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BOULDER PAVEMENTS AND THE SENSE OF MOVEMENT OF LATE PALEOZOIC GLACIERS IN CENTRAL EASTERN SÃO PAULO STATE, PARANÁ BASIN, BRAZIL

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RESUMO

Dois extensos pavimentos de clastos do tipo intratill ocorrem em dois níveis estratigráficos diferentes, dentro de um único diamictito do Subgrupo Itararé, na parte norte da Bacia do Paraná, Brasil. As direções médias de estrias dos clastos dos pavimentos inferior e superior são, respectivamente, N75°W e NS. Os sentidos dos movimentos da geleira neopaleozóica associada à formação dos pavimentos foram interpretados com base na provável inclinação a montante, das superfícies superiores biseladas de clastos dos pavimentos, o que indicou fluxo para o N e NW. O sentido geral de movimento da geleira foi, provavelmente, para N37°W.

O estudo pormenorizado de algumas características superficiais dos clastos dispersos nos diamictitos mostrou que 48% deles exibem estrias, a maioria do tipo subparalelo, mais comumente orientadas paralelamente aos eixos maiores dos clastos.

A ocorrência dos pavimentos e as feições superficiais dos clastos reforçam a interpretação de origem glacial para os sedimentos do Subgrupo Itararé na área. As evidências geológicas indicam que essas estruturas ter-se-iam formado ao longo de planos de deslizamento ou de cizalhamento, dentro de um till basal, sob uma geleira em movimento.

ABSTRACT

Two extensive intratill boulder pavements were identified included at two levels within a single diamictite horizon of the Late Paleozoic Itararé Subgroup, in the northern part of the Paraná Basin, Brazil.

Measurement of striae on cobbles and boulders of the lower and upper pavements averaged N75°W and N-S, respectively. Interpretation of local sense of glacier movement was based on the probable upglacier inclination of the upper plane surface of clasts in the pavements, which indicate flows towards N and NW. The general sense of movement was interpreted to have been towards N37°W. A detailed study of surface characteristics of clasts dispersed in the diamictites showed that up to 48% of the clasts are striate, mostly in the subparallel fashion. The striae are most commonly oriented parallel with the largest axes of the clasts.

A general glacial mode of origin already established for sediments of the Itararé Subgroup in the Paraná Basin is reinforced by the occurrence of the boulder pavements and features of diamictite clasts. The available geological evidences on the origin of the pavements indicate that they may have been formed along shear planes inside a basal till.

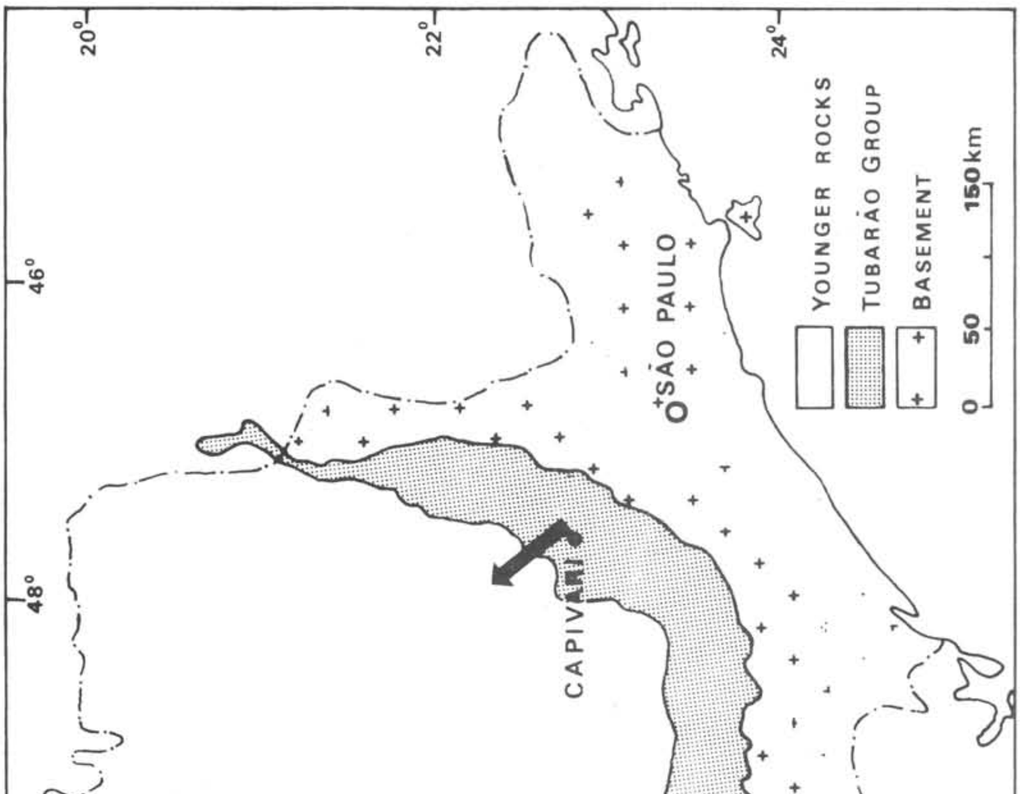


Fig. 1. Location of the studied and summarised data on sense of ice-flow.

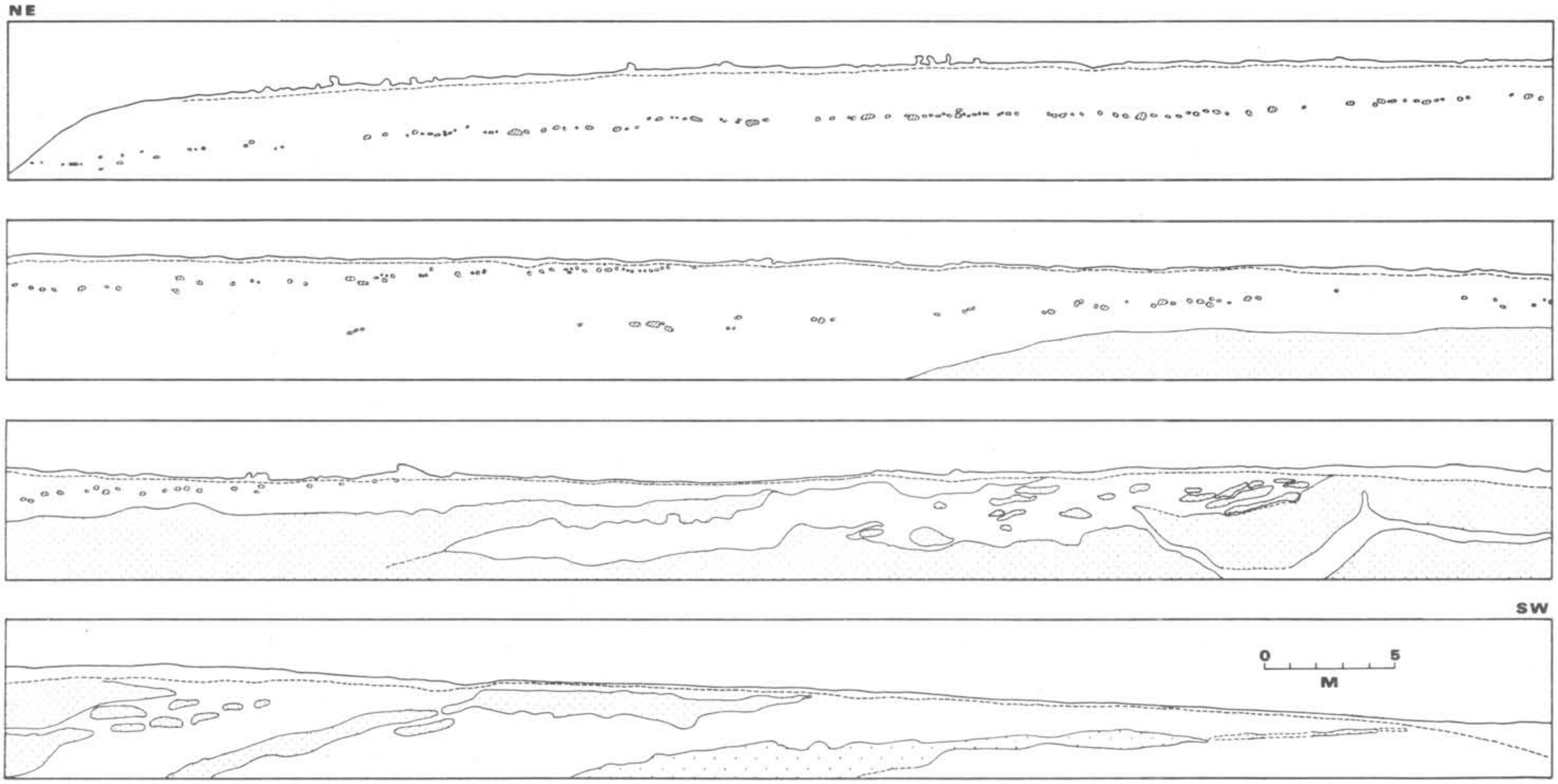


Fig. 2. Diagram of southern face of road cut. Explanation: blanck: diamictites; fine and coarse dotted: sandstones; oblique hatched: clasts; upper irregular coarse line: top of outcrop; upper interrupted fine line: lower limit of soil.

INTRODUCTION

Determinations of sense of Late Paleozoic (Gondwana) ice-flow in eastern Paraná Basin has been mostly based on orientation of folds atributed to ice-pushing (Martin, 1961) and paleocurrents studies of beds associated to the diamictites (Bigarella et al., 1967; Frakes et al., 1969). Deductions based on structures or features directly related to the movement of glaciers, as striae on pavements (Almeida, 1948; Amaral, 1965; Bigarella et al., 1967), or on boulder pavements (Rocha-Campos et alii., 1968, 1969; Frakes et al., 1969), elongation of streamline molded forms (Rocha-Campos et alii., 1968), etc., which are generally considered as more reliable indicators are still unsufficient, especially taking into account the large extension of the Itararé Subgroup outcrops. Although, as shown by Rocha-Campos (1967) and Frakes et al. (1969), both approaches yelded grossly similar results, indicating general sense of ice-flow towards north and northwest, further studies of ice-flow derived features combined with facies analysis are needed, to obtain a detailed paleogeographic picture of the Late Paleozoic glaciation, particularly its geographical and stratigraphical variations in pattern. These studies may be useful to depict number and distribution of the different glacial lobes and source areas during the long Late Paleozoic glacial interval in the Paraná Basin.

The purpose of this note is to describe structures indentified as glacial boulder pavements included within a single diamictite horizon in central-eastern São Paulo State and to discuss problems related to the interpretation of the sense of Late Paleozoic ice-flow in the area. Identification of these structure bears also on the discrimination of local facies of the diamictites.

STRATIGRAPHY

Strata and structures described below belong to the middle part of the Late Paleozoic Itararé Subgroup in central-eastern São Paulo State, outcropping on two parallel faces of a road cut of highway SP - 101, between kms 35 and 36 (Fig. 1). The following description is based on the southern face of the cut which is more easily accessible.

The local section (Fig. 2) is made up (from base to top) of sandy or silty, yellowish-greenish matrix diamictite, up to 5 meters thick, intercalated with several large or small, lenticular, elongated bodies of fine to medium or coarse grained, feldspathic sandstone, often pebbly. Clasts in the lower diamictite are relatively rare; their characteristics and composition are synthetized in Tables 1 and 2.

Several large, elongated sandstones interbeds at the upper part of the diamictite vary in thickness in a pinch-and-swell manner and are disrrupted and deformed. Some of the smaller sandstone lenses have apparently resulted from the fragmentation of the larger bodies. At least one large,cross-bedded sandstone body is channel-like in cross-section and shows a thin, wavy stratification. A large, lenticular, coarse, badly sorted, massive, feldspathic sandstone body, locally pebbly, at the top of the lower diamictite, is unconformably overlain by an upper diamictite bed. Surface of unconformity shows only minor irregularities and at several places the upper surface of sandstone bears a faint lineation, probably due to soft sediment deformation, as drag lines oriented according to N5^{o}W.

The upper diamictite is yellowish-greenish, silty matrix, mostly megascopicaly massive and homogenous. Maximum thickness exposed is about 5 meters. Clasts are relatively common widespread within the matrix and are also concentrated along two horizons forming two clast pavements. Lithology of clasts and some of their surface characteristics are shown on Tables 1 and 2.

DESCRIPTION OF THE CLAST PAVEMENTS

Reconstruction of the structures described below as planar and horizontal (or pavements) is based on their characteristics examined on the parallel faces of the road cut about 20 meters apart. They are better exposed along

LITHOLOGIES	Lower Diamictite	UPPER DIAMICTITE				
		Below Lower Pav.	Lower Pav.	Between Pavems.	Upper Pav.	Above Upper Pav.
RED OR VIOLET ARKOSE	4.3	26.0	2.0	12.0	18.6	44.0
QUARTZITE	39.1	18.6	10.2	7.0	7.2	29.4
RED OR VIOLET QUARTZITE	2.2	7.3	24.5	19.0	9.3	–
METARENITE	15.2	12.5	6.1	25.0	9.3	1.5
GNEISS	–	6.3	8.2	4.0	1.0	7.4
SCHIST	10.9	4.2	6.1	15.0	3.1	2.9
VERY FINE QUARTZITE (OR CHERT)	4.3	1.0	2.0	1.0	3.1	11.8
SANDSTONE	8.7	–	–	–	–	1.5
RED SILTSTONE	–	–	–	1.0	–	–
META SILTSTONE	2.2	–	–	3.0	–	–
GRANITE	10.9	15.6	36.7	6.0	41.2	–
METADIABASE	–	4.2	4.1	3.0	1.0	–
METAVOLCANICS	–	3.1	–	2.0	–	–
METACONGLOMERATE	–	–	–	–	3.1	–
PHYLLITE	2.2	–	–	–	2.1	–
PEGMATITE	–	–	–	–	1.0	–
VEIN QUARTZ	–	–	–	1.0	–	–
QUARTZ PORPHYRY	–	–	–	1.0	–	–

Table 1. Lithology of clasts of the two diamictites at Capivari (457 clasts).

the southern face of the cut, which will mainly serve as a basis for the description (Fig.2).

The upper alignement can be followed for at least 80 meters, from the northeastern extremity of the outcrop to about 1/4 of its entire lenght, being truncated by the present surface of the terrain. The alignement is astonishingly retilinear in vertical view and formed by more or less densely disposed pebbles, cobbles and boulders. Vertical dispersion is minimum (less than 1/2 meter) and irregular horizontal concentrations of clasts include imbrications.

The lower alignement, essentially parallel to the first, occurs two meters below and is exposed along at least 60 meters on the southwestern road cut, starting a few meters before the southwestern extremity of the upper alignement, to about the middle part of the cut. Except for the wider horizontal discontinuities and higher vertical dispersion, characteristics of the lower alignement are coincident with those of the upper one.

Closer examination of clasts along the two alignements on both road cuts revealed that many present an upper plane or faceted surface, mostly inclined towards south. They generally bear subparallel or sometimes grid type striae (Wentworth, 1936), the first generally parallel to the long axes of clasts of the pavement, which also tend to be parallel. Measurement of striae on 48 cobbles and boulders of the upper alignement and 13 in the lower, averaged N - S and N75°W, respectively (Fig. 3).

ORIGIN OF THE CLAST PAVEMENTS

Boulder pavements are flat-lying layers of clasts ranging from pebbles to boulders which occur between tills (intertill pavements), or inside a single till unit (intratill pavements, Dreimanis, in press). The upper surfaces of the clasts are beveled and contain striae oriented in a parallel fashion (Flint, 1957, 1961; Dreimanis et al., 1953, Dreimanis, in press). Intertill pavements may be part of the lower till, as demonstrated by examples where the clasts lithology of both are similar, but may also belong to the overlying till, in cases where the older

LEVELS	Total	TYPE OF STRIAE				ORIENTATION OF STRIAE			
	% Striate	Parallel	Subpar.	Grid	Scatter	Parallel	Oblique	Perpend.	Indet.
ABOVE UPPER PAVEMENT	48.0	6.1	87.9	6.1	-	72.7	9.1	9.1	9.1
BETWEEN PAVEMENTS	17.0	29.4	82.4	-	5.8	82.4	17.6	17.6	-
BELOW LOWER PAVEMENT	39.0	5.3	86.8	7.9	-	84.2	2.6	-	13.2
LOWER DIAM.	26.0	8.3	83.3	8.3	-	66.7	16.7	8.3	8.3

Table 2. Type and disposition of striae on 310 clasts of the two diamictites at Capivari. Explanation: parallel = $< 45^{\circ}$ of longer axis; oblique: $\pm 45^{\circ}$ of longer axis; perpendicular: = $\pm$ 90° of longer axis, indeterminate chaotic; type of striae according to Wentworth (1936). Percentages may be above 100 because more than one type of striae with different disposition occur on the same clast.

sediments do not contain clasts (Dreimanis, in press).

The first variety of intertill boulder pavements are thought to represent lag concentrates due to various processes of surface erosion of an older till, followed by rejuvenation of the glacier which is responsible for the reorientation of clasts, beveling of the lower till and regular striation on the clasts (Flint, 1957, 1961; Dreimanis, in press). According to Flint (1957) the rejuvenation may or may not be associate to an intervening deglaciation period.

Interpretation of the genesis of the other two types involves some difficulties. They are generally supposed to be formed by processes related to "changes in the dynamics of a moving glacier" (Dreimanis, in press) which may include plastering of a till by planation or shearing of higher and faster moving debris below a flowing glacier (Holmes, 1941; Dreimanis et al., 1953), and selective englacial or sub-

Fig. 3. General view of upper boulder pavement on southern face of road cut.

glacial erosion of finer particles around larger clasts, which remain fixed as a pavement (Dreimanis et al., 1953). There are at least empirical geological evidences for the occurrence of single or multiple slippage or shearing planes inside a basal till under a moving glacier, as demonstrated by the beveled upper surfaces of clasts of pavements bearing polishing, parallel striae, grooves and sometimes even crescentic marks (Dreimanis et al., 1953; Frakes et alii., 1966; Rocha Campos et alii., 1968, 1969). This mechanism is, however, difficult to conciliate entirely with proposed models of sedimentation below moving continental glaciers (see Carey et al., 1961, p. 877-880).

In spite of the present difficulties to explain the origin of some pavements, they are very significant paleoclimatological indicators, since no other process than glaciation is know to be able to produce concentration of clasts with the peculiar features described above. Boulder pavements are also useful in deciphering the direction of local flow of ice during deposition of the overlying till (Dreimanis et al., 1953; Elson 1957).

Clast pavements associated to Late Paleozoic (Gondwana) glacial sediments, coincident with the first ans third variety of boulder

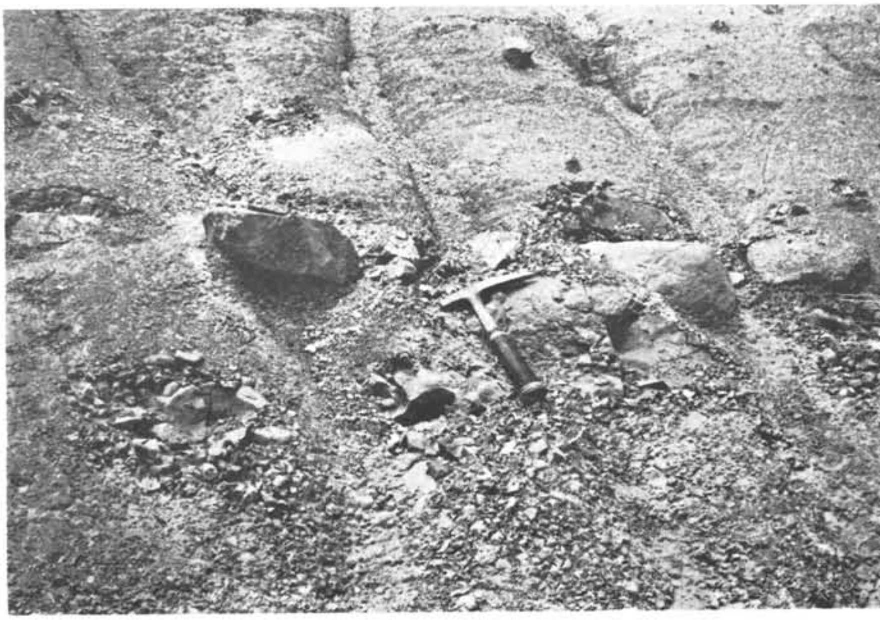


Fig. 4. Detail of upper boulder pavement showing four large clasts with plane upper surfaces.

pavements have been reported previously in the litterature from Antarctica (Frakes et alii., 1966, 1971), Brazil (Rocha-Campos et alii., 1968, 1969; Frakes et al., 1969). Africa (Frakes et al., 1970; Crowell et al., 1972; Rocha--Campos, 1976) and Australia (Crowell et al., 1971).

In the case of structures and strata here discussed, a general glacial environment of deposition of the Itararé Subgroup is now firmly established, as well as, its regional facies and paleogeography (Leinz, 1937; Rocha-Campos, 1967; Frakes et al., 1969, etc.). The two clast pavements at Capivari have all the essential features of intratill boulder pavements; judging from their dimensions in outcrop they may represent two of the most extensive structures of this type so far reported in pre-Pleistocene deposits. Their identification indicates that the envelopping diamictite at Capivari represents a former glacial drift deposited as till by the Late Paleozoic glaciers, most probably in the terrestrial enviroment. According to Dreimanis, in press, the intratill variety of pavements is associated to basal till.

CHARACTERISTICS OF CLASTS

A detailed study of lithology and of surface features of clasts of the local diamictites was attempted for the following purposes: a) to identify the lithology of clasts from the lower and upper diamictites and at the different levels of the upper one; b) to determine the presence of striae and other features usually considered as evidence of glacial action, their types (Wentworth, 1936), and distribution in relation to characteristics of clasts in the two diamictites, and at the different horizons within the upper diamictite (boulder pavements and intermediate zones). The two lines of investigation could furnish evidences towards the understanding of the origin of the diamictites, mechanisms of deposition and of the genesis of the boulder pavements. Additionally, they could be useful to understand the provenance of the sediments. In spite of special care taken during field work, the variable state of weathering of the different lithologies sampled, plus the erosion at the top of the outcrop caused some defficiency in the sampling.

In order to compare more quantitatively

the composition of clasts at the different levels, a cluster analysis was run on basis of the data of Table 1. Results obtained indicated closer correlation (above 50%) among samples derived from the two pavements and of levels below the upper and lower pavements, being thus consistent with the intetpretation of the clasts as concentrates from envelopping matrix. Two samples, one from the uppermost level of the upper diamictite, above the upper pavement and the other from the lower diamictite, showed poorer correlation (less than 50%) with the first group. Inadequate sampling at the uppermost level of the upper diamictite, due to selective weathering and/or erosion at the top of the outcrop may explain the results obtained for the first sample. With regard to the clasts from the lower diamictite, their relative lesser correlation may be due to slight difference in the composition of its source area. Qualitatively, inspection of Table 1 shows a predominance of metamorphic types among the clasts of the lower diamictite.

As discussed below, the directional data on ice movement during deposition of the local diamictites indicate that they came from areas towards the southeastern, probably from the Precambrian shield, and this is consistent with the general composition of clasts analysed (Table 1). Larger exposures of red or violet quartzites are, however, presently unknown in the crystalline basement.

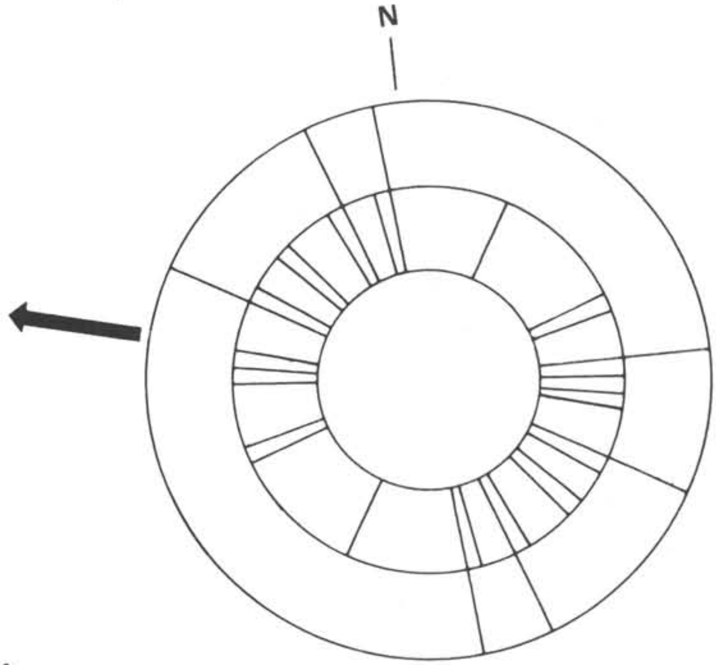
Results exhibited on Table 2, based on examination of 310 clasts, are close comparable with those obtained by Wentworth (1936) in a study of shapes and surface features of Pleistocene till clasts. The predominant striae pattern is subparallel, usually parallel to longer axes of elongated clasts. Other types found are grid (and/or possibly scatter), followed closely by the parallel pattern. The subparallel, grid and scatter varities are usually considered as glacial criteria, while the parallel type is not considered as unequivocal, since they occur frequently associated to tectonic activity (Frakes et al., 1969). The parallel disposition of striae with regard to long axes of elongated clasts suggests that these were transported through sliding inside the original till, most probably parallel with the flow of the sediment (Wentworth, 1936; Holmes, 1941).

SENSE OF MOVEMENT OF LATE PALEOZOIC GLACIERS IN THE AREA

Figs. 3 A and B summarize results of measurements of orientation of striae on top of clasts of the two parallel boulder pavements. The lower one, based on 13 clasts, shows a maximum in the northwest-southeast direction, while the upper yelded a maximum oriented in the north-south direction. Determination of sense of ice movement in each case was based on the probable upglacier inclination of the upper faceted ends of clasts. They are mostly inclined towards south and the senses of movements must have been towards north. Other possible indicators of sense of flow, as imbrication of clasts, train of fragments (Frakes et alii., 1966), seemed less reliable, or could not be used locally.

This situation reveals that direction of shearing over two different planes, within a single till unit, only two meters apart from each other, may differ substantially, in the present case of about 75°, possibly due to heterogeneities inside the till mass.

The general sense of glacier movement during deposition of the upper diamictite is interpreted to have been according to N37°W (average of the two sets of striae). In view, however, of the orientation of drag-lines on top the underlying sandstone (N5°W), the main movement may have occurred according to this direction, thus coinciding better with one set of striae. Deductions of direction of ice-flow on basis of only a few measurements may thus be complex, even when associated with indicators as reliable as the boulder pavements and the general geological context should be examined.



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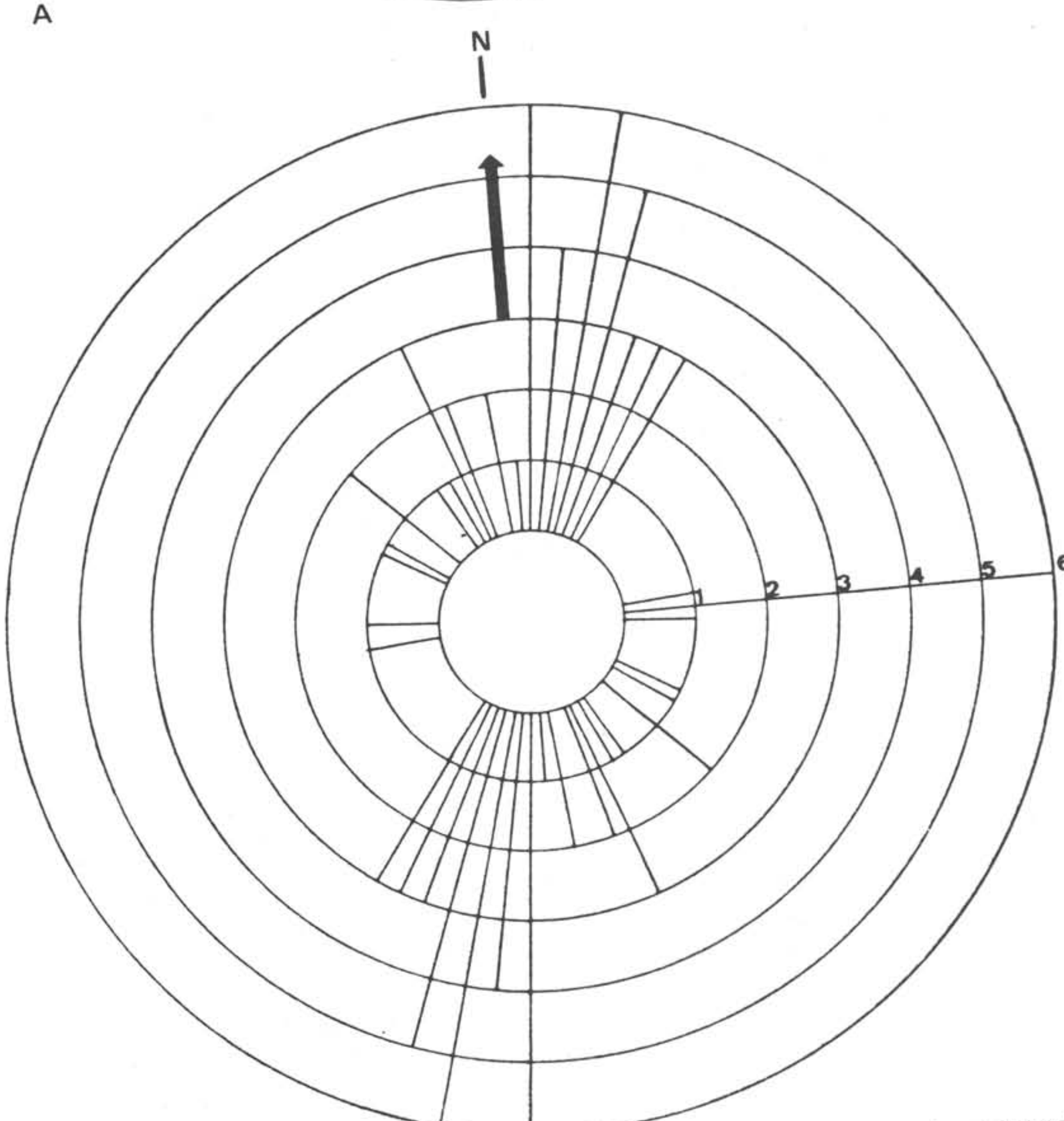

B

Fig. 5. Directional data: A: striae on clasts of lower pavement (13 determinations); B: striae on clasts of upper pavement (48) determinations). Arrows show interpreted senses of movements.

The inferred glacial history of the area may be synthetized as follows: a) deposition of the lower diamicton as till; deformation of sandstone interbeds may indicate some post-deposition mass movement which caused disruption of the included sand bodies. Reworking of the former diamicton by flowing melting water may have occurred possibly associated to a deglaciation period; b) rejuvenation of the glaciation with deposition of the upper diamictite as a basal till; erosion of the underlying sediments occurred while they were still in the hydroplastic state, as demonstrated by the draglines on top of the sandstone. Part or all deformation of the sandstone interbeds in the lower diamictite could be, alternatively, due to flow of overlying ice. Formation of the two boulder pavements occurred probably simultaneously, along shear planes developed on basal till by the flow of the younger glacier above it.

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