Permian Varves from Wynyard, Tasmania

By

MAXWELL R. BANKS
University of Tasmania,

J. L. LOVEDAY
Soils Division, C.S.I.R.O.,

and

D. LL. SCOTT

(WITH 3 PLATES AND 6 TEXT FIGURES)

ABSTRACT

Thinly laminated to very thinly bedded varved mudstones are associated with tillite and thinly cross-laminated sandstone in the Wynyard Tillite in the Wynyard area, north-west Tasmania. Many of the varves are highly coloured. Simple drainage and composite varves are present. The varves show slump structures and ripple marking. Sedimentary structures, textures and the types of erratics indicate derivation from the south or south-west. Oil shale, probably of Upper Artinskian age, occurs within fifty feet of the top of the tillite and is conformable with it. At least three advances and retreats of the Permian ice sheet are indicated. The Wynyard Tillite is defined in terms of the Australian Code of Stratigraphic Nomenclature.

INTRODUCTION

The Wynyard Tillite was first recorded by Stephens (1869) who, although recognising it as a glacial deposit, did not comment on its age or formally name it. It was called the Wynyard Formation by Montgomery (1896) but it is mainly known through the detailed description by David (1907). Although earlier authors describe rocks in the formation which could be varves, they did not recognise them as such. The present authors have recorded their discovery in a short preliminary note (Banks, Loveday and Scott, 1954).

During a survey by the Soils Division, C.S.I.R.O., in the summer of 1953-4, Messrs. Loveday and Scott first noticed these rocks and described them to the other author who suggested they might be varves. On a subsequent trip to the area, closer observations were made and specimens collected for examination. All the facts confirm the earlier suggestion that these rocks are varves.

Colours were determined by the use of the Rock-colour Chart (Goddard et al, 1948) and the formulae which accompany colours in the text refer to this notation. Bedding and cross-bedding terminology is that of McKee and Weir (1953). The authors wish to acknowledge, with many thanks, the assistance of Mr. G. E. A. Hale, of the Tasmanian Museum, in determining the clay minerals.

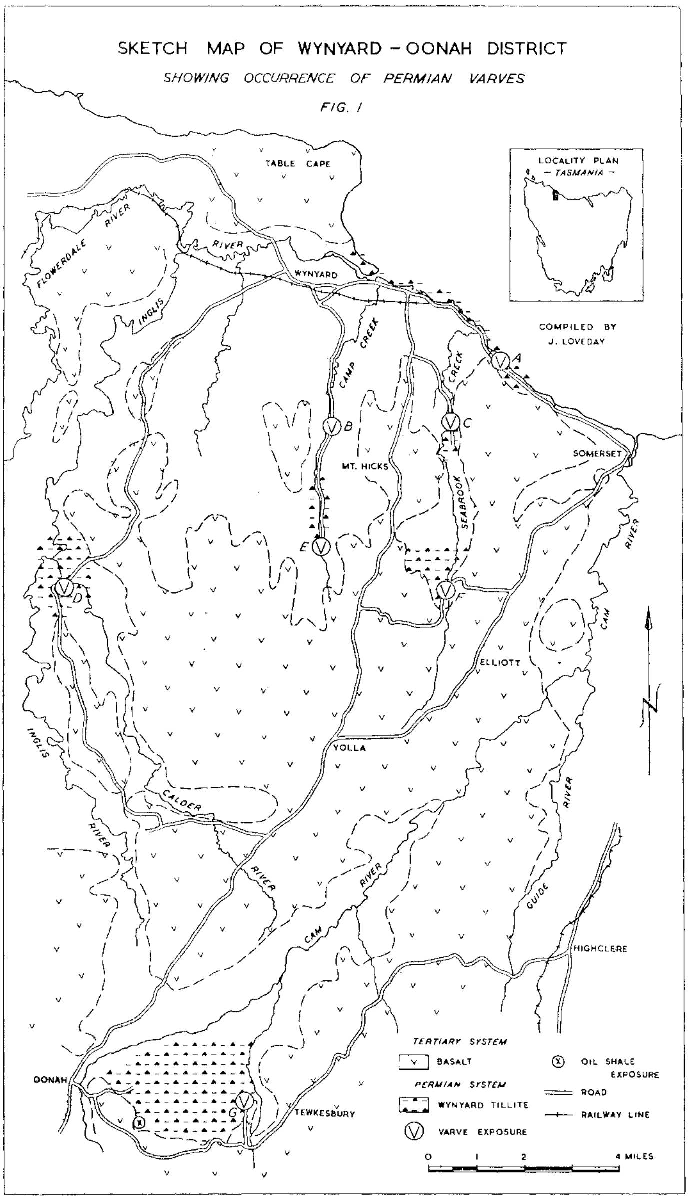

FIG. 1.—Sketch Map of Wynyard-Oonah District showing occurrence of Permian Varves.

WYNYARD TILLITE

The Wynyard Tillite is defined as that formation of tillite, with subordinate sandstones and varved mudstones, resting unconformably on Devonian or older rocks and overlain conformably by sandstones and siltstones, as exposed in the creek bed east of Oonah Post Office. The tillite is 1220 ft. thick according to David (1907) and is probably Sakmarian and Artinskian in age. The type area is the Wynyard district, but no uninterrupted section can be quoted.

This formation has received various names in the past, as shown in the following list:—

Wynyard Formation:
- Montgomery, 1896
- Waller, 1902
- Twelvetrees, 1905
- Noetling, 1909

Wynyard Glacial Formation:
- Hills and Carey, 1949
- Banks, Loveday and Scott, 1954

Wynyard Glacial Stage: Voisey, 1938
Wynyard Mudstone Conglomerate: Hills, 1913
non Wynyard Stage: Nye and Lewis, 1928

The geographic name was first applied by Montgomery (1896), but it had been recognized as a tillite by Stephens (1869). Montgomery gave its age as Permo-Carboniferous and has been followed in this by Kitson (1902), Twelvetrees (1905), David (1907) and most other authors. However, Noetling (1909) incorrectly considered it to be Pleistocene. The name tillite is here used in preference to glacial formation as the formation is dominantly tillitic. The tillite occurs at least as far south as the Hellyer Gorge (Lewis, 1929) and as far south-west as the junction of the Arthur and Keith Rivers. It is commonly exposed in gullies, cut through the basalt south of Wynyard. Details of the lithology and age of this formation are discussed by David (1907) and the present authors (see later).

The varved mudstones occur on several horizons within the tillite formation and may eventually prove to be members occupying consistent stratigraphic horizons. The geographic distribution of the varved mudstones is shown in the accompanying map (fig. 1) and the occurrences will be discussed in the order used on the map.

STRATIGRAPHY AND FIELD OCCURRENCE

At Doctors Rock (A in fig. 1)* two miles east of Wynyard on the coast Tertiary basalt unconformably overlies varved mudstones and tillites on the shore platform. Several hundred yards further east, the tillite rests unconformably on pre-Dundas Group rocks. On the shore platform immediately east of Doctors Rock varved mudstones are found closely associated with tillite near the base of the formation. The varved mudstones include many thin beds of cross-laminated sandstone and these show the cross-lamination dipping in a northerly direction. The surface of these sandstone beds is frequently ripple-marked.

* Exposure sites, subsequently referred to by capital letters, are shown in fig. 1.

Several exposures of varved mudstones (B and E) occur in cuttings on the road along Camp Creek to the reservoir and the best exposure occurs a few yards down-stream from the reservoir wall (E). All specimens of varved mudstone collected from here showed simple varves, varying in thickness from 0·8 to 8 mm. The winter layers of these specimens were also much thicker than the summer layers which in several cases were of claystone grade and which were usually no coarser than very fine siltstone with some fine erratics. These would seem to be distal simple varves (Antevs, 1951) and this is borne out by the occasional

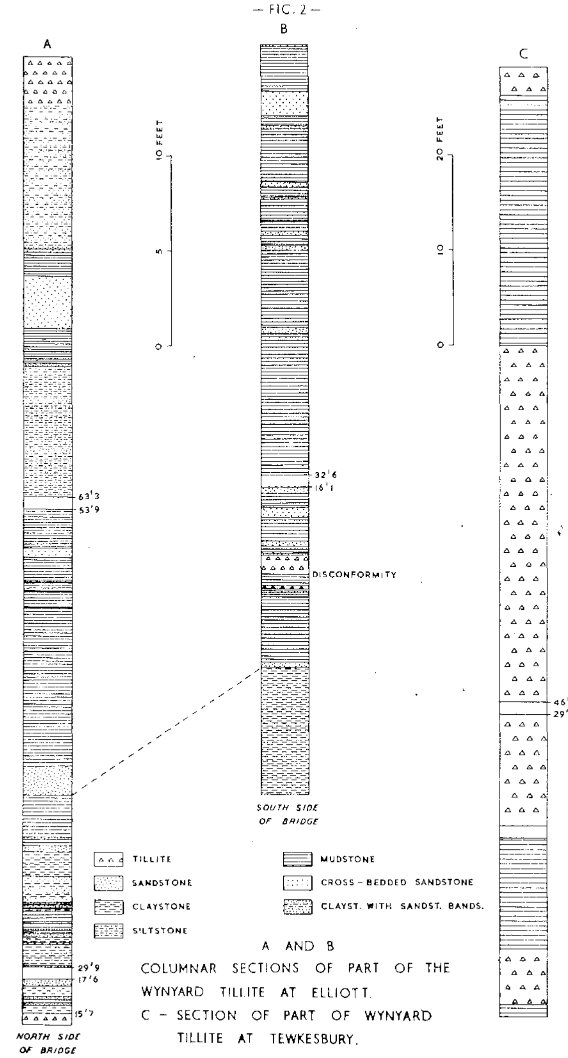

FIG. 2 (*a*).—Columnar section of part of Wynyard Tillite at Elliott.
(*b*).—Columnar section of part of Wynyard Tillite at Tewkesbury.

unvarved claystone beds. At B on the lower part of Camp Creek, the varved mudstones are associated with tillite.

In a road metal quarry beside Seabrook Creek (C) a thickness of about 20 feet of varved mudstones with erratics is revealed. The siltstone layers are ripple-marked. The most notable feature of the rocks in this quarry is the presence of elliptical concretions up to 60 cm. in length, which appear to be restricted to a narrow band. These concretions, which will be described a little later, show contorted bedding and are slump structures.

Where the West Calder Road crosses the Calder River (D) tillite can be seen at river level passing up into varved mudstones which in turn pass up into tillite as seen in road cuttings on the West Calder Road south of the bridge.

The best exposure of varved mudstones seen in the area was in road cuttings and quarries near the Seabrook Creek crossing on the Elliott-Mt. Hicks Road (F). Here, almost 100 feet of varved mudstone, tillite and fine-grained sandstone are exposed resting on tillite in the creek bed. This tillite is described in a later section. The section beside the road to north and south is given (fig. 2 (*a*)). Several granite erratics were found in the tillitic bands, the largest observed being four feet in diameter.

The section above this tillite consists of alternations of fine-grained, cross-laminated, laminae or very thin beds of sandstone, with thinly laminated and laminated sets of varved mudstone. Laminae and thin beds of tillite are present on at least eleven horizons but these seem to become rarer between 50 and 80 feet and above this they are uncommon.

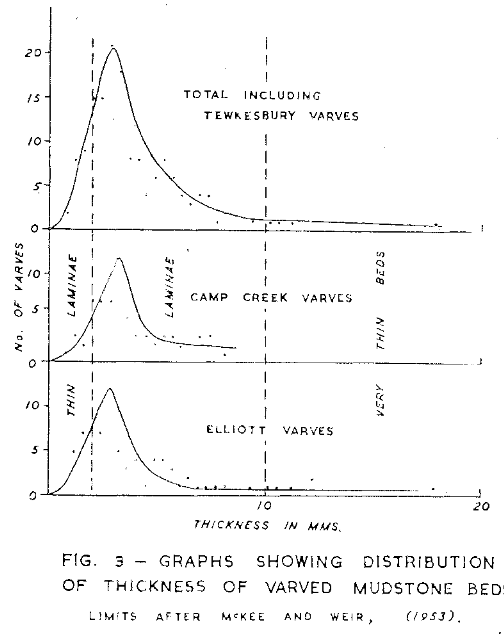

FIG. 3.—Graph showing distribution of thickness of beds of the varved mudstones.

The sandstone bands are of interest, as they consist of fine-grained quartz with some clay matrix. They are dusky yellowish brown (10YR2/2) and brownish black (5YR2/1). They are thinly cross-laminated, the cross-lamination being revealed by dark bands. It was observed here and at Doctors Rock that the surfaces of these bands were usually ripple-marked. The varved mudstones were observed to be usually laminated, some thinly laminated and some very thinly bedded. Figure 3 shows the relative distribution of thicknesses of varves.

These varved mudstones were frequently highly coloured, especially on the south side of the bridge. The colour is normally olive grey, with some summer layers a light brown, but on weathering, iron minerals present are oxidised especially along joints and bedding planes, producing rich purples, reds and deep browns, which give the rock a most striking appearance.

The southernmost outcrop of varved mudstones observed was in a cutting on a disused road at Tewkesbury (G). Here three varved mudstone members are interbedded with tillites as shown in fig. 2 (*b*).

A most interesting section was examined in the bed and valley walls of the creek immediately east of Oonah Post Office (see fig. 4).

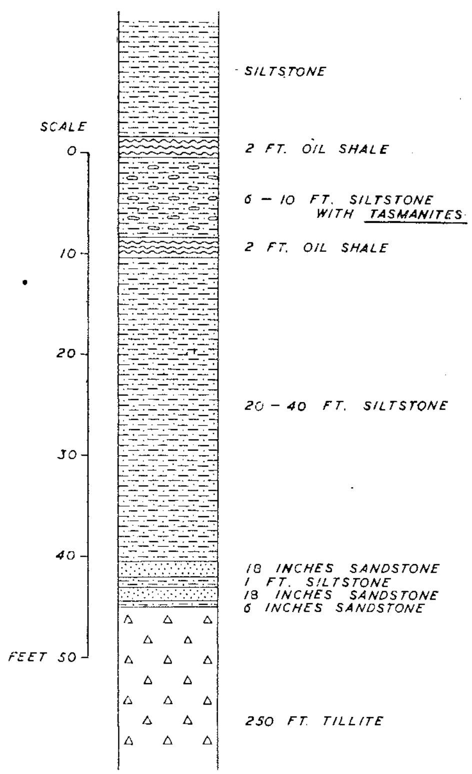

FIG. 4.—Columnar section of Permian near Oonah.

The bottom of the tillite was not seen, but at least 250 feet of this rock were exposed in the creek below and just above the falls. No sign of varved mudstones was seen in this section either in the form of outcrops or as fragments in the creek debris. The tillite is overlain by six inches of dark-grey siltstone, eighteen inches of fine-grained, white, massive, very tough sandstone, a foot of grey siltstone, eighteen inches of sandstone, again white, massive and very tough and then twenty to forty feet of dark-grey siltstone. This siltstone is followed by two beds of oil shale separated by six to ten feet of dark-grey shaly siltstone, with some spores. The top oil shale is overlain by a dark siltstone, which is in turn unconformably overlain by Tertiary basalt. Large pyritic nodules are common in all these sediments above the tillite, but fossils are rare. The importance of this section is that the oil shale contains foraminifera identified by Crespin (1947) as *Ammodiscus multicinctus* Crespin and Parr, *Hyperamminoides acicula* Parr, *Crithionin teicherti* Parr, *Pelosina hemispherica* Chapman and Howchin, *Ammobaculites woolnoughi* Crespin and Parr and *Digitina recurvata* Crespin and Parr, indicating correlation with the Latrobe Tasmanite and the Upper Marine Group of New South Wales. Thus the oil shale is Upper Artinskian in age. Because of the small stratigraphic thickness (less than 50 feet) between the oil shale and the top of the tillite, it is probable that the top of the tillite goes well into the Artinskian and that glaciers were active late in the Artinskian in this area.

Notes on the Sedimentary Petrology and Structures

Tillite

A specimen of tillite (U.T.G.D. 6055) from the base of the Elliott section was examined under the microscope. The tillite band of the fresh rock is medium dark-grey (N4). The associated siltstone is medium bluish-grey (5B5/1), but becomes light olive-grey (5Y5/1) on weathering. Claystone associated with the tillite is also medium bluish-grey. Both graded and ungraded beds are present. In the ungraded specimen (6055*b*) the modal grain size is about 0·25 mm. with about 30 per cent of the particles in the modal grade. Grains from 0·06 mm. to 2·2 mm. were measured but about 25 per cent of the band was unresolvable under the highest power of the microscope. The grains are dominantly angular, with some sub-angular and a few sub-rounded ones. Larger fragments tend to be slightly more rounded than the smaller and some have flat surfaces. The particles vary from almost equidimensional to very elongated. An orientation parallel to the bedding plane is distinctly preferred. Quartz is the only common mineral and forms about 10 per cent of the coarse band. The matrix consists of quartz, a micaceous material which may be a clay mineral and unresolvable material. Rock fragments constitute about 55 per cent of the coarse band. The rock fragments include quartz schist, quartz mica schist, carbonaceous siltstone, chloritic quartzite, quartzite, crystalline dolomite, calcite (some of which may be authigenic), graphitic mica schist, ilmenitic chloritic feldspar schist, siliceous granular limestone, puckered quartz sericite schist, plagioclase with chlorite inclusions, fossiliferous siltstone, chloritic quartz keratophyric tuff, chlorite haematite quartz rock, pyritic carbonaceous silty sandstone, ilmenitic fragments, micaceous slightly ilmenitic sandstone and oolitic dolomite. The most common rock types are the granular limestone and graphitic mica schist and phyllite.

The fine band, with modal grainsize about 0·009 mm. and variation from 0·002-0·012 mm., contains inclusions of tillitic material up to 2·7 mm. long by 1 mm. wide. There are also distinct bands of particles from 0·015-0·02 mm., which diverge around the tillitic erratics. These coarser bands contain micaceous minerals, which are possibly clays, quartz and some calcite. The quartz and calcite grains are angular and from equidimensional to slightly elongated. The micaceous minerals in both coarse and fine bands are distinctly lath shaped and orientated parallel to the bedding plane. The finer bands are dominantly micaceous with some quartz and other minerals.

The contact between the coarse band (a tillitic arenite) and the fine band (a tillitic fine lutite) is sharp but irregular due to the uneven surface of the arenite on which the siltstone was deposited. The rock is considered as of glacial origin because of the presence of large numbers of varied rock fragments, the angularity and the poor sorting. The presence of tillitic erratics in the fine siltstone is of particular interest.

The other specimen examined (6055A) showed distinct gradation from a modal grain size of 1·5 mm. in the coarsest part down to 0·01 mm. in the finest part. Thus the rock varies from a medium arenite to a fine siltstone. Sorting is poor throughout and a considerable proportion of clay material is present, at least 15 per cent in the fine siltstone portion. Probably only 40-50 per cent of the particles would fall into the modal grade of each portion. In all grades the fragments are dominantly angular, with many sub-angular and a few sub-rounded ones. Fragments vary extremely in sphericity from almost equidimensional to elongated forms 6½ times as long as wide. Many distinctly tabular fragments are present. Quartz varies in amount from about 10 per cent in the arenite portion to 40 per cent in the siltstone and 50 per cent in the fine siltstone fraction. Several fragments of feldspar were seen. Clay minerals or sericitic mica are abundant in the matrix and form at least 40 per cent of the finest grade of the rock. Rock fragments form about 60 per cent of the rock in the arenite grades, but are less than 5 per cent in the lutite grades. They consist of quartzite, quartz mica schist, quartz feldspar mica schist, chlorite schist, quartz schist, fine chloritic sandstone, carbonaceous siltstone with sandstone bands, serpentinite, phyllite, mica schist, spilite, laminated carbonaceous siltstones, quartz-chlorite rock, graphitic schist, and an older tillite or subgreywacke. A feature of the slide is the occurrence of about 10 per cent of carbonaceous material, much of which may be graphite, as it is flaky and oriented parallel to the bedding. Haematitic and limonitic staining is present, but not common. This rock is considered to be of glacial origin on the same grounds as the previous rock, with the additional evidence in this case of graded bedding.

Varved Mudstones

Twelve specimens of varved mudstones were carefully measured and examined under the binocular microscope and a thin section (6046*b*) was also examined.

The thin section showed portions of eight varves and details of this slide are summarised as Table I.

TABLE I

Summary of Characters of Varved Mudstone U.T.G.D. 6046 (b)

Varve No.	Thickness Component Bands		Total	Grade		Composition
				Modal	Range	
	mm.		mm.	mm.		
VIII	0·78		0·78	0·01	n.d.	clay minerals plus quartz
VII	1·20	W.L.	1·50	0·009	n.d.	—
	0·30	S.L.		0·035	n.d.	—
VI	0·42	W.L.	0·54	0·009	n.d.	—
	0·12	S.L.		0·025	n.d.	—
V	0·30	W.L.	0·60	0·009	n.d.	quartz and clay minerals equal
	0·30	S.L.		0·03	n.d.	
IV	0·54	W.L.	1·14	0·005	up to 0·009 mm.	quartz 50%, clay mins. 40%, rock fragments
	0·60	S.L.		0·03	up to 0·55 mm.	—
III	0·24	W.L.	6·38	0·005	n.d.	clay and quartz, quartz 75%, clay 25%
	3·6	S.L. 5·64 mm.		0·05	n.d.	clay 60%, quartz 40%
	0·6			0·06	n.d.	quartz 70%, clay 30%
	1·44			0·08	up to 0·16 mm.	plagioclase
II	0·66	W.L.		0·005	up to 0·009 mm.	mainly clay with some quartz
	0·12	S.L. 0·54 mm.		0·015	n.d.	quartz, clay rock fragments
	0·24		1·20	0·012	n.d.	—
	0·18			0·03	up to 0·06 mm.	dominantly quartz with some clay
I	0·42	W.L. 1·5 mm.		0·005	n.d.	dominantly clay with some quartz
	0·36		—	0·016	up to 0·23 mm.	quartz and clay
	0·72			0·009	up to 0·012 mm.	—

S.L. indicates Summer Layer.
W.L. indicates Winter Layer

Examination of this table will show that the varves are dominantly thinly laminated but varve III is laminated. The maximum grade of the summer layers is 0·08 mm. with most of them about 0·03 mm., while the maximum grade in the winter layers is 0·009 mm., with several varves showing a grade in the winter layers of less than 0·005 mm. Thus the varves vary from very fine arenites to very fine siltstones or claystones, with many of the winter layers down to the clay grade. Quartz and micaceous (or clay) minerals are dominant with only occasional fragments of plagioclase and rocks. The micaceous minerals are particularly common in the winter layers and they usually are elongated parallel or sub-parallel to the bedding. Haematitic and limonitic stains are common throughout, with some concentrations. The grains are dominantly angular, with very little rounding shown. Varves I and IV to VIII are simple varves in Antev's terminology, although Varve I has coarse bands in the winter layer. The winter layers become proportionally thicker upwards as compared with the summer layers. Varves II and III have fine layers in the summer layer and are thus the composite varves of Antevs. Varve III is especially interesting because of its thickness and the very thin winter layer as compared to the summer layer. It represents, perhaps, a year in which the glacier approached much closer than in any of the other seven years.

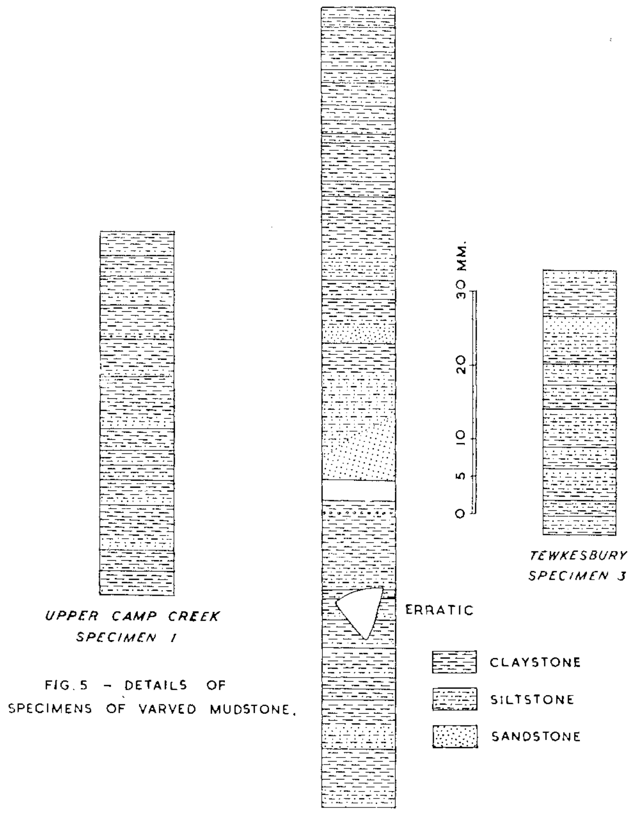

FIG. 5.—Columnar section showing details of varved mudstones—
(*a*) Specimen from Upper Camp Creek.
(*b*) Specimen from Elliott.
(*c*) Specimen from Tewkesbury.

Some details of three specimens, one from Camp Creek, one from Elliott and one from Tewkesbury, are here shown as fig. 5. The Camp Creek varved mudstones are mainly thinly laminated to laminated, with individual varves from 0·8 to 8 mm. thick. The summer layers are usually fine siltstone, with a coarse siltstone or fine sandstone in a few cases and are rarely silty claystones. The winter layers are invariably claystone. Erratics present are usually less than 3 mm. in greatest dimension and the majority are less than 1 mm.; however, one reached 25 mm. in longest dimension. In many varves they are concentrated as a thin line at the base of the summer layer. In one or two varves a siltstone band occurs within the claystone of the winter layer. In the majority of varves measured from Camp Creek the winter layer was distinctly thicker than the summer layer and only rarely did the proportion drop to approach unity. In the case of the eighth varve of the specimen recorded as fig. 5 (*a*) the summer layer lensed out rapidly and within the specimen almost thinned out completely. The colours do not vary greatly. Summer layers are mostly dusky yellow (5Y5/4, 5Y6/4) with some pale olive (10Y6/2) and greyish orange (5Y7/4). One band was purple (5P5/2). The winter layers are dominantly olive-grey (5Y3/2, 5GY3/2, 5Y5/2, 10Y5/2, 10Y4/2, 5Y3/4). Weathering has produced ferruginous concretions in the silty layers in some cases. Sixty-seven varves were measured in specimens from this locality. All are simple varves in Antevs' (1951) terminology. Because the winter layers are usually thicker than the summer layers these varves are thought to have been formed at some distance from the ice front, i.e., they are distal varves. Because of the fine grainsize of the summer layers, the lake in which these varves were deposited is considered to have been deep at Camp Creek.

The varves measured from Elliott were from 1·2 mm. to 18 mm. thick, the latter being an exceptional figure. Most of these varves are thinly laminated or laminated, with a few very thinly-bedded. The summer layers are usually siltstone, but quite a number are fine sandstone and unusually thick; rarely the summer layers consist of very fine siltstone or silty claystone. The winter layers are dominantly claystone but a few are very fine siltstones. The winter layers commonly have bands of coarser material in them and they also commonly contain erratics up to 2 mm. and rarely up to 12 mm. in longest dimension. Erratics also occur in the summer layers and most of the erratics in the varves are less than 1 mm. in longest dimension. However, one was 2 cm. long. Concentration of erratics at the base of the summer layers was not observed in these varves as it was in the Camp Creek specimens. Much more variation in the ratio of thickness of the winter to that of the summer layer was found in the Elliott varves than in those from Camp Creek. In a number of cases from Elliott the summer layer was very much thicker than the winter layer, e.g., Varve 9 (fig. 5, *b*). In many cases the two layers were almost equal and in perhaps a very slight majority of cases the winter layer was the thicker. The colour of the Elliott varves was extremely variable probably due to oxidation on weathering and in some cases this oxidation was demonstrably joint controlled. The summer layers vary from olive-brown (5Y3/4), pink (5R8/4), pale red (10R6/2), orange-pink (5YR7/4) to other combinations of red and yellow. The winter layers are much less variable, the predominant colour being greyish-olive (10Y4/2), with olive (10Y5/2) and light olive-grey (5Y5/2). A total of 83 varves was measured from this locality. All the varves measured from Elliott are simple varves, although more from this locality have coarse bands in the winter layer than is the case with the specimens from Camp Creek. Varve 11 (fig. 5*b*) is excessively thick, being one and a half times as thick as any other varve measured and over six times the modal thickness of the Elliott varves measured (2·85 mm. approx.), which is a little lower than that of all varves measured (3·0 mm. approx.). Six very thinly bedded varves occur among all those measured, all six being from Elliott, and it is probable that all of these are drainage varves. Because of the greater relative thickness of summer layers to winter layers in the Elliott varves as compared to the Camp Creek varves, the former are considered to have formed closer to the ice front as a whole than the latter. The Elliott varves are also generally coarser in grade in both summer and winter layers than those from Camp Creek, suggesting deposition in shallower water.

One specimen of varved mudstone from Tewkesbury was measured and contained nine varves. The thicknesses varied from 2 to 7 mm., most of the varves being laminated. Summer layers were mostly fine sandstone or coarse siltstone and winter layers mostly silty claystones or very fine siltstones. All the varves are simple. Occasional erratics up to 2 mm. occur. The colour varies from moderate greenish-yellow (10Y7/4, 10Y7/6) in summer layers to light olive-grey (5Y4/1) and greyish-olive (10Y4/2) in the winter layers. The properties of the specimen are summarised as fig. 5*c*. No general conclusions can be drawn from these observations on a single specimen.

Clay Minerals

The winter layers from several specimens from Camp Creek and Elliott were examined by differential thermal analysis by G. E. Hale who reported that the clay mineral present was kaolinite.

Sedimentary Structures

The most striking feature of the varved mudstones is the graded bedding, which is very well displayed indeed. Usually this grading is from siltstone up to claystone, but occasionally from silty claystone up to fine claystone and also from fine sandstone up to clayey siltstone. This grading is shown in Plate, figs. 2 and 3.

The bedding varies from thinly laminated in a few varves to laminated in the majority of varves (82%) and very thinly bedded in a few varves (4%) (see fig. 3). The modal thickness of the varves measured is about 3·0 mm. The associated sandstones and tillites are mostly very thin-bedded with rare one thin-bedded, but no detailed measurements were made on these. The tillites outside the varve members are frequently thick or very thick-bedded.

FIG. 6.—Sketch section of slump structure from Seabrook Creek.

Bedding planes in the varves are usually flat, but disturbances of two types, slumping and ripple-marking, are present. No detailed observations were made on either of these structures. Ripple-marking was seen particularly at Doctors Rock, Lower Seabrook Creek and Elliott. Many of the ripples were due to wave action and one set in the floor of the southern quarry at the Elliott locality trended just east of north. Frequently the cross-laminated sets in the varves had a rippled upper surface—in most cases wave-rippled. Most of the slump structures in the Elliott varves are extremely small folds (amplitude about 1 mm. or less) of a complicated character, on the top of the varves. They do not occur on the top of every varve. These may be associated with the beginning of circulation in the glacial lake at the onset of unusually warm spring seasons. This type of small scale slumping was not seen elsewhere but at Elliott. However, evidence of slumping on a larger scale was seen in the Lower Seabrook Creek locality. In the road metal quarry here, concretions up to 50 cm. in longest dimension are common on a restricted horizon. These concretions are discoidal with the short axis perpendicular to the bedding. Sections cut through several of these with a hacksaw showed that the siltstone bands in them were very contorted and broken with overfolds, recumbent folds and thrust faults on a minor scale. Most of these structures seem to be directed from a southerly direction. A sketch of a section of one of these is included (fig. 6). They would seem to indicate that the floor of deposition sloped down to the north. David (1907, p. 276) described similar concretions (in his coastal section) varying in length from 1 to 27 feet. However, he ascribed no origin to these.

A very noticeable feature of the varves at the Elliott locality (F.) and at Doctors Rock (A.) is the presence of numerous sets of cross-laminae interbedded with the sets of varved strata. As far as could be seen the sets of cross-laminae are tabular and laminated-to-thinly bedded. Specimens measured had sets from 4 to 22 mm. thick, but some seen in the field were thicker than this. The sets measured were all thinly cross-laminated. They were formed of brownish-black (5YR2/1) and dusky yellowish-brown (10YR2/2) fine sandstones composed dominantly of angular quartz fragments with a clayey matrix. The top surface of these sets is frequently ripple marked. Cross-laminae at Doctors Rock and Elliott indicate current directions from the south-east, south, or south-west.

Age and Palaeoecology

Age

The base of the Wynyard Tillite is exposed at several places on the shoreline east of Wynyard. The tillite rests here with marked angular unconformity on rocks of Lower Cambrian or Precambrian age, which are steeply folded, while the tillite dips slightly to the north-west. The tillite itself contains fragments of fossiliferous rocks as young as Lower Devonian (e.g., Florence Quartzite is common as erratics) as well as granites, lithologically very similar to those thought to have been intruded in the Middle Devonian. The upper age limit of the Wynyard Tillite has not previously been fixed with any certainty, but the section observed at Oonah now provides this limit. The oil shale, 30-50 feet above the top of the tillite contains foraminifera which suggested to Crespin (1947, p. 15) a correlation with the lower part of the Upper Marine Group of New South Wales. This group is considered by Teichert and Fletcher (1943, p. 159) to be of " Artinskian age or only slightly younger." Thus, unless a long diastem has been overlooked, it is probable that the top of the Wynyard Tillite is high in the Artinskian. As this formation is probably the product of essentially continuous, fairly rapid deposition, its base is unlikely to be older than Sakmarian. Thus, until more positive fossil evidence is available, the Wynyard Tillite will be regarded as of Sakmarian and Artinskian age.

Palaeogeography

The composition of the erratics in the tillite and varved mudstones as observed in the field and under the microscope adds little to the list of rock types provided by David (1907) and Kitson (1902). All were recognisable or deducible as belonging to Precambrian, Cambrian, Ordovician, Silurian or Devonian Systems as developed in Western Tasmania. Cross-lamination seen at Elliott, Lower Seabrook Creek and Doctors Rock indicated currents from a southerly direction and the slump structures indicate that the original floor of deposition sloped down to the north. These deductions are in accord with the provenance of the erratics and confirm the idea of an ice-covered land to the south and south-west.

At the beginning of the Permian, ice-sheets probably covered the whole area and as they retreated southward they left thick deposits of ground moraine behind them on the land surface. Glacial lakes developed on this moraine where streams were dammed by surface irregularities, terminal moraines or subsidiary glaciers. In these lakes varved muds were deposited and in some years the winter was interrupted by warm spells, resulting in the deposition of coarser layers in the winter clays or fine silts. These coarser layers may have been the result, on the other hand, of sudden access of new drainage from a subsidiary lake in which the moraine or ice barrier was suddenly removed. This sort of event certainly happened as is shown by the presence of drainage varves at Elliott. If the varves at Camp Creek and Elliott were deposited in the same glacial lake, as is possible, the lake was deeper at Camp Creek than at Elliott and Elliott was closer to the source of the varved muds than was Camp Creek as shown earlier. Minor variations in the intensity of glaciation are indicated by the presence of thin tillite beds in the varves, indicating short-term advances of the ice-sheet. Beds of cross-laminated normal sandstones may indicate short-term retreats whereby more water was made available to the streams flowing from the ice-front. Because of the retreat, these streams had to carry the rock-flour and boulders greater distances, thus producing normal sandstones by sorting. Major advances of the ice-front are recorded where varves are overlain by thick tillites and this is seen to have occurred at least three times by the succession in the disused road at Tewkesbury. The exact number of advances and retreats of the ice front cannot yet be stated. Much more work remains to be done before the detailed palaeogeographical history of the area is finally elucidated.

As the ice retreated for the last time the sea flooded in over some barrier, probably to the north, and pyritic siltstones and sandstones, with a few marine fossils, were deposited. The water may well have been brackish, which would account for the rarity of fossils. Poor circulation is indicated by the presence of pyrite nodules and carbonaceous matter and this suggests a partially closed, cold-water basin. Shallow water, poor circulation conditions with the accumulation of gymnosperm spore cases resulted in formation of the oil shale, probably near an old shore line.

REFERENCES

ANTEVS, E., 1951.—Glacial Clays in Steep Rock Lake, Ontario, Canada. *Bull. Geol. Soc. Amer.*, 62, 10, pp. 1223-1262.

BANKS, M. R., LOVEDAY, J., AND SCOTT, D. LL., 1954.—First Record of Permian Varves from Tasmania. *Aust. J. Sci.*, Vol. 17, No. 2, p. 66.

CRESPIN, I., 1947.—Foraminifera in the Permian Rocks of Australia. *Bur. Min. Res. Bull,*, 15, *Pal. Series*, No. 5, pp. 1-31.

DAVID, T. W. E., 1907.—The Permo-Carboniferous Glacial Beds at Wynyard, near Table Cape, Tasmania. *A.A.A.S.*, Vol. XI., pp. 274-279.

GODDARD, E. N., et al., 1948.—Rock Colour Chart. *Nat. Research Council.*

HILLS, C. L., 1913.—The Preolenna Coal Field and the Geology of the Wynyard District. *Geol. Surv. Tas.*, Bull. 13, pp. 10-14, 63-65.

HILLS, C. L., AND CAREY, S. W., 1949.—Geology and Mineral Industry. *A.N.Z.A.A.S.*, Handbook of Tasmania.

KITSON, A. E., 1902.—On the Occurrence of Glacial Beds at Wynyard, near Table Cape, Tasmania. *Proc. Roy. Soc. Vic.*, N.S., Vol. XV., pt. 1, pp. 28-35.

LEWIS, A. N., 1929.—Permo-Carboniferous Glaciation. *A.A.A.S.*, Vol. XIX, pp. 95-96.

MCKEE, E. D., AND WEIR, G. W., 1953.—Terminology for Stratification and Cross-stratification in Sedimentary Rocks. *Bull. Geol. Soc. Amer.*, 64, 4, pp. 381-390.

MONTGOMERY, A., 1896.—Report on the Mineral Fields of the Gawler, Penguin, Dial Range, Mt. Housetop, Table Cape, Cam River and Portion of the Arthur River District. *Sec. Mines Rep.*, (1895-96), pp. i-xix.

NOETLING, F., 1909.—Notes on the Glacial Beds of Freestone Bluff (Sandy Cove) near Wynyard. *Proc. Roy. Soc. Tas.*, 1909, pp. 157-169.

NYE, P. B. AND LEWIS, A. N., 1928.—" Geology " *Handbook to Tasmania.*, *A.A.A.S.*, Hobart.

STEPHENS, T., 1869.—Remarks on the Geological Structures of Part of the North-West Coast of Tasmania, with Special Reference to the Tertiary Marine Beds near Table Cape. *Proc. Roy. Soc. Tas.*, 5, 1868-1871, pp. 17-21.

TEICHERT, C. AND FLETCHER, H. O., 1943.—A Permian Ammonoid from New South Wales and the Correlation of the Upper Marine Series. *Rec. Aust. Mus.*, XXI, 3, pp. 156-163.

TWELVETREES, W. H., 1905.—Report on North-West Coast Mineral Deposits. *Sec. Mines Rep.*, 1905.

VOISEY, A. H., 1938.—The Upper Palaeozoic Rocks of Tasmania. *Proc. Linn, Soc. N.S.W.*, Vol. 63, pts. 5-6, pp. 309-33.

WALLER, G. H., 1902.—Report on the Recent Discovery of Cannel Coal in the Parish of Preolenna, &c. *Sec. Mines Rep.*, 1901-1902.

LOCALITY INDEX

Calder River	Burnie	28	41° 5′	145° 38′
Camp Creek	Burnie	28	41° 2′	145° 48′
Doctors Rock	Burnie	28	41° 0′	145° 47′
Elliott	Burnie	28	41° 6′	145° 47′
Hellyer Gorge	Burnie	28	41° 17′	145° 37′
Mt. Hicks	Burnie	28	41° 5′	145° 45′
Oonah	Burnie	28	41° 14′	145° 43′
Seabrook Creek	Burnie	28	41° 1′	145° 47′
Tewkesbury	Burnie	28	41° 13′	145° 45′
Wynyard	Table Cape	22	41° 1′	145° 42′

FIG. 1.—Photomicrograph of tillite (spec. U.T.G.D. 6055 (*b*)).

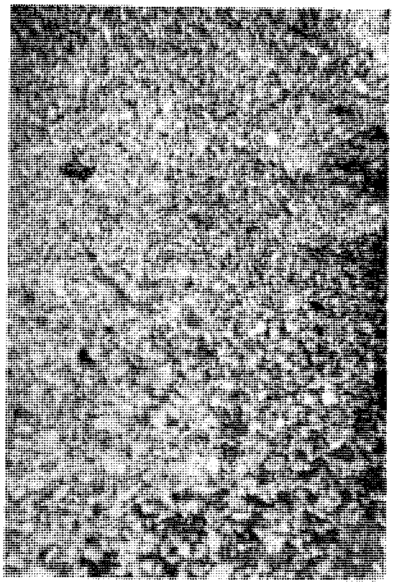

FIG. 2.—Photomicrograph of varved mudstone (spec. U.T.G.D. 6046 (*b*)).

FIG. 3.—Photograph of varved mudstone from Elliott showing grading and slumping.