CHAPTER 5

DIRECTIONAL INDICATORS

5.1 INTRODUCTION

The direction of ice motion in the northeastern district has in the past relied on inference and supposition with the exception of the tne work done by Talent about the likely sources of the fossiliferous boulders.Until now no other approach has been tried and this is likely because of the limited outcrop thought to be in the area. A glacial pavement has been identified in the vicinity of Moyhu and some sense of likely directions of ice motion obtained from pebble long axis fabrics. The fabrics are not sophisticated determinations because of the weathered nature of the outcrops but serve as additional evidence. To mount a sophisticated fabric survey was considered beyond the scope and time limitations of this thesis. Considerable planning and field sampling would be necessary together with pilot surveys to eliminate where possible those fabrics which have been modified by diagenesis and subsequent weathering.

Besides the direction of ice motion it is possible to give some indication of the local variability of palaeoslope because of the plunge directions of fluvioglacial trough cross-beds. These data are not reliable indicators of regional palaeoslope because within any fluvial system it is possible to have local palaeoslopes in almost any direction. The directions when plotted along with other data may have more significance than if they stand alone.

5.2 THE MOYHU PAVEMENT

The glacial pavement (see plates 60, p.164) is partly exposed in a small gulley (GR.491390, Royal Australian Survey Corps [ed.1] 1970, sheet 8124 series R652 topographic map 1:100.000) about 5 km WSW of Moyhu. Small scale erosion features are visible on the pavement and they are:

* Striae;
* Crescentic gouges and
* Lunate fractures.

They would have been produced at the time of formation of the entire pavement. These features are clearly not related to any inhomogeneity of the host rock nor are they related to fluvial erosion even though the pavement is now part of the bed of a small ephemeral watercourse. The erosional features have directional attributes which are at right angles to the flow direction of the present watercourse in that part of the gulley. The surface of the pavement is clearly striated in a north-south direction. The striae range in depth from about 0.5 mm to about 1.5 mm and have a curved cross-section with rounded eroded shoulders. The existence of these small scale erosional features is essential for the confident recognition of a glacially induced pavement. Figure 3 shows rather idealised forms of both a lunate fracture and a crescentic gouge. All three features are shown in plate 61, p.166 as they appear on the Moyhu pavement.

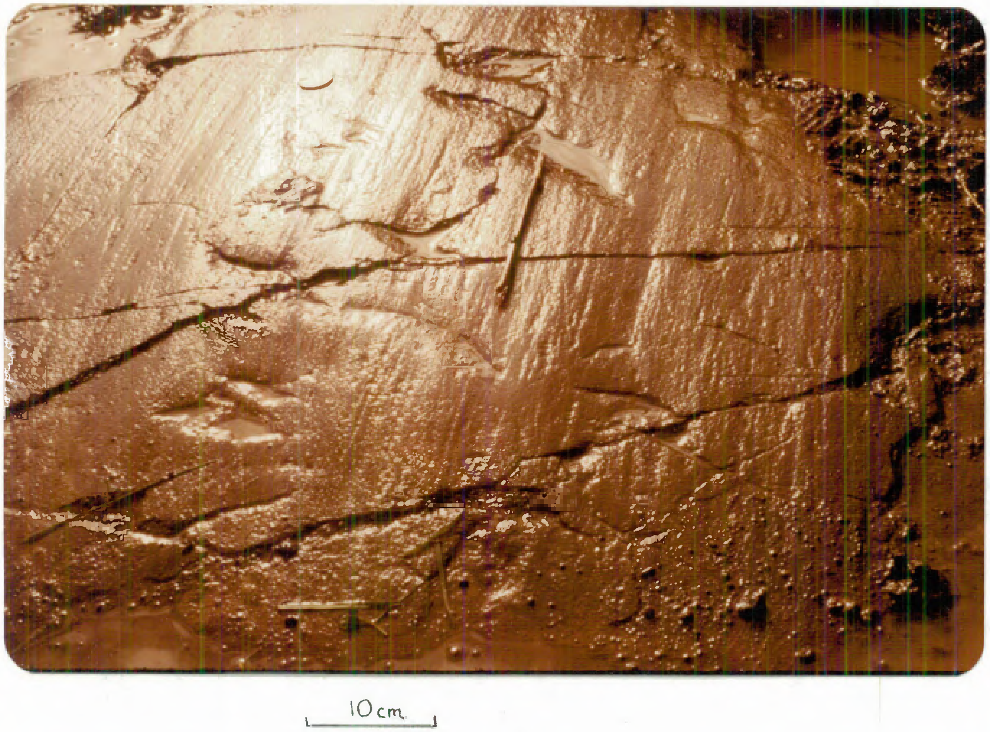

Plate 60 A view north, showing erosional features on the surface of the Moyhu glacial pavement (GR. 491390 RAS. sheet 8124, 1970, 1:100 000).

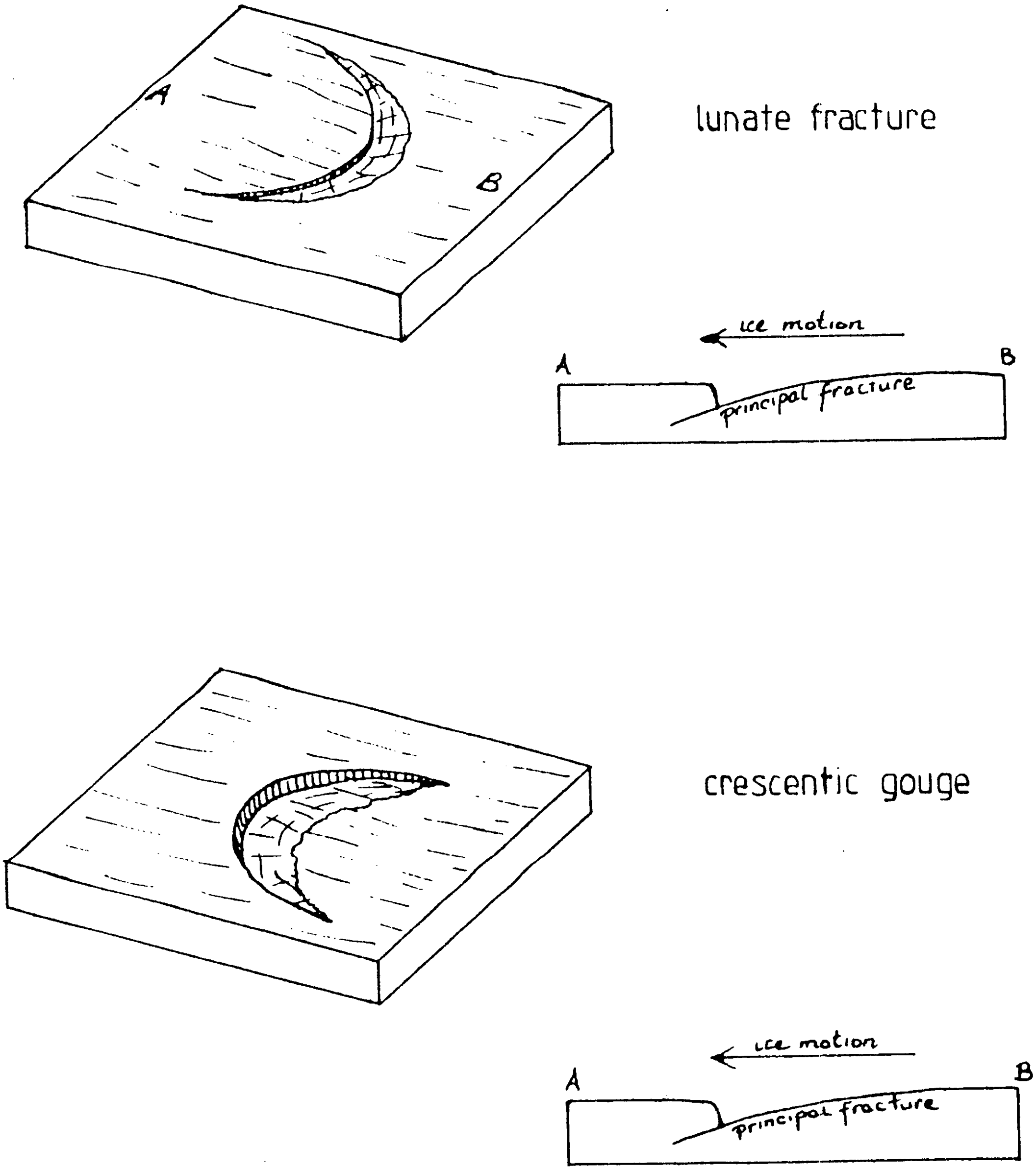

Figure 3 Friction crack features on a glacial pavement

Plate 61 Erosional features on the Moyhu glacial pavement
l - lunate fractures
c - crescentic gouge
s - striae

Gilbert (1906), Harris (1943) and Dreimanis (1953) are among those who have worked with the use of friction cracks as directional indicators. The most productive work was with crescentic gouges as indicators of ice motion over pavements (in Embleton and King, 1968). The interpretation of direction is based on experimental investigation as well as field observation. Regardless of the amount of dip, the principal fracture of a crescentic gouge always dips in the direction of ice motion. Embleton and King (1975) report the contrary views of Anderson and Sollid (1971). Other crescentic features e.g., lunate fractures (see figure 3, p.165) are thought by Embleton and King (1968) to be unreliable indicators of ice motion because their principal fracture may dip either in the direction of ice motion or against it.

For the Moyhu pavement the crescentic gouges show a northerly ice motion and perhaps by chance so do the lunate fractures.(see plate 61, p.166). To supplement the annotated black and white photograph (plate 61, p.166), an oblique colour photograph (plate 60, 164) of the wetted surface provides easier recognition of the same features. The pavement is doubtless of glacial origin and now gives the absolute ice motion in this region: toward the north. Craig and Brown (in press, Aust. Jour. Earth Sci.) have reported seven glacial pavements and a miniature roche moutonnée which confirm ice motion to the north.

5.3 FABRIC DATA

The determination of reliable fabrics from the northeastern district glacial deposits is only possible at two locations;they are not sophisticated determinations but are nevertheless valuable indicators in conjunction with other data. The following long axis orientations are identified:

* 049° Wooragee Valley (GR.762829, Royal Australian Survey Corps [ed.1] 1971, sheet 8225 series R625 topographic map 1:100.000).

* 360° Myrrhee road cutting(GR.436316, Royal Australian Survey Corps [ed.1]1970, sheet 8124 series R625 topographic map 1:100.000).

5.4 OTHER DIRECTIONAL INDICATORS

The remaining directional indicators are related to an ablation phase. They are in the form of cross-stratification in bedded deposits which either unconformably overly basement or conformably overly Permian bedded or unbedded Permian diamictites.

The plunge directions of trough cross-beds are listed below. Axial plunges are difficult to assess because of the poor quality of the outcrops, but vary between 2° to 8°. Trough axial orientations for the Wooragee Valley are :

* 179° x4;

* 194°;

* 204°;

* 209°;

* 219°;

* 224°;

* 344°.

Orientations for trough axes in outcrops from the area south of the Ovens-King River Valley are:

* In the vicinity of the Moyhu pavement

  [a] 194°;

  [b] 199°;

  [c] 239°;

  [d] 244°;

  [e] 259°;

  [f] 264° and

  [g] 299° x2

Asymmetrical ripple marks from the same general area suggest current motion toward N and NW. Festoon cross-bedding (not accurately measured) also suggest currents toward N, NW, and W .

* 2 km south of the Moyhu pavement

[a] 174^{o};

[b] 176^{o};

[c] 179^{o};

[d] 189^{o}.

Estimated trough axes give current directions N to W for an area about 5 km south of the pavement.

All data are plotted as rose diagrams with the length of each line representing the frequency of the recorded direction (5 mm = 1 reading). The rose data plus fabric and pavement directions are all plotted onto a common topographic base (see figure 4, p.171).

5.5 THE SIGNIFICANCE OF THE DIRECTIONAL DATA

The data are consistent with a general northerly ice motion with perhaps some divergence toward the Wooragee Valley. The Myrrhee fabric appears to be consistent with the direction of ice motion determined from the pavement and supports the view of a more southerly source of the fossiliferous clasts earlier thought to be derived directly from Heathcote and requiring transport in direction 070^{o}. The palaeocurrent data suggests S through to N palaeoslopes for the Wooragee Valley, S through to NW in the vicinity of the pavement and palaeoslopes ranging from S to W through to N for areas south and southwest of the pavement.

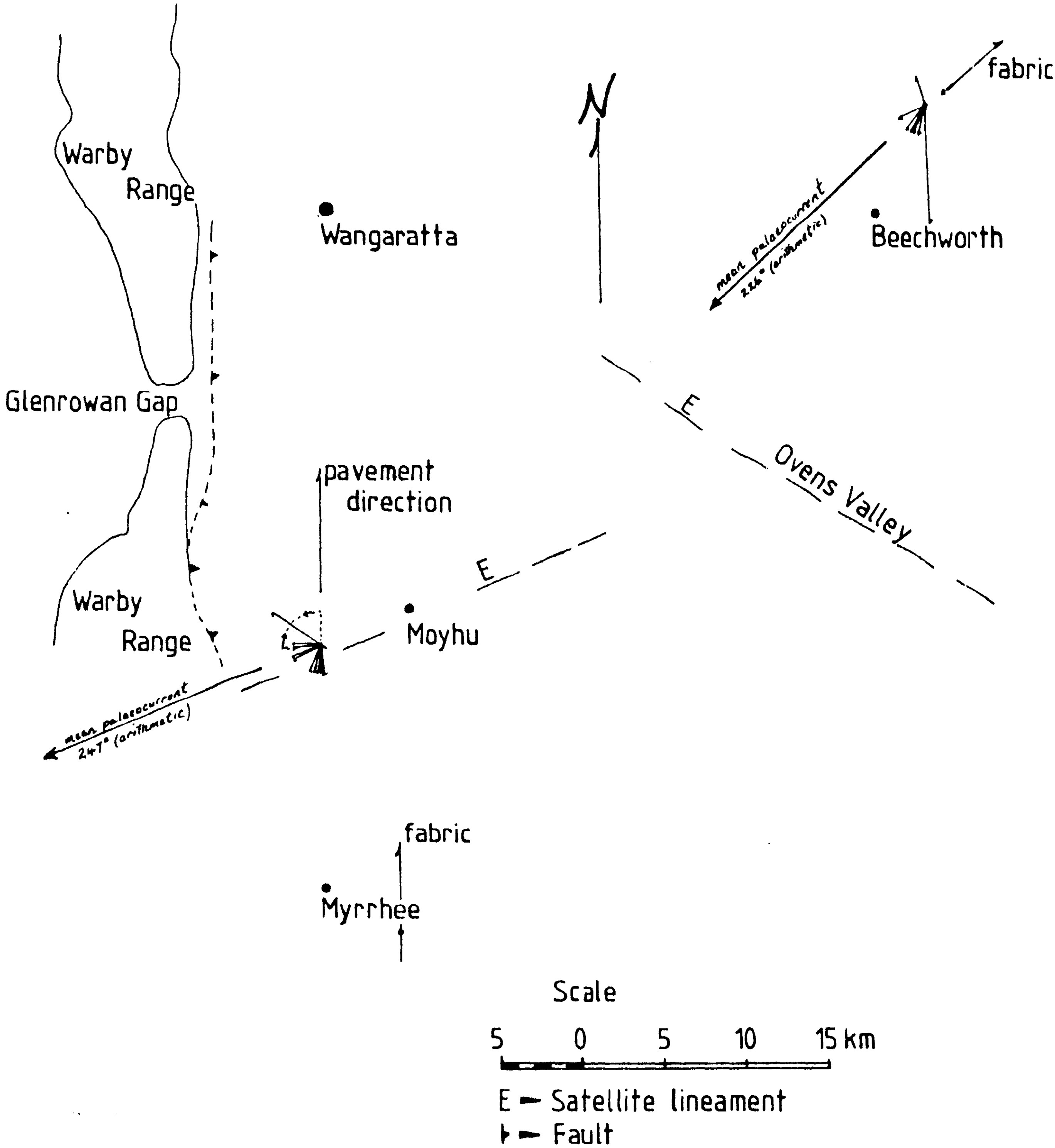

Figure 4 Northeastern district directional data

The palaeoslopes are almost entirely confined to the SW and NW quadrants but because of the relatively small number of reading available no reliable interpretation about regional palaeoslopes can be made. Great variability of current directions is to be expected in sedimentary environments adjacent to an ice-front and so too few readings could be quite misleading.

CHAPTER 6

CLAST MORPHOLOGY

6.1 INTRODUCTION

Much has been written about the shape of clasts transported by ice (e.g., Von Engeln, 1930; Wentworth, 1936; Holmes, 1960; Drake, 1972 ; Boulton, 1978; Domack, Anderson and Kurtz, 1980). The view that glacial abrasion produces characteristic clasts shapes was held as early as the beginning of this century (e.g., Mansfield, 1907) but the idea of a typical shape has never met with wide approval. The relative rarity of the supposed typical shape (Gregory, 1915) has always led to arguement.

Von Engeln (1930) identified two characteristic shape categories, one primary, one secondary. The primary shapes evolve as a result of subglacial abrasion and approach a shape "...roughly that of a flat-iron minus the handle" or similar to "...the prows of flat-bottomed boats". Whatever the comparison used, the essential feature was the roughly triangular shape of the clast. Von Engeln listed eight identifying features of "Type faceted and striated pebbles". They are:

1. The roughly triangular shape in plan with the facet of the largest area and that which is flattest down;

2. The pointed but scour-snubbed nose at the apex of the narrowest angle of the bottom facet;

3. An only slightly scoured or hackley back side above the baseline of the bottom triangle;

4. A tendency to a hump form of the top side of the flat-iron;

5. Lateral facets running off toward the snubbed point;

6. Chipping or nicking of the underside or at the apex of the point;

7. A tendency of the striations on the lateral facets to be directed diagonally downward toward the point;

8. Indications that variations from the norm or failure to develop of one of these features in a well-processed pebble are due to a particular, and still obvious, configuration of the original fragment or to the nature,rock structure and composition of the specimen.

Von Engeln pointed out that from the flat-iron shape the direction of ice motion could be determined because the broad back would bear the thrust and so the long axis would be aligned parallel to the flow (but see Boulton 1978, 782 - 785 where the reverse orientation has been observed in modern glacial deposits).

The secondary shapes suggested by Von Engeln are rounded basically ovoid forms which could also be elliptical or cylindrical, generally non-faceted and bear multi-directional striae. Von Engeln suggested these shapes are less characteristic of glacial action although they are far more abundant than the flat-iron forms.

Wentworth agreed with the idea of characteristic glacial clast shapes resulting from abrasion but concluded it would have the form of a pentagonal wedge. The difference between the Von Engeln and Wentworth shapes is only minor; there is agreement about the gross form. There was no such agreement from Holmes (1960). He disagreed both with Von Engeln and Wentworth and thought the question of shaping of glacial clasts by abrasion needed further study. From his own study of glacial cobbles and pebbles from Central New York till, he concluded that the percentage of ovoid forms increases with transport distance and that cobbles increase in roundness much faster than pebbles which (?because of their size and the stresses involved) are much more susceptible to crushing and therefore may pass through many cycles of rounding.

Holmes (1960,1659) believes Von Engel's non-faceted secondary clast category is the true type form of glacial clast shape and toward which glacial abrasion tends. Drake (1972) carried out similar investigations to those of Holmes and came to much the same conclusion, namely that after prolonged transport, stable clast forms evolve but that it is not a size dependant process. Drake suggests the decreasing order of stable clast forms is:

* Spheres;
* Discs;
* Rods (Rollers) and
* Blades.

Boulton (1978) believes the earlier investigators took a far too simplistic view of glacial transport and the form of clasts is a response to the particular transport path which they follow within the glacier: there is no type-form for the environment as a whole. The criteria for Boulton's transported related clast forms were based on direct observations of modern glacial environments, especially Breidamerkurjoekull in southeastern Iceland and Buchananisen in Spitsbergen. Boulton's criteria are:

* Angular and subangular boulders which have been derived supraglacially and transported at a high level without undergoing a phase of traction. This group is characteristic of supraglacial morainic till.
* Subrounded to rounded boulders with several directions of striae. These have undergone a phase of traction and are characteristic of flow -till, melt-out till and lodgement till.

* Large rounded and streamlined boulders about 0.5 m to 1 m in diameter, with long axes and striae parallel to the direction of glacier flow, and sharply truncated distal extremities indicating that they have been embedded in subglacial till. This third group not only indicates a lodgement till but also the flow direction of the glacier.

According to Boulton the third type of boulder is so common in modern tills that it would be difficult to conclude that a till containing them could be anything but a lodgement till.

Without detailed descriptions of clastforms, Boulton shows the difference between boulders from various transport paths within present-day glaciers by plotting their roundness and sphericity indicies using Krumbein's (1941) roundness-sphericity matrix. The same technique has recently been used by Domack,Anderson and Kurtz (1980), and is again referred to by Anderson, Kurtz, Domack and Balshaw (1980). They used the technique to identify basally transported clasts incorporated into floating ice deposits and grounded ice deposits (see Domack et al. 1980, 813) from the George V continental shelf, Antarctica. This technique should equally be applicable to the clasts from ancient diamictites suspected to be of glacial origin. The physical behaviour of glaciers and their accompanying debris must surely be much the same in the past as it is now.

6.2 GLACIAL CLAST MORPHOLOGY: NE VICTORIA

Many striated and some faceted pebbles and cobbles have been found in deposits from the northeastern Victoria, particularly from the Wooragee Valley near Beechworth, from the southern portion of the Ovens-King River Valley, from the two major road cuttings in the vicinity of Whitlands and the Myrrhee road turn-off and from the Lake Nillahcootie deposits south of Benalla.

Rare but distinctive forms have been found which clearly resemble the type-forms described by Von Engeln and Wentworth and are shown in plates 11 and 12, p.98 but by far the most common clast shape are those resembling Von Engeln's secondary type-form (Holmes' primary form: the ovoid clast). Well rounded spheroidal and discoidal forms are very common shapes from northeastern glacial deposits. One very distinctive wedge-form shown in plate 11, p.98 almost perfectly fits Wentworth's description of the rare but classic "pentagonal wedge".
Two other clasts shown in plate 62, p.179 have the shape attributes described by Boulton (1978) as indicative of a basal transport history; one is unmistakably the streamlined bullet shaped clast indicative of lodgement tills and tillites.

These rarer forms have striae which are unidirectional, supporting the interpretation of the clasts being part of the basal transport zone of a glacier. Other clasts (which are more common) have multi-directional striae and fit Boulton's second group of clast shapes indicating an englacial transport history with only partial traction zone contact. Striated fossiliferous clasts have only been found with multi-directional striae and are well rounded spheroidal or discoidal shaped. This suggests the fossiliferous clasts have a long transport

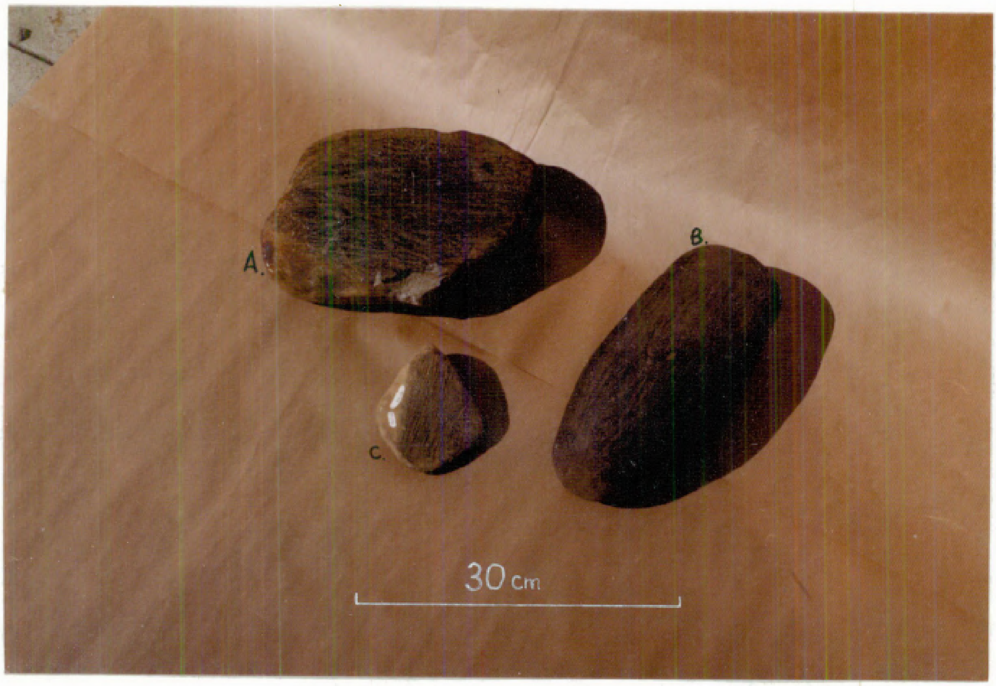

Plate 62 Distinctive clast shapes from northeastern Victoria. (A & B) Streamlined bullets (Boulton,1978), (C) Pentagonal wedge (Wentworth,1936). Striae are enhanced by rubbing the clasts with carbon paper.

history and are essentially englacial debris with limited traction zone contact. This is at least consistent with likely distant sources: either 150 km SW or another source area suggested by faunal assemblages, further S, perhaps beyond Victoria. The rarer clast shapes are not fossiliferous and could have been derived from relatively closer sources. A short transport history is consistent with their less stable shapes and only traction zone characteristics being imparted on them.

In the road cutting sections to the south beyond the Ovens-King River valley, pebbles and small cobbles of the more common clast shape were collected by trench sampling from conglomeratic phases so that their shapes and composition could be investigated. Clasts were collected from the two major cuttings along the Whitlands-Whitfield road (sample 79/11: Lower cutting and 79/13: Upper cutting). Clasts have been classified into shape categories according to the Zingg (1930) intercept ratio technique, each being assigned an index of roundness and sphericity according to Krumbein's (1941) system. Only the coarser than granule fraction was used and each clast lithology was identified. Table 5, p.181 lists the relative proportions of shape categories and rock types for each sample.

The form data are consistent with data presented by both Holmes (1960) and Drake (1972). In both samples from the road cuttings, spheroidal forms are by far the most common, followed by discs, rods and blades. When the relative proportions of various shapes from each sample are compared using chi-square analysis (at the 0.2 level of significance or above) there is no significant difference between the mean clast form of the two road cutting samples. The similarity of the two road cutting pebble suites is further supported by using the Student

Table 5 The proportion of various pebble shapes and the proportion of constituent rock types for pebble suites from diamictites in the Whitfield - Whitlands road cutting northeastern Victoria

	Sample	N.E. Victoria Pebble Suites 79/11 (97 pebbles)		79/13 (99 pebbles)	
S	Spheroids	54%		51%	
H	Discs	32%		36%	
A	Rollers	9%		12%	
P	Blades	5%		-	
E					
S		100		100	
C	Sandstone	88%	(85)	75%	(74)
O	Siltstone	3%	(3)	15%	(15)
M	Mudstone	2%	(2)	15%	(15)
P	Quartz	3%	(3)	-	
O	Chert	2%	(2)	5%	(5)
S	Agate	2%	(2)	-	(1)
I	Schists	-		1%	(1)
T	Gossanous	-		1%	(1)
I	Igneous	-		1%	(1)
O	Not ident	-		1%	(1)
N					
		100	97	100	99

t-test statistical evaluations of the mean population Zingg intercept ratios: there is no significant difference between the mean pebble intercepts from the Lower and Upper cuttings (see table 6, p.183) The same similarity holds if their Krumbein roundnesses are compared (see table 7, p.184)

The simplest explanation for the lack of significant differences between clast forms from the Upper and Lower road cuttings is that they both have been derived from the nearby Carboniferous fluvial conglomerates: a reasonable assumption. This would help explain the high proportion of well rounded spheroidal sandstone clasts. This explanation is not acceptable for two reasons. First, the samples contain multi-directionally striated, rounded spheroidal and discoidal clasts; (some fossiliferous, some resembling the characteristic glacial shapes) suggesting glacial transport of greater than a few kilometres, which is the distance to the nearest Carboniferous fluvial conglomerates that could have acted as a source. The second reason is that there is no record of the Carboniferous containing any fossiliferous clasts which in any way resemble the Siluro-Devonian fauna of Heathcote.

The most consistent interpretation is that the samples from the two road cutting are probably derived from the same source perhaps a Heathcote-like source and have had virtually identical transport histories. This similarity of clast shape and form as well as faunal assemblage exists between other sites in and adjacent to the Ovens-King River Valley. The shape (form and roundness) suggests the samples from the two road cuttings (and therefore similar deposits in the district) consist of a very specific mixture of glacially transported clasts.

Table 6 A significant difference matrix for Zingg intercept ratios based on student t-tests of pebbles from Whitfield - Whitlands road cuttings, northeastern Victoria

SAMPLE LOCALITY	N.E. VICTORIA AUSTRALIA		HOOKER VALLEY GLACIER N.Z.		TAYLOR VALLEY ANTARCTICA	
	b/a	c/b	b/a	c/b	b/a	c/b
79/11 N.E. VICTORIA AUST.	NO t(194,205) to 0.2	NO t(194,0.05) NONE	YES t(694,0.05) to 0.001	YES t(694,0.05) to 0.001	NO t(801,0.05) to 0.01	YES t(801,0.05) to 0.01
79/13 N.E. VICTORIA AUST.	-	-	YES t(694,0.05) to 0.001	YES t(694,0.05) to 0.01	YES t(803,0.05 to 0.001	YES t(803,0.05) to 0.001
HOOKER VALLEY GLACIER N.Z.	-	-	-	-	YES t(1211,0.05) to 0.001	YES t(1211,0.05) to 0.001

Table 7 A significant difference matrix for Krumbein roundness based on student t-tests of pebbles from Whitfield - Whitlands road cuttings northeastern Victoria

	79/13 N.E. VICTORIA, AUST.	HOOKER VALLEY GLACIER N.Z.	TAYLOR VALLEY ANTARCTICA
79/11	NO t(194, 0.05) to below 0.9	YES t(692,0.05) to 0.001	YES t(692,0.05) to 0.001
79/13	-	YES t(964,0.05) to 0.001	YES t(803,0.05) to 0.001
HOOKER VALLEY	-	-	YES t(1211,0.05) to 0.001

The attributes of form and roundness of clasts collected from Hooker Valley, N.Z. and Taylor Valley, Antarctica (Barrett, 1980) are compared with those of the Victorian road cutting samples, using Student's t-test statistics. Data are shown on figure 5, p.187. The mean clast form of the Victorian samples are shown and only the Taylor Valley sample is similar but plots beyond the 95% confidence interval enclosure.

Table 6, p.183 summarises the significant differences between the mean clast shapes based on the Student t-test statistic. The table shows the differences between the Victorian samples are not significant but the differences between all other combinations in the matrix are highly significant except for one: Victorian sample 79/11 from the Lower road cutting and Taylor Valley. In all cases the differences are significant beyond the 0.05 and frequently beyond the 0.01 level of significance. The differences between samples may be explained in terms of the rock types in the samples being compared. The Victorian samples are mainly sandstones whereas Hooker Valley samples consist of quartz schist and pelitic schist. Taylor Valley samples consist of granite, porphyry, vein quartz dolerite and basalt. Taylor Valley clasts have the closest relationship with Victorian sample 79/11 but the clast compositions are not strongly related. Some important aspects of the Hooker and Taylor Valley data are that the relative proportions of rock types are not known and the samples have been collected from a mixture of glacial environments. Boulton (1978) shows that form is very strongly influenced by the glacial transport path. Hooker Valley samples, N.Z. and Taylor Valley samples, Antarctica both include clasts from subglacial (basal till), supraglacial (talus and stream deposits) ice marginal streams and proglacial streams. The relative proportions from each environment is not known.

The key to the character of the Victorian samples is only shown (figure 6, p.188) when the Krumbein roundness and sphericity are compared with detailed data from Breidamerkurjoekull, Iceland where Boulton (1978) identified the form and roundness character of clasts from clasts in various glacial transport zones. The mean clast data for Hooker Valley and Taylor Valley have also been added for extra comparison.

The Victorian clasts plot as a mixture of clasts from two transport environments: traction zone and lodgement till types and are quite separate from the zone of supraglacial clasts; the mean clast data from both Hooker and Taylor Valley plot as a high proportion of traction zone clasts and are each quite separate from the Victorian data.

6.2.1 SUMMARY AND CONCLUSIONS

The interpretation most consistent with the glacial clast morphological data and detailed descriptions of clasts from diamictites in the region is that the Nillahcootie deposits (Ch.3, p.94 and Ch. 6, p.173) with its unidirectionally striated rare type-forms and a basement contact still visible in outcrop, consists of a basal lodgement tillite overlain by a mixture of traction zone and lodgement zone debris for example, in debris derived from a melt-out till (see glossary). The road cuttings near Whitlands appear to consist of debris derived both from a basal transport and an englacial transport zone. There is no intact lodgement tillite at least in the upper road cutting.There may be in the lower three units of the Lower road cutting (see plate 25, p.106). Mixtures of traction zone and lodgement till are preserved as

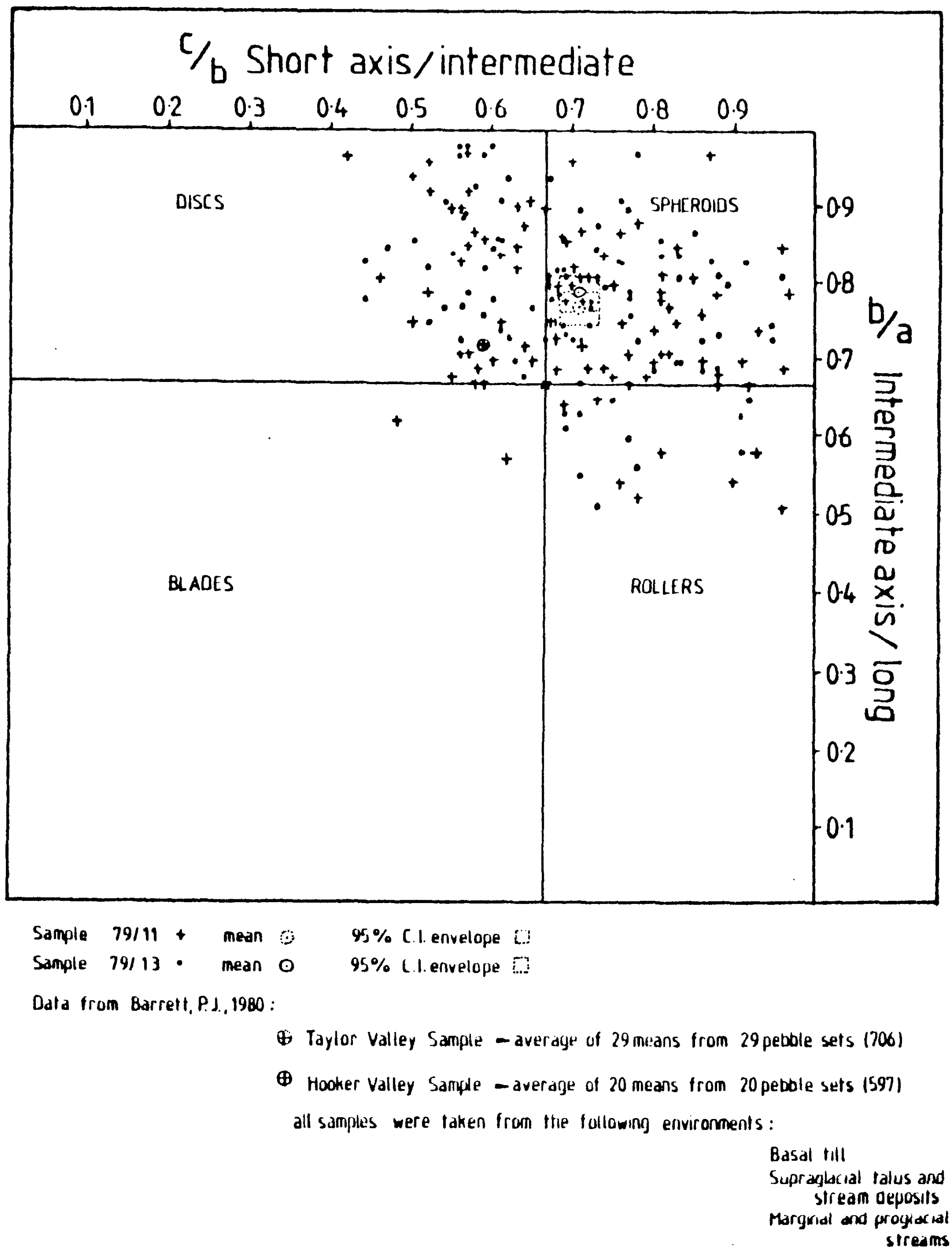

Figure 5 Zingg classification for axial ratios for pebbles from Whitfield - whitlands road cuttings (Vic., Aust.), Taylor Valley (Antarct.) and Hooker Valley (N.Z.)

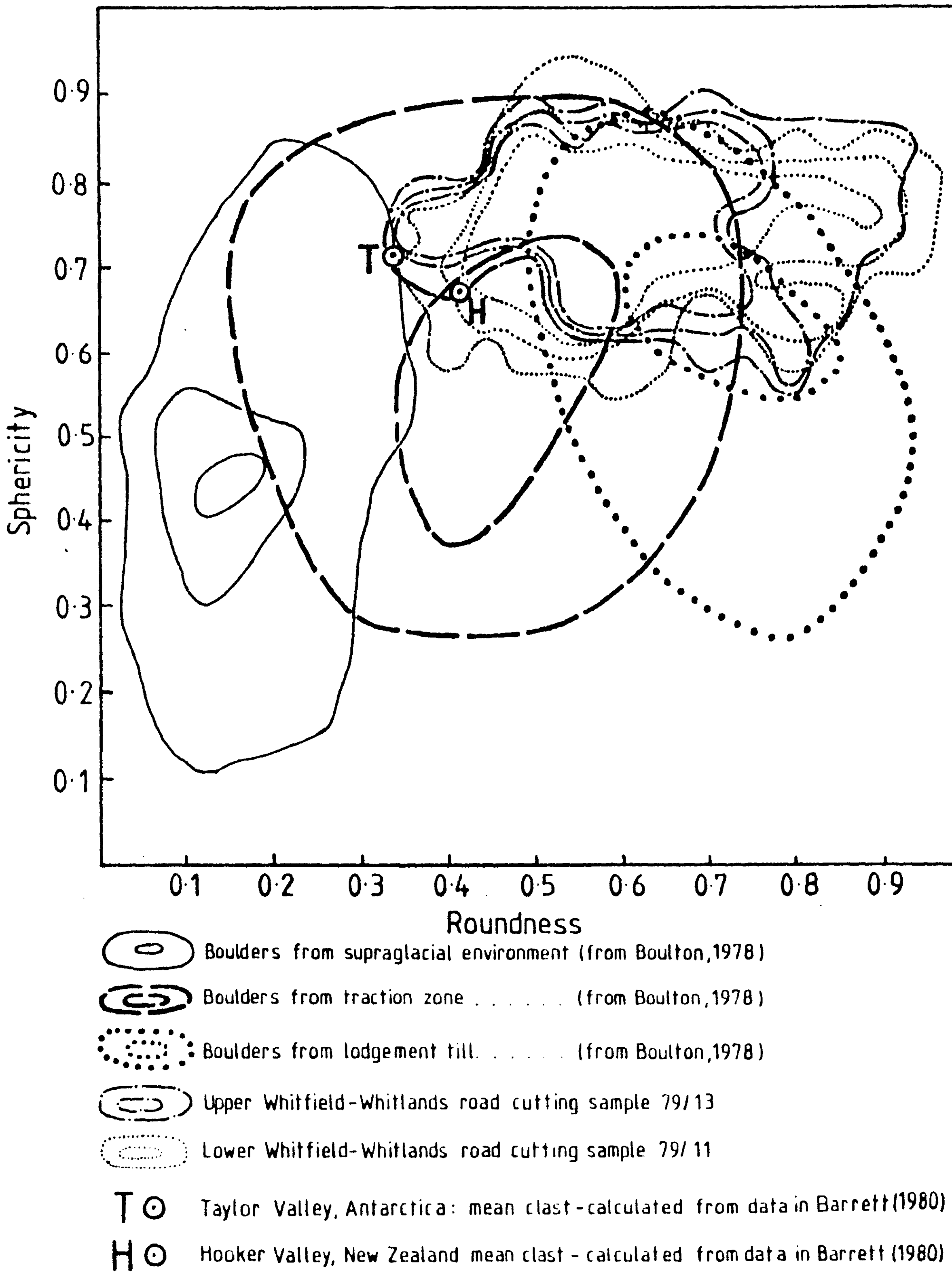

Figure 6 Northeastern Victorian clast types based on Boulton's (1978) zones of glacial transport

tillites in other parts of the northeastern district for example, to the W of the Warby range and to the E at Wooragee. At some of these areas for example the Upper and Lower road cuttings, near the Moyhu pavement and at Wooragee there are deposits associated with ablation phases of a glacial environment.