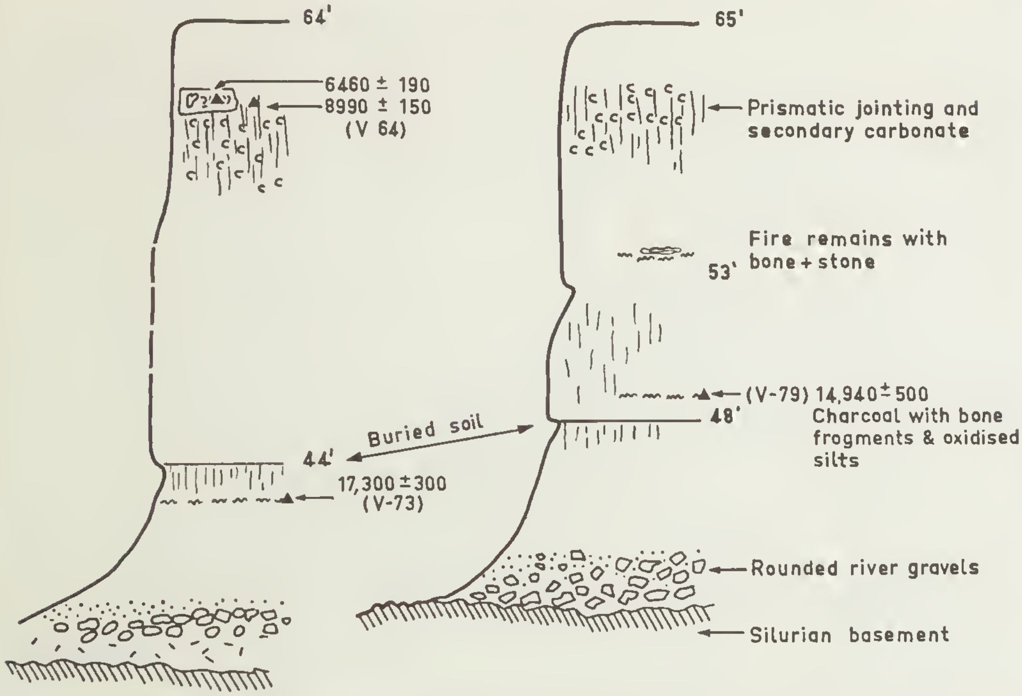

Fig. 20—Sections showing correlation between Green Gully soil pit and weir site. The stratigraphic break with weak soil development is bracketed by radiocarbon dates (V-73 and V-79) which place age of soil formation at approximately 16,500 to 15,000 B.P.

with this estimate, although radiocarbon age determinations on secondary carbonates tend to yield values younger than the true age of carbonate accumulation. This age however, is consistent with carbon mobilization and accumulation near 9,000 B.P. at both sites.

Secondly, the true age represented by sample NZ-366 (15,000 ± 1,500) could fall anywhere in the range of 12,000 to 18,000 B.P. But since sediment 6 ft 9 in. below has yielded an age of 18,000 ± 500 B.P. (NZ-207), the true age of NZ-366 is not likely to be older than 15,000 while it could be considerably younger.

In view of the doubts attached to the extrapolation of the Braybrook sample, the disconformity at Dry Creek may be younger than the age assigned to it by Gill (1966), and may be related instead to the disconformity at Green Gully. Correlation between sites on this basis, assuming synchronous pedogenesis in the Keilor paleosol (carbonate organization, organic activity, etc.) remains tentative; furthermore, it requires different rates of deposition at each site as in Fig. 18. The difficulties in such a correlation perhaps may be resolved by additional stratigraphic and radiocarbon data, especially from the cranium site.

Terrace Formation and Environmental History

Causes of terracing

Of the three major processes commonly invoked in terrace formation (tectonic, eustatic and climatic processes) all have played some part in the evolution of the Port Phillip sunkland in which the Maribyrnong River terraces are located (Hills 1960, Bowler 1966). Keble and Macpherson (1946) advanced evidence of minor tectonic deformation affecting the Maribyrnong River downstream from Keilor. These comprised the 'Footscray and Keilor warps', but as they conceded (p. 67),

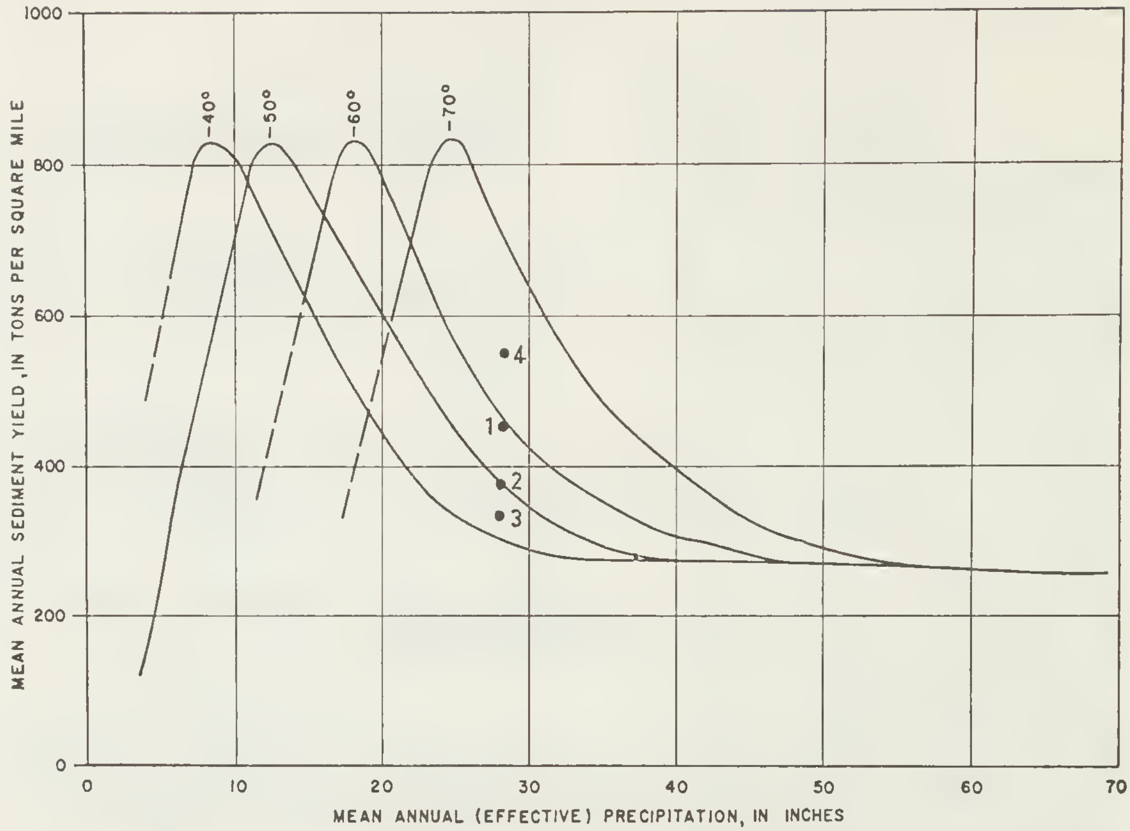

Fig. 21—Curves showing the relationship of sediment yield to variations in mean annual rainfall for a range of mean annual temperatures from 40° to 70° (from Schumm 1965). Point 1 is equivalent to present environment of Maribyrnong River catchment upstream from Keilor. Points 2 and 3 show estimated position during cold glacial conditions with mean temperature lowering conservatively and maximally estimated at 9° and 15°F respcctively lower than present mean annual temperatures. Point 4 shows estimated position during interglacial time with mean temperatures conservatively estimated at 5°F higher than present.

they produced little significant effects on the river profile. Gill (1961) has questioned the presence of these structures. More important movements have occurred during Quaternary time on the major tectonic lineaments controlling the sunkland, i.e. on the Rowsley Fault on the W. and on Selwyn's Fault on the E. Movements post-dating the Newer Basalt flows have affected the profiles of the Barwon, Moorabool and Werribee Rivers in the W., causing deep incision and formation of terraces upstream from the faults on which movement occurred. But the Maribyrnong River has not been so affected, as it does not cross a major structure.

Some tilting of the sunkland block by differential movement on marginal structures cannot be ruled out, although the effects are difficult to evaluate. It is indeed probable that some such tilting has occurred, but its effects on stream profiles are not known. There is neither specific evidence to associate terracing in the Maribyrnong River with tectonic movement—nor is there sufficient evidence to rule out totally a small tectonic influence.

Keble and Macpherson proposed a eustatic origin for the terraces which they associated with the Würm glacio-eustatic oscillations. The Keilor terrace was deposited synchronously with rising sea level in the glacial to late glacial period from 18,000 to about 8,000 B.P., but the eustatic rise need not have caused the aggradation as Gill (1953, 1957) has pointed out. The long profile of that terrace passes from R.L. 64 ft near Green Gully to beneath sea level some 10 miles downstream near Maribyrnong (Gill 1961). The gradient of the terrace surface is in excess of that of the river bed, which is hard to reconcile with eustatically controlled aggradation. Moreover, aggradation was active at least 15,000 B.P. when sea level was perhaps 200 ft lower than present and when the shore line was located further out into Bass Strait. Any direct cause and effect relationship between aggradation at Keilor and sea level oscillations in Bass Strait is an unlikely proposition, although both occurred simultaneously.

As argued by Gill (1953, 1954), the most likely cause of terrace formation is climatic change. The textural evidence from the Keilor terrace is consistent with all but the basal 4-5 ft being deposited from suspended load. The top 30 in. of the terrace, as established earlier, has been deposited by overbank deposition, synchronous with the existence of the channel eroded into the Keilor terrace proper. Texturally this top 30 in. is so similar to the remainder of the terrace sediment that a similar overbank depositional regime may be invoked to account for the entire thickness of the fine sands and silts comprising the top 23 ft of this terrace.

But attempts to extrapolate from river terrace stratigraphy to climatic reconstruction encounter many difficulties. Flint (1957) has pointed to the tendency to ignore the many complex variables involved in the response of any drainage system to a particular change in the climatic regime. A single shift in climate may produce different effects in neighbouring basins or in different parts of the same basin. Nevertheless, many Quaternary workers have relied heavily on fluviatile evidence to support their climatic hypotheses, sometimes drawing opposite conclusions from the same evidence (cf. the controversy over Nile terrace sediments: Butzer 1964, p. 304; Fairbridge 1963, p. 308; or the disputed climatic control of prior streams on the Riverine Plain: Butler 1960, Langford-Smith 1959). The Maribyrnong river terraces have also been used as evidence in favour of high rainfall or pluvial conditions during late Pleistocene time. Gill (1954, p. 111) states 'Keilor time was one of much heavier rainfall . . .' and again (1956) 'the rainfall was greater in Keilor times because from the same valley floor the waters of the river built a much higher floodplain'. This conclusion may be in part correct but it does not necessarily follow from the evidence cited. The use of floodplain or terrace levels to reconstruct discharge presents many difficulties as the following calculations will show.

The best example of high floodplain deposition is found in the M.M.B.W. section on the right side of the river S. of the soil pit. Here interdigitating layers of different colour and texture within the Keilor terrace, dip conformably to the E. off the steep W. slope (Fig. 19). These represent alternate layers of alluvial and colluvial deposition; the former are texturally identical with the silts of the Keilor terrace and thicken towards the floodplain to the E., while the latter show poor sorting with a high percentage of medium to coarse sand and thicken upslope to the W.

Alluvial deposits have been identified here higher than R.L. 76 ft requiring flooding in excess of this level for their deposition. Assuming a channel was present with its bed near the base of the terrace, this would involve a minimum flood height of 34-36 ft above the channel floor, corresponding to a depth of approximately 13 ft over the upper level of the floodplain (R.L. 63 ft).

The highest recorded discharge in the Maribyrnong River occurred during the flood of 1916 when the river reached a height of 36 ft on the gauge 1 mile upstream from the soil pit, corresponding to a discharge of 17,000 cusecs (State Rivers and Water Supply Commission 1964). Assuming the same flood-height in the soil pit area, it is possible to compare the cross-sectional area involved in the flow of the 1916 flood with the reconstructed cross-sectional area of the flooding required to deposit the highest sediments of the Keilor terrace. In Table 5 the surface of the terrace is presumed to have aggraded to near 63 ft across the valley sloping up to near 76 ft where alluvium has been identified. The presence of a channel of approximately the same dimensions as the present river channel is assumed (2400 sq ft). On the basis of this reconstruction, the cross-sectional area of a flood reaching to R.L. 76 ft in Keilor terrace time can be calculated.

TABLE 5

Comparison of discharges necessary to deposit upper part of Keilor terrace with those of largest recorded flood in Maribyrnong River

	Area A	Gradient S	Discharge Q	Velocity V
1916 flood assuming flood height at Green Gully of 36 ft. above channel floor as recorded on gauge 1 mile upstream	8,970	0·0010	17,000 (measured)	1·895
Reconstructed figures for deposition of Keilor terrace to R.L. 76 ft assuming average floodplain level near 63 ft and maximum channel aggradation to 43 ft	10,540 (A_k)	0·0014	23,600 Q_k	V_k

A = cross-sectional area of flow across the valley in square feet.
S = average downstream gradient of floodplain surface from near Keilor to a point 12 miles downstream.
Q = discharge in cusecs.
V = average velocity across floodplain (ft/sec.) calculated from relationship $Q = A \times V$

From Manning's equation, $V \alpha S^{\frac{1}{2}}$ when depth and roughness factors are constant. In the case in question, the depth of reconstructed flow across the floodplain surface is approximately 13 ft in both cases and both surfaces would present similar resistance to shear.

$$\text{Thus } V^2 = KS \text{ where } K \text{ is constant}$$

Substituting the values for the 1916 flood conditions from Table 5

$$K = 3591$$

Using this value of K, the velocity of flow across the Keilor floodplain surface can be determined.

$$V_k = (3591 \times 0{\cdot}0014)^{\frac{1}{2}}$$

$$\text{But } Q_k = V_k \times A_k$$

Substituting values for V_k and A_k

$$Q_k = 23{,}600 \text{ cusecs.}$$

Note that even if no adjustment is made for the differences in the gradients of the floodplain surfaces, then on the basis of cross-sectional area alone, the discharge required to deposit the highest Keilor terrace sediments would exceed that of the 1916 flood provided a channel was present. But in drainage basins subject to ephemeral flow in S.E. Australia, channels are sometimes absent. After high intensity rain, water flows across grass-covered alluvium depositing a layer of silt and clay. It is possible under conditions of reduced flow during an arid period, that even large channels such as that of the Maribyrnong River may have been infilled. Ephemeral flow, lacking coarse bedload sediment, would then be limited to the floodplain rather than to a channel regime. Assuming that such conditions were possible, and if no channel was present during the deposition of the high level alluvium, the depositing discharges would be reduced from 23,600 to 18,200 cusecs, close to that of the present maximum recorded discharge of 1916.

Two interpretations can therefore be placed on this type of evidence. In the first, assuming the presence of a channel, deposition is associated with flow stages higher than any recorded under the present regime. In the second, the processes responsible are ephemeral stream activity or sheet flow across an alluviated valley floor after high intensity rains. This type of evidence may therefore be called upon to support both an arid climatic hypothesis as well as the pluvial conditions discussed above. In the writer's opinion, a channel was probably present during deposition of the upper terrace levels. But in the absence of confirmatory evidence for the existence of a channel at that time, the climatic reconstruction remains tentative. Moreover, it says nothing of the mean annual flow through the system and the climate which controlled it, for which additional evidence must be sought.

In recent years many studies have highlighted the complexity of drainage basin analysis and its relationship to hydrological regimes. Taking these variables into account, attempts have been made to determine in a semi-quantitative way the relationships between drainage basin morphology, river behaviour and climatic change (Chorley 1957, Dury 1965). The type of analysis most likely to assist in the interpretation of alternating phases of fluviatile erosion and deposition described here is that drawn from a study of modern stream behaviour over a wide range of climatic and hydrologic conditions. Such an attempt has been made by Schumm (1965) using data from modern streams representing a wide range of conditions. The complexity of changes induced by a single shift in climate, as it affects different drainage basins or different parts of the same basin, are demonstrated by Schumm (Table 2, p. 790). However, as Schumm points out, in the absence of additional field data, this type of analysis can only point in the general direction of change and provide orders of magnitude rather than quantitative answers. Nevertheless, it provides the best means presently available for objectively interpreting an alternating sequence of erosion and deposition. This study will therefore conclude with an analysis of the evidence from the Maribyrnong River terraces in terms of the hydrologic and climatic relationships proposed by Schumm.

Hydrologic and climatic environment

The cyclic sequence of deposition, erosion, and soil formation demonstrated above, has been interpreted as due to changes of considerable magnitude in the climatic system controlling the fluviatile regime. The radiocarbon data and evidence of soil development indicate variable rates of deposition within the Keilor terrace, and therefore variations in the rates of sediment supply during the formation of that deposit. Sedimentation rates of 1·1 ft/1,000 yr. existed between the deposition of the radiocarbon samples V-73 and V-79 from the lower part of the terrace, compared with 2·1 ft/1,000 yr. between the equivalent levels represented by V-64 and V-79. If the evidence from the upper soil development, which had already begun before deposition of V-64, is further taken into account, the sedimentation rate for the central body of Keilor terrace alluvium (from R.L. 44 to R.L. 54 ft in the soil pit) must have been considerably in excess of 2·1 ft/1,000 yr.

From 11,000 to 6,000 B.P., depositional rates on the Keilor floodplain were reduced to less than 1 ft/1000 yr. Rapid aggradation recommenced at approximately 4,500 B.P. with the deposition of sediment of GGJ, equivalent to the basal Maribyrnong alluvium and to the alluvial cover on the upper level of the Keilor terrace. Estimates from radiocarbon samples V-77 and V-78 (Table 3) would suggest the high rate of vertical aggradation of 10 ft/1,000 yr. during this period.

These rates, in so far as they reflect variations in sediment yield or sediment concentration, can be used to relate the alluvial depositional phases to the hydrological data of Schumm (1965) and Langbein *et al.* (1949). Fig. 21 shows the position of Maribyrnong River data on the curves relating rainfall, sediment yield and mean annual temperature. A large change in both sediment yield and percentage run-off can be brought about by a temperature change alone without any necessary change in absolute precipitation (Schumm 1965, Langbein *et al.* 1949). The effects of such temperature change are represented by the family of curves for different mean annual temperatures in Fig. 21. Assuming that precipitation remained constant, a small drop in temperature would have a similar effect on sediment yield as an increase in precipitation, i.e., sediment yield would decrease. Higher yields would accompany a decrease in mean annual precipitation or an increase in temperature, both of which would have a similar effect on run-off.

Thus if aggradation results from high sediment yields, then to produce these conditions in the Maribyrnong basin would require a shift from the present towards more arid conditions either in terms of lower rainfall or higher temperatures. Conversely, erosion of the floodplain corresponding to low sediment yield would accompany an increase in rainfall or decrease in temperatures, either of which would result in increased discharges.

While it is seldom, if ever, valid to infer precipitation changes from terrace evidence alone, independent evidence exists for world-wide temperature lowering during the last glacial maximum from approximately 30,000 to some time after 20,000 B.P. Estimates from the N. Hemisphere range from as low as 3°C from evidence near Lake Nevada (Antevs 1952) to more than 8°C (Schnell 1961, Schwarzbach 1961, Charlesworth 1957). From evidence in SE. Australia, Galloway (1965) has postulated a fall in temperatures of 9°C (16°F). Estimates vary according to the type of data used and the site from which they are drawn, but most favour a world wide lowering for which 5°C (9°F) is a conservative estimate. Temperature changes during interglacials may similarly be estimated as being approximately 5°F higher than at present.

In Table 6 estimates of run-off, discharge and sediment yield for glacial and interglacial conditions have been made using the relationships of Schumm (1956) and Langbein *et al* (1949). Additional data (Fournier 1960, Douglas 1967) suggest the need to modify the Schumm-Langbein curves in the region of high rainfall. But within the precipitation range relevant to the Maribyrnong Valley, there is no reason at present to doubt the general validity of the curves. For the purposes of the calculations, precipitation is assumed to have remained constant. In this way, the direction of changes and the order of magnitude may be estimated provided precipitation changes remained small, a reasonable assumption in view of the general lack of evidence in S. Australia for widespread increases in rainfall during glacial time (Galloway 1965).

From these calculations, glacial discharges two to three times higher than

TABLE 6

Hydrologic data from present regime of Maribyrnong River compared to postulated glacial and interglacial conditions, assuming no changes in precipitation

	Present regime	Glacial regime		Interglacial 5°F above present
		9°F below present	15°F below present	
Precipitation (ins.)	28	28	28	28
Mean annual temp. (F°)	59	50	44	64
Pan evaporation (ins.)	40	23	15	53
Run-off (ins.)	3·3*	7·0	10·0	2·0
Mean annual discharge (acre ft × 1,000)	86·6	172	262	52
Sediment yield (tons/sq. mile)	460	380	340	560

* From State Rivers and Water Supply Commission

TABLE 7

Correlation of terrace chronology, sediments and soil with a tentative sequence of climatic fluctuations

Terrace Sequence	Radiocarbon Age Years B.P.	Geological-Hydrological Sequence	Soil Development	Climatic interpretation (following relationships proposed by Schumm, 1965)
MARIBYRNONG GGM		Erosion active with occasional floodplain deposition. Point bars from lateral stream migration	Weak soil formation *black alluvial soil*	
MARIBYRNONG GGL	2,000	Rapid deposition of Maribyrnong terrace		Low run-off produced by high temps. or low rainfall
MARIBYRNONG GGJ	4,500	High sediment yields ? Low discharge		
KEILOR upper (Intermediate Zone)	6,000 8,000	Erosion of Keilor terrace, chanel incision, low sed. yield, occasional floodplain deposition during high stage flow ? High discharge	Main period of soil formation on Keilor terrace sediment with biotic activity and carbonate mobilization producing *chernozemic profile*	High run-off produced by high rainfall or low temperatures
KEILOR middle	12,000	Rapid deposition of middle zone Keilor terrace from suspended load regime, high sediment yield Low discharge		Low run-off produced by high temperatures or low rainfall
KEILOR basal	15,000	Non deposition Transition	Weak soil on basal Keilor	Increasing temperatures
KEILOR basal	17,000 20,000 31,000	Deposition of basal Keilor terrace simultaneously with erosion and destruction of Arundel floodplain by lateral stream migration. Shallow channel, bed-load regime High discharge	Soil formation on Arundel terrace sediment producing *red-brown earth profile*	Low temperatures, low evaporation producing high run-off.
ARUNDEL		Sediment of Arundel terrace deposited ? Low discharge		- Low run-off.

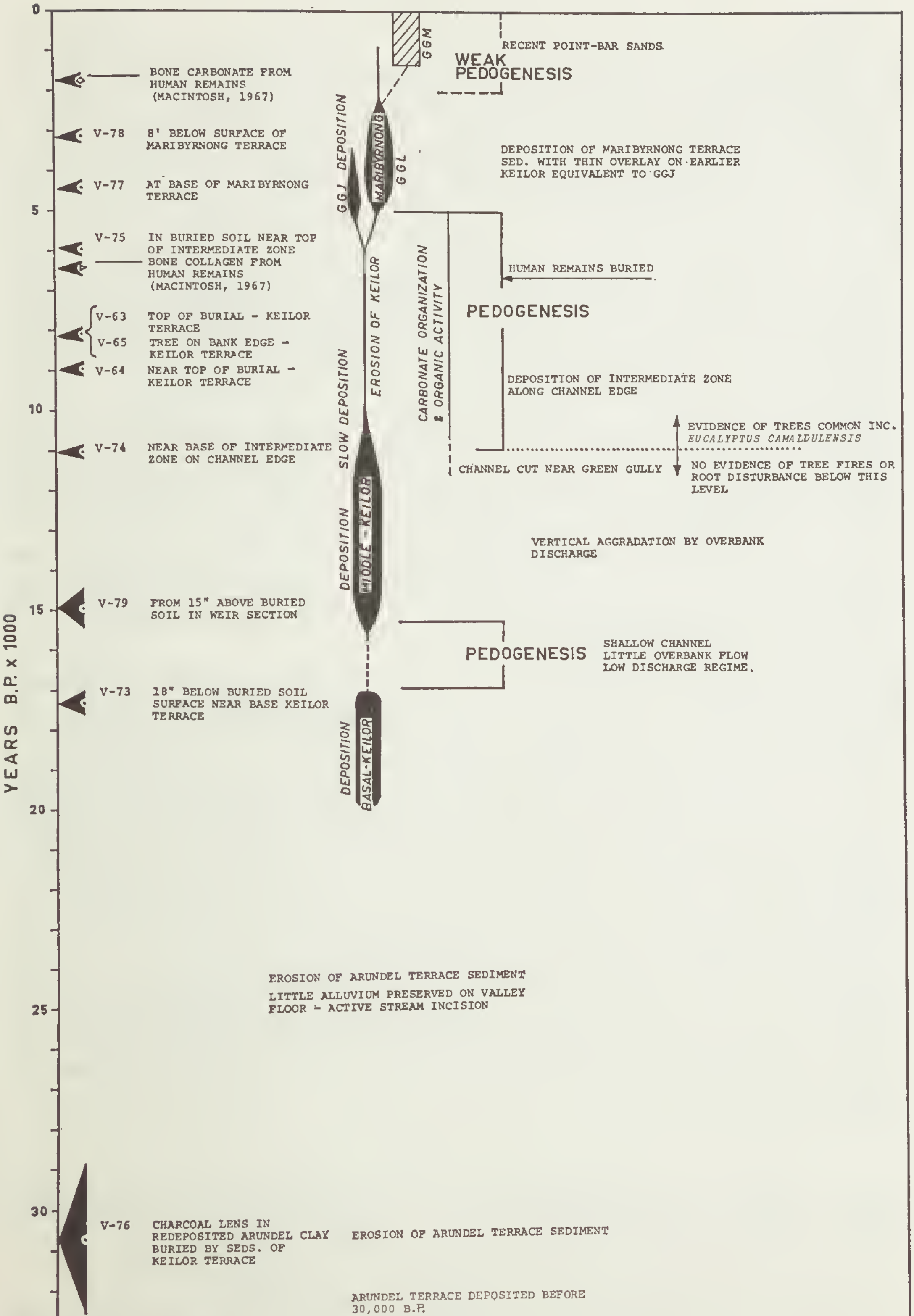

Fig. 22—Diagram summarizing main sequence and radiocarbon chronology of deposition and soil formation in evolution of terraces. Vertical thickness of triangles represents one standard deviation from mean radiocarbon ages.

present mean annual discharge would be accompanied by sediment yields to 25% lower. Low interglacial discharges would be accompanied by sediment yields in the order of 25% higher than present values.

In the terrace sequence, periods of rapid aggradation require rates of deposition in excess of erosion. Such conditions would have existed during periods of high sediment yield assisted by low discharges resulting in high rates of sediment concentration. Thus aggradation was most active during periods of relative aridity. During periods of erosion or floodplain destruction, more sediment was removed than was deposited. This would be favoured by low sediment yields and high discharges. Thus terrace erosion with little floodplain deposition and active pedogenesis, is attributed to periods of lower temperatures or higher rainfall than the present. But in either of these circumstances, whether the floodplain is under the dominant influence of either erosion at one time or deposition at another, both processes may have operated simultaneously. During periods of high discharge and low sediment yield, overbank flow may have produced minor aggradation on the floodplain simultaneous with active floodplain destruction.

On the basis of these relationships, the hydrologic and climatic environments have been reconstructed and correlated with the geological and pedologic events recognized in the sequence as set out in Table 7. In this scheme, the period corresponding to the low temperature-high discharge glacial maximum (from 30,000 to approximately 18,000 B.P.), which from Schumm's data should be a period of erosion, correlates with the major destruction of the Arundel terrace with simultaneous deposition of the basal zone of the Keilor terrace. This agreement between the theoretical and observed data lends confidence to the reliability of the remaining interpretations. The pause in sedimentation with weak soil development bracketed by radiocarbon dates (14,940 and 17,300 B.P.) near the base of the Keilor terrace, corresponds to a stable or transitional phase from a high discharge bed-load regime, to a low discharge suspended-load regime, probably associated with rising temperatures following the cold glacial maximum. Rapid aggradation followed, with active floodplain construction continuing until approximately 12,000 B.P. under the influence of a relatively arid climate with either higher temperatures or lower rainfall than present. Near 12,000 B.P. discharges increased, and channel incision occurred with consequent floodplain erosion. In the absence of frequent overbank deposition, pedogenetic processes, including biotic activity and carbonate segregation, actively developed on the floodplain alluvium keeping pace with slow deposition and resulting in the deep well-organized chernozemic profile. These conditions came to an end soon after 5,000 B.P. with a return to lower discharges and another short period of rapid floodplain construction which extended from approximately 4,500 to 2,000 B.P.

It is not yet possible to correlate precisely this sequence with other climatic terrace sequences such as that of the Shoalhaven River at Nowra (Walker 1962), or with the fluviatile sequence of the Riverine Plain (Butler 1960, Pels 1966). High discharges in sandy bed-load streams have been suggested for late glacial environments of the Goulburn River (Bowler 1967) and Murrumbidgee River (Schumm 1968). Radiocarbon dates from the high discharge phase of the Goulburn, correlate well with the erosion of the Arundel and deposition of the basal Keilor terrace sediment, interpreted here as due to high discharges and low sediment concentration. Moreover, the age of the youngest red-brown earth soils is there placed near 20,000 B.P. as in the case of the Arundel terrace (Table 7), suggesting that with more field evidence it will be possible to correlate in detail the climatically controlled episodes in various basins. Until such data are available from a range of different environments, climatic interpretations based on a single fluviatile system remain tentative.

Conclusions

The major events recognized in the sequence and their radiocarbon chronology ages are summarized in Table 7 and are represented diagramatically in Fig. 22. The Green Gully human remains, the discovery of which initiated the work reported in this paper, were buried in the Keilor floodplain approximately 6,500 years B.P. near the margin of a river channel. Floodplain aggradation had almost ceased some 5,000 years earlier allowing a soil profile to develop on the stable floodplain surface. The grave was cut into this soil and the sediment filling it was itself subject to later pedogenesis before burial beneath younger silts approximately 4,500 B.P.

The stratigraphic units recognized near the soil pit further demonstrate the possible complexity of terrace formation in contrast to the often too simple textbook 'cut-and-fill' explanations. The data moreover raise questions of a fundamental nature about the role of overbank flow as a factor in alluvial aggradation—one often thought to be of relatively minor importance (c.f. Leopold, Wolman and Miller 1964, p. 326).

The cyclic sequence of erosion, deposition and soil formation provides an example of the importance of Late Quaternary climatic change in the pedology and surficial geology of SE. Australia. At the risk of erecting yet another system of inadequate climatic hypotheses, the sequence in this valley can be interpreted in the light of the climatic-hydrologic relationships proposed by Schumm. Using these data, the main periods of aggradation are correlated with high sediment yield, low discharge and high sediment concentration. Conversely, erosion and floodplain destruction are attributed to periods of low sediment yield and high discharge. The former are interpreted as high temperature environments while the latter represent low temperature conditions.

Radiocarbon data establish the age of maximum erosion as being synchronous with the main temperature reduction during the last glacial maximum, lending support to the strength of the climatic interpretations. If the terrace sequence is climatically controlled, it will have its regional representatives in other river basins. Some similarity is recognized to the Goulburn River in N. Victoria, where the radiocarbon ages of both the late glacial high discharge phase of stream activity and the formation of red-brown earth soils resemble those proposed here for the Maribyrnong Valley. But climatic reconstruction based on fluvial evidence, although often used in Australia and elsewhere, is still liable to ambiguity. In the absence of similar sequences repeated throughout a number of drainage basins, the interpretations based on these data remain speculative.

While the interpretations may require amendments or alterations in the light of new evidence from this and other systems, the description of the terraces, their sediments, soils and absolute chronologies provides a basis for comparison with other fluviatile sequences. The account of alternating deposition and soil formation presented here may assist in understanding the relationships between stream behaviour, floodplain construction and soil development in other non-glacial fluviatile environments of SE. Australia.

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Explanation of Plates

Plate 2

Upper—Section exposed by completed stratigraphic excavation (cf Fig. 7). Photo by courtesy Director, Institute of Applied Science of Victoria.

Lower—Mahon's soil pit, December 1965, looking NW. along contact between Keilor terrace on left and terrace GGJ on right. The upper section of partially completed stratigraphic excavation is exposed on right, while site of burial excavation is visible on upper left.