NEW GLACIAL FEATURES OF THE UPPER PALEOZOIC ITARARÉ SUBGROUP IN THE STATE OF SÃO PAULO, BRAZIL

By

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ABSTRACT

Elongated topographic forms composed of bedrock veneered by conglomerate, diamictite and sandstone and linear concentration of clasts included within diamictite are described from the Itararé Subgroup (Tubarão Group), in São Paulo State, Southeastern Brazil. Another possible elongated molded structure composed of sediments only is also briefly.

The topographic structures are interpreted as streamline forms molded by the flow of ice, and the clast concentration appear to correspond to a type of boulder pavement.

These features constitute additional evidence for a glacial mode of origin for the diamictites and associated sediments of the Itararé Subgroup.

RESUMO

Corpos alongados compostos de embasamento capeado por diamictito, conglomerado e arenito e concentração horizontal de clastos incluídos em diamictito são descritos no Subgrupo Itararé (Neopaleozóico), no Estado de São Paulo. Uma outra estrutura alongada composta sòmente de sedimentos é brevemente descrita.

Os corpos alongados são interpretados como formas topográficas lineares moldadas pelo fluxo das geleiras neopaleozóicas e a concentração de clastos parece corresponder a um tipo de pavimento de clastos.

Essas feições constituem evidências adicionais a favor de uma origem glacial dos diamictitos e rochas associadas do Subgrupo Itararé.

INTRODUCTION

During the last few years additional evidence has been acumulating in favor of a glacial environment of origin for the rocks of the Itararé Subgroup (Rocha-Campos, 1967a) which is a thick sequence of sediments distributed along the eastern margin of the Paraná Basin.

Among the most important glacial features recently described, the occurrence of striated surfaces overlain by diamictites (Amaral, 1965; Bigarella et al., 1967), channel-like bodies of sandstone and conglomerate and wedge-bodies of sandstone interpreted respectively as fossil eskers and «crevasse»-fillings open in frozen till (Frakes et al., 1968), confirm a glacial environment during deposition of the Itararé Subgroup.

Furthermore, these features have provided new paleogeographic data for the determination of ice flow direction during Gondwanic glaciation, that are consistent with the paleogeographic picture already known (Martin, 1961; Rocha-Campos, 1967a).

In the present paper elongated topographic forms composed both of bedrock and sediments are interpreted as streamline bodies molded by the flow of glacier ice, and horizontal concentration of clasts similar to the Pleistocene boulder pavements of the northern hemisphere are described from the Itararé Subgroup, State of São Paulo. Reference is also made to another possible elongated body composed of sediments only. These features represent additional evidence supporting a glacial origin for the sediments, and provide new data for the determination of direction of glacier movement during the upper Paleozoic glaciation.

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GEOLOGICAL SITUATION

The features described occur in the central and northern part of the State of São Paulo, in the eastern outcrop belt of the Tubarão Group, in Paraná Basin, Brazil (fig. 1).

The rocks studied belong to the Itararé Subgroup, the lower unit of the Tubarão Group in the State of São Paulo, according to the stratigraphic scheme presented by Rocha-Campos (1967a).

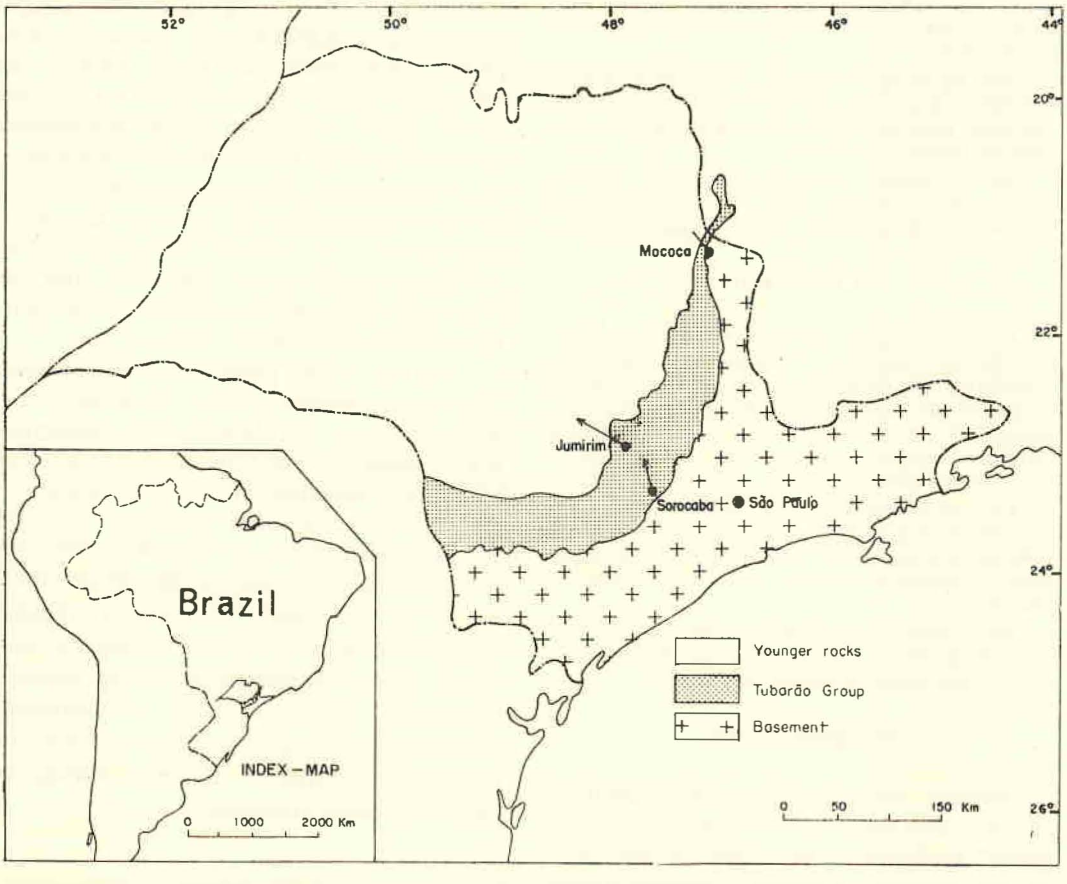
The stratigraphic position of the features is variable. At Mococa they occur at the lowermost part of the local section of the Itararé Subgroup and include the crystalline basement. At Jumirim the features studied occur at the upper part of the Itararé, approximately 10-20 meters below the contact with the Tatuí Formation (Rocha-Campos, 1967a), the uppermost unit of Tubarão Group in the area.

The age of these rocks is not firmly established yet. A lower Permian age was recently suggested for the upper half part of the Itararé Subgroup in central São Paulo State (Rocha-Campos, 1967b). Possibly the same age can be extended to the lower section.

DESCRIPTION OF THE FEATURES

Elongated topographic bodies

The features studied are exposed in both faces of a road cut roughly oriented toward SW-NE along the roadway between Casa

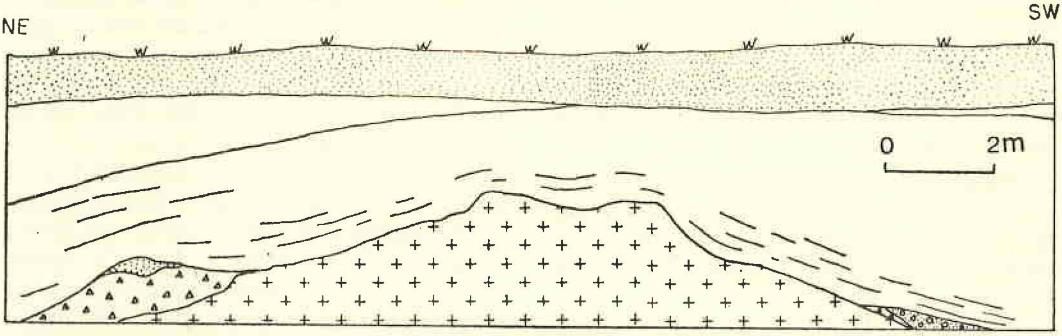


1. Location of outcrops studied in the State of São Paulo. Arrows at Mococa and Sorocaba indicate axes of elongated bodies. Point of arrow at Jumirim indicate deduced direction of ice-movement.

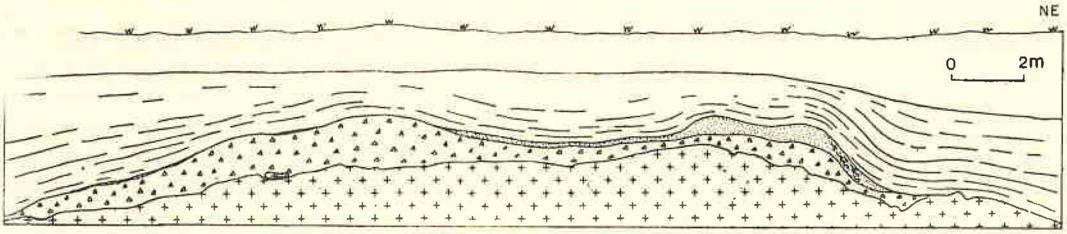
Branca and Mococa, at kilometer 261,5, approximately 3 km south of Mococa.

The local rocks are decomposed and were covered by a crust of mud that was partially removed to make observation easier.

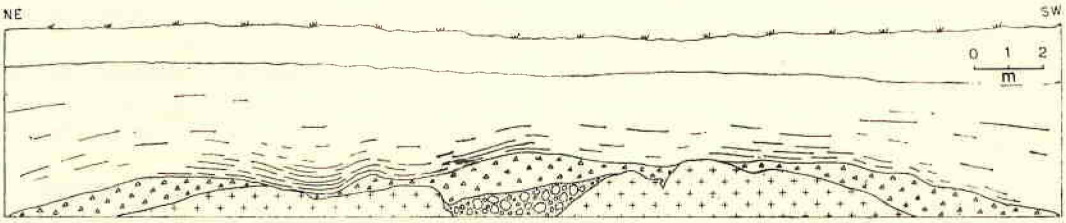
The north and south faces of the road cut are 20 meters apart from each other. Correlation between the two faces allowed the reconstruction of two parallel, elongated bodies, designated A and B, which are semielliptic in section and 22 meters apart. The axis of structure A is elongated toward N20°W, and of structure B toward N35°W (magnetic).



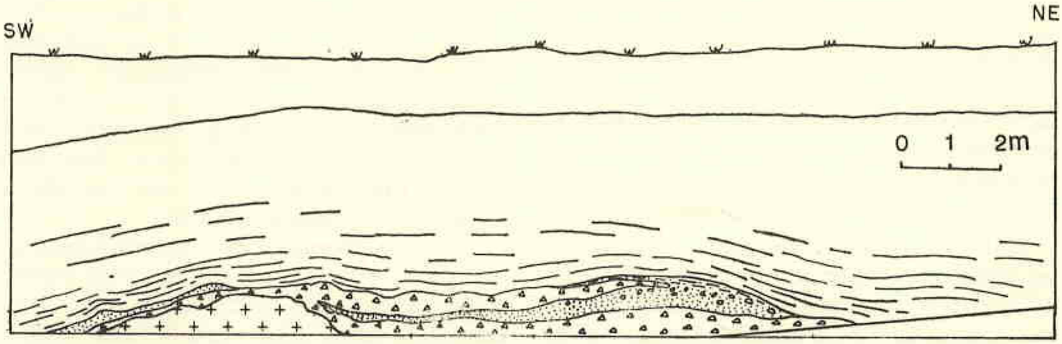
2. Diagram of southern face of body A at Mococa. Symbols: crosses, bedrock; open circles, conglomerate; triangles, diamictite; unpatterned with discontinuous concentric lines, laminated fine sandstone; unpatterned, medium grained sandstone and soil; dotted.



3. Diagram of northern face of body A. Symbols as in fig. 2



4. Diagram of southern face of body B. Symbols as in fig. 2.



5. Diagram of northern face of body B. Symbols as in fig. 2. Darker oblique straight line at lower right represent road surface.

These structures are formed by a core of the local basement rock which is granite-gneiss, covered by a veneer of diamictite, conglomerate and medium to coarse grained sandstone. The structures are overlain by siltstones and fine to medium grained feldspathic sandstone (fig. 2-8). Locally all the sedimentary rocks are red in color. The entire sequence in roughly 6 meters in thickness. Another boss of granite-gneiss appears in the southwestern extremity of northern face for which no counterpart was found on the southern face.

Distribution of the sediments within each body varies between faces of the cut. Generally the sediments tend to be thicker in the northern face. This is better shown for structure A (figs. 2-3; 6-7). The northern face of body B is not well exposed, but presumably a thicker section of diamictite and/or conglomerate and sandstone occur below the road surface (figs. 4-5 and 8). The thickeness of the sediments varies also in relation to the core topography, being greater in the lower parts and smaller in the higher parts.

Structure A has a single core (figs. 2-3; 6-7) while in structure B, the granite-gneiss core is bifid, at least at the southern face (figs. 4 and 8); only the southwestern basement boss appears at the northern section of structure B (fig. 5).

Sediments forming the elongated bodies show a very high degree of compaction, especially the diamictite that constitutes locally the most resistent rock. The overlying rocks are friable and rest discordantly on the elongate bodies. Arching of the stratification over the structures indicates differential compaction of the overlying sediments (figs. 2-5). Argillite laminae intercalated in sandstone that cover the northern face of structure A are complexely folded in a manner suggesting slumping, diverging from the plane of symmetry of the body (fig. 3). Laminate siltstones that appear in the upper part of southern face of structure A seems to be truncated above the structure by the medium to coarse sandstone bed (fig. 2).

Both the surface of the granite-gneiss core as well as the upper surface of the diamictite of the two structure are normally smooth and frequently finely striated. The striae are parallel, with direction varying from N35°W to N55°W (magnetic). (Fig. 9.)

The upper surface of the granite-gneiss core also shows irregularities formed by acute projections into the diamictite, underlain by horizontal wedge-shaped fissures filled with diamictite. Vertical wedge-like cracks filled with diamictite also occur (figs. 4 and 10). At the northern face of structure B a large block of granite-gneiss is a apparently only slightly displaced from its former position separated from the basement core by a thin film of diamictite (figs. 3 and 11).

Taking as a reference the plane of the road bed, structure A has a section of 22 meters at the southern face enlarging to 30 meters at the northern face. The maximum exposed height also increases from 2,4 meters to 3,2 meters. Structure B shows a section of 32 meters at the southern face decreasing to 16 meters at the northern face. The height also diminishes from 2 to 1,3 meters.

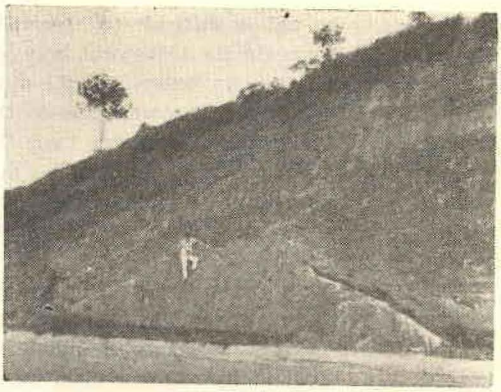
Origin of the elongated topographic forms

There are several indications that the structures described formed bodies with relief before the deposition of the overlying sediments: the discordant contact, the attitude of the stratification of the overlying sediments indicating diferential compaction, the aparent truncation of the beds towards the top, and the slumping structures along the flanks of the bodies. Preservation of these features indicates rapid burial by the overlying rocks, before destruction by erosion.

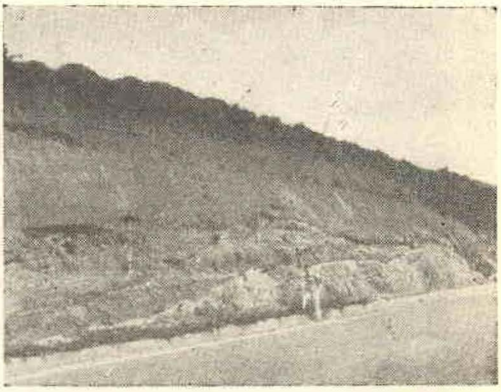
Direct association with diamictite indicates that the features could have been formed by the streamline flow of the upper Paleozoic glaciers.

Features of glacial deposits of Pleistocene age with characteristic of shape, structure and composition similar to the ones studied at Mococa are assembled into a large group called streamline molded forms by Flint (1957). These include positive and negative elements with dimensions varying from centimeters (e. g. a glacial striae), to kilometers in length (e. g. the great drumlins). Features of intermediate size, both positive and negative, can occur generally in large swarms, rarely isolated.

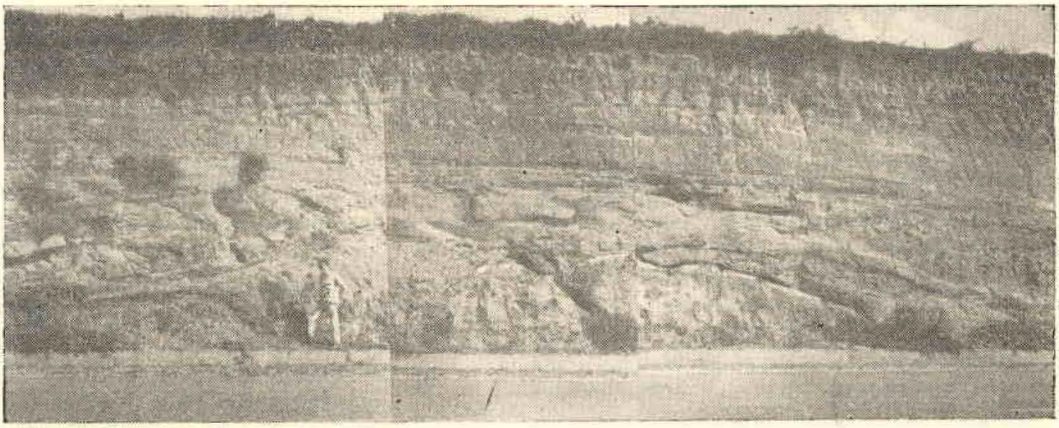
Among streamline molded forms the longest and best known are the drumlins (Alden, 1905; 1918; Slater, 1929; Hollingwort, 1931; Gravenor, 1953; Charlesworth, 1957; Flint, 1957). Drumlins, as well as other positive elements, can have a composition ranging



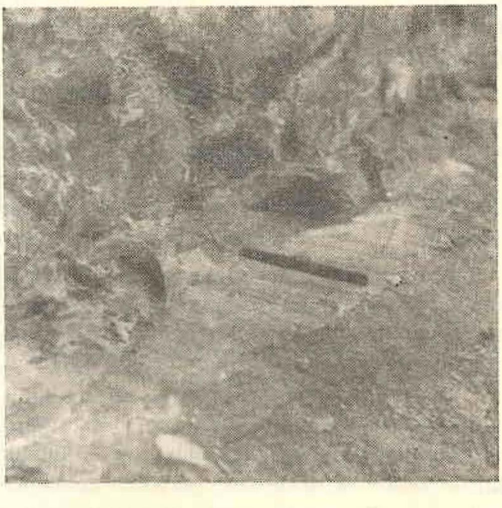
6. View to the north east at Mococa showing southern face of structure A. Note thicker veneer of diamictite and sandstone.



7. View to the northwest at Mococa showing northern face of structure A. Lower whiteish zone marks contact of diamictite and basement rock and upper one marks contact of covering rocks and diamictite.



8. View to the southeast at Mococa showing southern face of structure B. Note valley filled with conglomerate between the two granite bosses.



9. Parallel striae on the upper surface of diamictite at southern face of structure B (Mococa).

10. Vertical wedge-shaped cavity in the bedrock filled diamictite at southern face of structure B (Mococa).

11. Large granite-gneis block separated from bedrock by diamictite at northern face of structure A (Mococa).

from entirely of bedrock at one extreme, to entirely of drift at the other. The origin of these structures is still a matter of debate. Bodies composed entirely of bedrock are obviously erosional. Those composed of drift associated with a core of bedrock and, especially those composed only of drift are more difficult to explain. Essentially there are two ideas, either that they have formed by erosion; second that they have resulted from accretion of drift. Gravenor (1953) presented a review of some theories concerning the origin of drumlins and listed their most important characteristics.

A complete explanation for the origin of the features described in this paper presents the same problems.

At Mococa the elongated molded form could have been formed by erosion, or erosion and deposition.

Polishing and striation of the upper surface of the granite-gneiss basement indicates that it was abraded by glacier ice.

The overlying diamictite is tightly packed against the irregularities of the basement topography, filling the V-shaped cavities. This is interpreted as being caused by deposition under the weight of a glacier. The presence of striae on the upper surface of diamictite is indicative of erosion after, or more probably during deposition of the veneer of sediments.

Whether the erosion of bedrock and deposition of sediments was produced by the same glacier or not is difficult to ascertain. However, the approximate agreement between the elongation of the two bodies and the direction of the striae on the basement and on the diamictite could be and indication that the erosion of basement and deposition and erosion of diamictite, conglomerate and sandstone occurred more or less simultaneously.

The diamictite discordantly overlies the conglomerate filling the valley between the two granite bosses of structure B indicating that it was deposited by running melt water before the accretion of the diamictite cover.

At structure A and possibly at structure B the thickening of the diamictite and sandstone veneering the granite bosses suggest a crag-and-tail association.

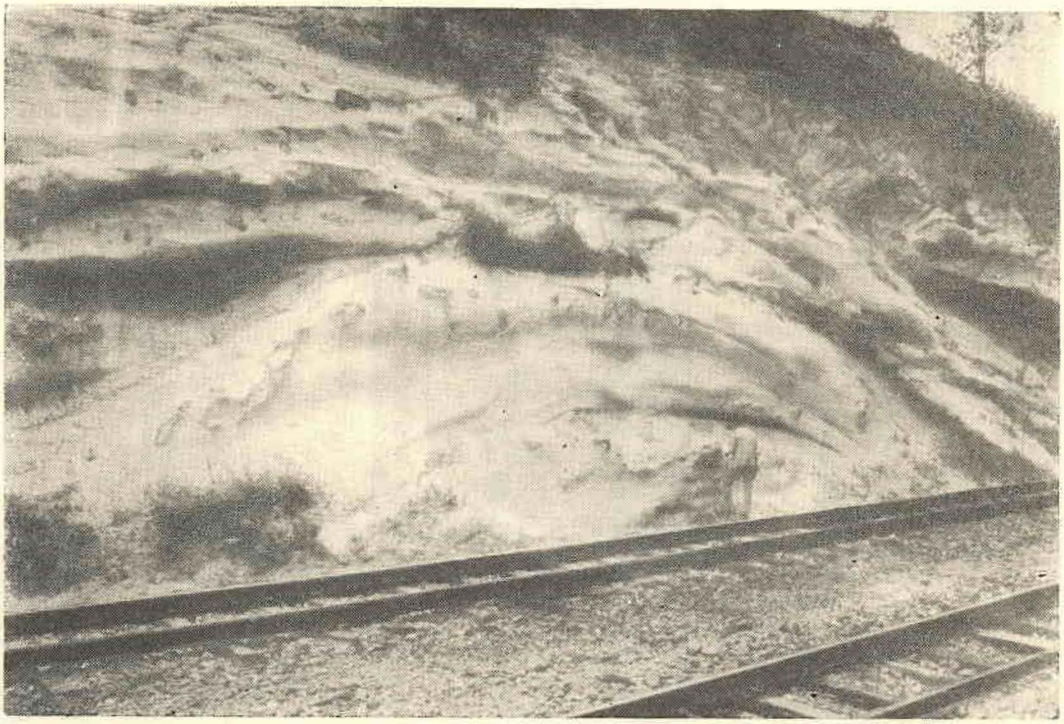
The horizontal and wedge-shaped fissures of the basement could be the effect of glacial plucking or they could represent frost cracks. Separation of the blocks of granite-gneiss in the northern face of the structure could have had a similar origins. Another possible explanation is to interpret these features as due to sheeting of the granite-gneiss with enlargement of the fissures during deposition of the diamictite. This case would involve exposure of the granite-gneiss surface to weathering for a considerable space of time before deposition of diamictite.

In the Pleistocene deposits these elongated molded bodies generally occur in swarms. The rarity of occurrences of the structures in pre-Pleistocene sediments could, however, be explained by difficulties in preservation, especially of the larger bodies, and by lack of outcrops that make their recognition difficult, or both.

Nevertheless, other possible elongated molded forms were examined in the Paraná basin. A good example is the one exposed in the two faces of a cut at kilometer 107 of the Sorocabana Railroad, near the town of Sorocaba.

The structure has a shape similar to the one at Mococa, but it is composed entirely of sediments, mainly feldspathic, poorly sorted sandstones and mudstone (figs. 12-13).

At this locality there is no direct association with diamictite. However, diamictite with facetted and striated clasts and showing tillitic fabric is beautifully exposed some 200 meters to the south west, probably only a few meters above the structure. The sedi-



12. View of southern face elongated structure at Sorocaba. Note truncation of overlying sandstone beds over the structure and concentric discontinuous joints of the "core".

ments belong to the basal portion of the Itararé Subgroup in the area.

An origin through folding for this feature is improbable since it is included in a flat lying sedimentary sequence. The apparent concentric structure shown by the discontinuous concentric jointing of the «core» does not seem to be related to stratification.

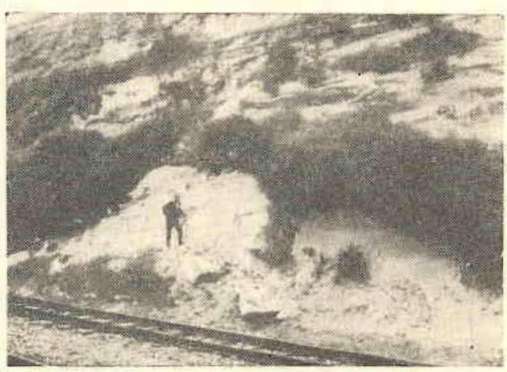
Erosion and/or deposition by glacier ice could be responsible for the formation of the elongated body at Sorocaba. The concentric structure parallel to its upper surface is remindful of the concentric banding described by Slater (1929) in Pleistocene drumlins and considered indicative of origin through accretion of drift.

Clast concentration

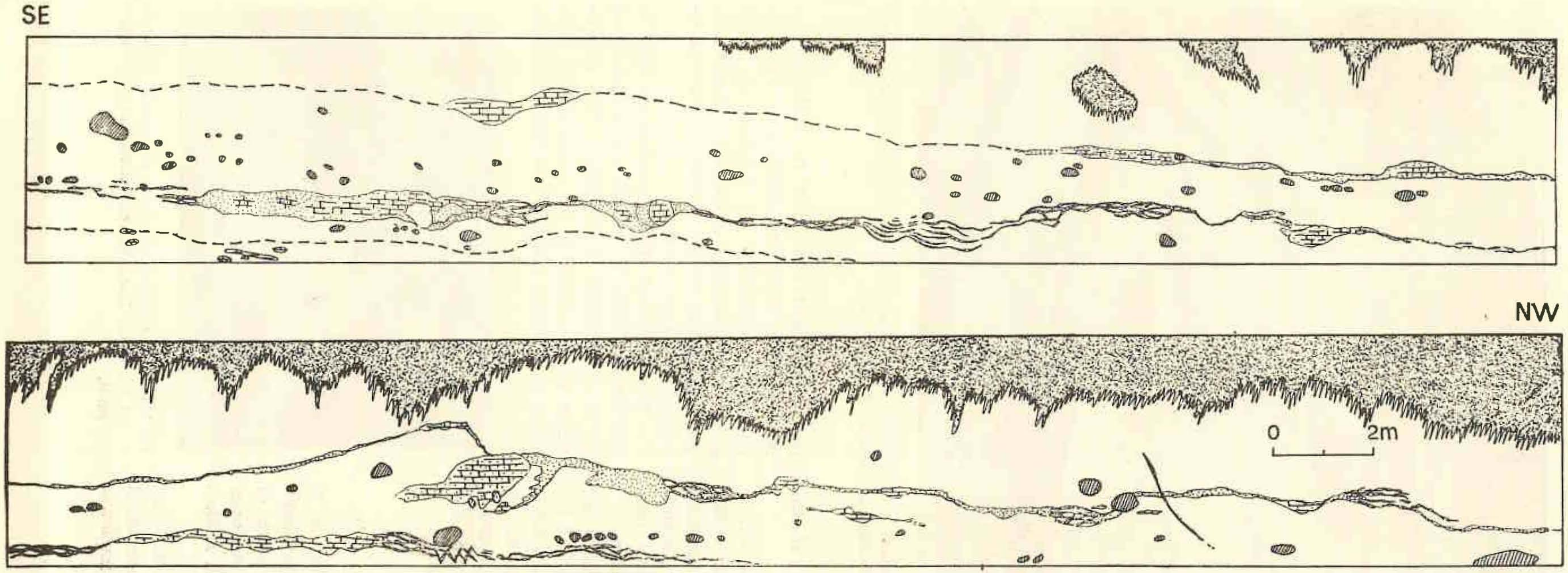
The locality studied for this feature is the two faces of a cut on the Sorocabana Railroad approximately 200 meters south of the railroad station at Jumirim. A brief description of this outcrop appeared in Frakes and Crowell (1969).

In the roughly southeast-northwest cut, about 15 meters apart, a linear and horizontal concentration of clasts occurs within the lower part of a light olive-gray to dusky-yellow, medium-gray, indurated diamictite. The diamictite is underlain by medium to corse grained yellow-gray feldspathic sandstone. The upper part of the section is covered by vegetation (figs. 14-16).

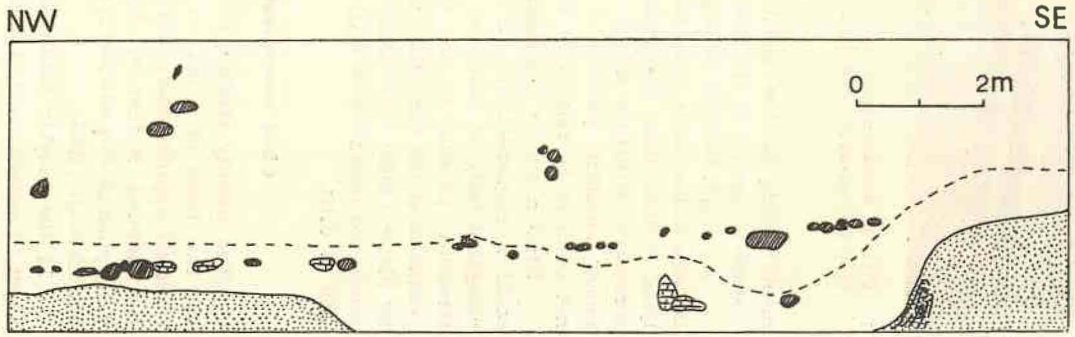
The clasts of the concentration vary in size from cobbles to blocks and boulders, up to 90 centimeters in diameter. The composition of the clasts is the same as the relatively rare clasts dispersed in the diamictite,



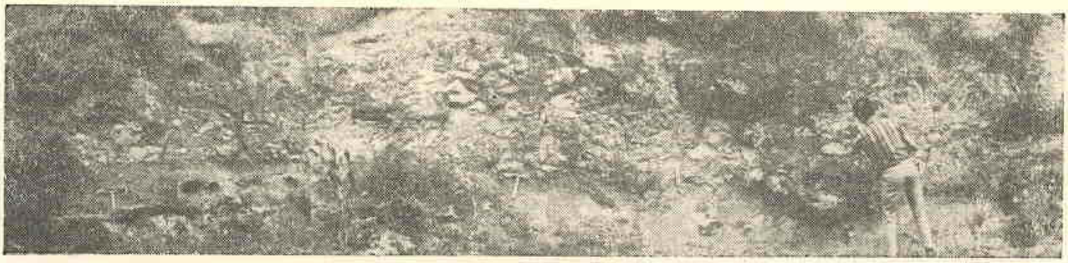
13. View of northern face of elongated structure at Sorocaba. Band of vegetation marks its upper limit.



14. Diagram of northern face of railroad cut at Jumirim. Symbols: umpatterned, diamictite; obliquely hatched, clasts; stippled, sandstone; squares, calcareous sandstone; irregular dots, vegetation. Upper descontinuous line represent probable prolongation of upper intercalation zone; lower interprupted line represents boundary between the two zones of diamictite.

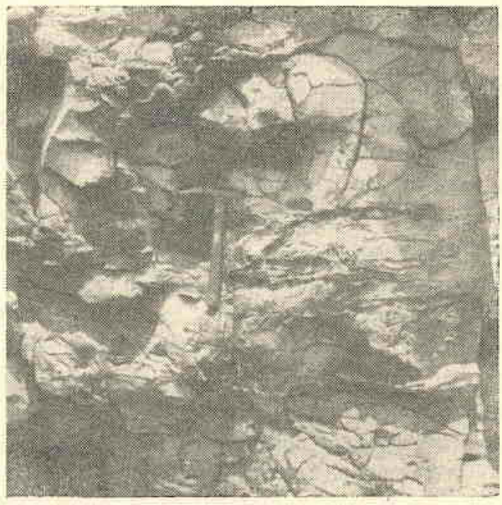


15. Diagram of southern face of railroad cut at Jumirim. Symbols as in fig. 14.



16. View of the southern face at Jumirim. Note the two zones of the diamictite, clast concentration, and calcareous concretions at left.

17. Part of the clast concentration included in diamictite at the northern face at Jumirim. Note upper beveled surface of clasts.



18. Layers and veins of sandstone showing celular disposition within the diamictite on the northern face at Jumirim.

which are predominantly quartzite and granite-gneiss. Size variation and general shape also coincide (fig. 14-15).

The horizontal concentration can be followed for 50 meters along the better exposed western face (fig. 14). At its southern part a higher dispersion of the clasts makes the recognition of the concentration difficult, but in the rest of the exposure the linear disposition is clearer, although in places the clasts are separated laterally by 2-3 meters. At some places they are almost in contact with each other with a few showing an imbricated disposition (figs. 14-15). Direction of imbrication is approximately toward N55°W (magnetic).

At the southern face the concentration is exposed over a distance of at least 12 meters (figs. 15-16). The northwestern side of the outcrop is covered by vegetation and talus debris. The general characteristics are the same as on the other face.

Several clasts of the concentration show their upper surface facetted (fig. 17) bearing series of striae or narrow grooves oriented in a parallel fashion. Measurement of the striae in at least 10 clasts indicate only slight divergence, the average being approximately N60°W (magnetic). Other features are associated with the striae in some of the clasts, especially on the upper surface of largest boulder at the northwestern extremity of eastern face. This includes crescentic marks and possibly chatter marks. Orientation of the axis of the crescentic marks is parallel to the striae on the clasts. These features have been described in detail elsewhere (Rocha-Campos et al., 1969).

In the southern side of the northern face and in the exposed part of the southern face two zones can be observed in the diamictite. These are separated by an undulating and transitional boundary. In the lower one, about I meter thick, the diamictite is yellow-gray, fragmenting in small, centimetric slabs. Epigenetic calcareous concretions are common in this zone and show a horizontal disposition. A test in the field indicated that the matrix is also more calcareous. In its upper part the diamictite is highly compacted and medium-gray in color (fig. 15). The clast concentration is included mainly in the upper zone of the diamictite in the northern cut (fig. 14). In the southern cut most of the clasts are enclosed in the lower zone whose upper limit cuts the clast concentration in two places (figs. 15-16).

The northern face differs also from the southern face by having two horizontal and parallel zones of fine to medium grained sandstone and calcareous sandstone intercalations in the diamictite, 1 to 1.5 meters apart, and varying in width from a few milimeters up to one meter (fig. 14). The intercalations occur as horizontal or oblique layers or veins of fine to medium grained sandstone. The latter are extremely ramified in places forming a kind of cellular or honeycomb structure (figs. 14 e 18). These pass laterally to irregular masses or lenses of highly calcareous sandstone. Contact with the enclosing diamictites is sharp and regular in most places. No internal structure could be observed in the sandstone.

The two zones are almost continuous along the northern face, except for the southern end of the upper one (fig. 14). The clast concentration is included between the two intercalation zones along most of the northern face (fig. 14).

Origin of the clast concentration

Boulder pavements are a type lag concentrate that results from the removal of the fine matrix of tills by wind or running melt water after deglaciation of a locality. Renewed glaciation abrades the concentrate forming a more or less continuous pavement of clasts with beveled upper surfaces, that commonly bear striae oriented in a parallel fashion. The pavement is usually covered by till of different composition than the till below the clasts. Boulder pavements can also result from the rejuvenation of a glacier with renewed subglacial erosion after deposition of a till, without the interference of a deglaciation period. (Flint, 1957; 1961). In this case the overlying and underlying till may be lithologically very similar.

Several of the characteristics of the clast concentration at Jumirim are comparable to those of the Pleistocene boulder pavements. These include the horizontal and more are less linear disposition of the clasts and the upper beveled surface of the clasts bearing parallel striations and other marks (Flint, 1957; 1961). Similarity of composition of the clasts of the concentration and those included in the till is also in agreement. The literature does not refer to imbrication of clasts in Pleistocene pavements but their occurrence is probable.

The main differences are the greater lateral and vertical dispersion of the clasts, and lack of a diamictite of different composition overlying them.

Lack of detailed description of boulder pavements in the literature makes comparison of small features difficult. Lateral separation of clasts seems to occur in the Pleistocene examples. Flint (1957, p. 120, fig. 7-11) ilustrates a boulder pavement from Canada where the clasts are sometimes 2-3 meters apart. Slight vertical dispersion also can be observed in the photograph.

The apparent lack of a diamictite of different composition above the clast concentration in the Brazilian example could perhaps be explained by the absence of a deglaciation period following the deposition of the clasts. The composition of the matrix of the diamictite above and below the clast concentration could be very similar and mixture of the two materials would make difficult the recognition of a physical break.

An alternative, but less probable explanation would be to interpret the clast concentration at Jumirim as a type of fabric resulting from shearing action inside a lodgement till. The parallel disposition of the striae and other glacial marks on the clasts, and the extension of the clast concentration seem to mitigate against this.

A definite explanation for the formation of the two zones of sandstone lenses, layers and veins is lacking. Geometric aspects and disposition of these features coincide with those of ice veins and layers developed in frozen ground for which they could represent pseudomorphs (Taber, 1943; Schafer, 1949).

The zonation observed in the diamictite could be due to recent weathering with leaching of the carbonate from the upper part of the diamictite and deposition in the sandstone intercalations and as concretions in the lower part of the diamictite.

CONCLUSIONS

Elongated topographic forms composed of bedrock with a veneer of diamictite, sandstone and conglomerate, and entirely of sediments occur in the Itararé Subgroup. These features show analogies to streamline elongated bodies produced by the flow of ice during Pleistocene glaciation.

The linear clast concentration enclosed in a diamictite at Jumirim also show several points in common with the descriptions of Pleistocene boulder pavements and could have a similar mode of origin.

Occurrence of these features directly associated with or included in a sequence that contains diamictites is indicative of a glacial origin for these rocks.

Elongation of the structures and direction of striae on the upper surface of the bedrock and diamictite at Mococa are parallel and trend N45°W (magnetic). Possible crag-and-tail distribution of the drift on the bedrock could indicate displacement of upper Paleozoic glaciers from the southeastern quadrant. Elongation of the axis of the structure at Sorocaba is toward N15°W (magnetic).

Directions of striae and grooves and of the axes of crescentic marks on the upper surfaces of clasts of the boulder pavement at Jumirim are parallel and oriented toward N60°W. A few clasts of the pavement are imbricated, direction of imbrication beeing toward N40°W. This is interpreted as indicative of ice flow toward northwest in the area.

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