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Excursion A4

GUIDE BOOK

LATE PALEOZOIC GLACIAL SEDIMENTATION IN EASTERN PARANÁ BASIN

11-15 July, 1988

by

Antonio Carlos
A. C. Rocha-Campos
Paulo Roberto
P. R. dos Santos &
José Roberto
J. R. Canuto

Instituto de Geociências
Universidade de São Paulo

São Paulo, SP, Brasil

Claudio
(With contributions by C. Riccomini and
Benjamin Bley
B.B. de Brito Neves, Instituto de
Geociências, USP, São Paulo)

7th Gondwana Symposium
July 18-22, 1988
São Paulo, SP, Brasil

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PREFACE

The purpose of the field excursion is to demonstrate the main characteristics, facies and stratigraphic distribution of the Late Paleozoic diamictites of the Itararé Subgroup in the eastern Paraná Basin, in the area to the southwest of Curitiba in southern Paraná and northern Santa Catarina States, South Brazil (Fig. 6). In addition there will be opportunities for brief examination of Gondwana beds immediately below and above the diamictite sequence.

The facies of the Itararé sediments in the area of excursion differs from that of beds in the northern part of the basin by the widespread occurrence of glaciogenic sediments ressedimented through several types of mass gravity movements and larger incidence of marine fossiliferous beds. Diamictites, varvites, sandstones and shales may form regional extensive mappable bodies, associated to special setting in sub-basins. Some of the fossiliferous marine shales are corretable with similar rocks in central Santa Catarina or northern Paraná States and thus, may constitute stratigraphically important key or marker beds.

A variety of diamictite types, both massive or stratified, occur in association with other glaciogenic deposits interpreted as deposited in glacial-terrestrial and subaquatic/glacial marine conditions.

Observations will be made on outcrops along three roads that radiate southwestwards from Curitiba and thus, offer a panorama of the stratigraphy and features of the glaciogenic sediments of the Itararé Subgroup in the area.

Description of Excursion

A4. Late Paleozoic glacial sedimentation in the eastern Paraná Basin

Trip will examine outcrops of diamictites and other lithologies of the Itararé Subgrup in central and southern Parana and northern Santa Catarina, representative of terrestrial grounded glacier, subaqueous/glacial-marine associations. Stops will include beautifully exposed striated pavements on Devonian Furnas sandstones, and examples of diamictites interpreted as lodgement/basal tillites, flow tillites and other terrestrial to subaqueous/submarine mass gravity deposits. Evidences of multiple glaciation shown by succession of basal tillites with sheared lower contacts; thick varvites with rafted clasts; fossiliferous marine shales. Periglacial (involutions) and glaciotectonic features.

- Summary of Itinerary -

Day	Date/Distance	Description
1	July 11-Monday 481 km	Start: São Paulo, SP. End: Curitiba, PR. Principal features: a) Ribeira Fold Belt; b) Cenozoic sediments of the São Paulo and Curitiba BasinO; c) unconformity between the Devonian Furnas sandstone and Eopaleozoic sediments; d) striated pavement on the Devonian Furnas sandstone; e) fluvio-glacial Vila Velha sandstone.
2	July 12-Tuesday 264 km	Start: Curitiba End: Curitiba Principal features: a) contact between the Itararé Subgroup diamictite and glacial polished Precambrian granite; b) succession of massive diamictites (basal tillites) resting disconformably on sandstones and shales the Campo do Tenente and Rio do Sul Formations; c) flow diamictites and deformed fluvioglacial sandstones; d) glacial marine flow diamictite; marine shales and mudstones; thick varvites of the Mafra Formation; e) marine shale; possible glacial involutions in the Rio do Sul Formation.
3	July 13-Wedresday 204 km	Start: Curitiba, PR. End: Curitiba, PR. Principal features: a) linear or wide bodies of fluviatile sandstone; b) laminated flow tillite; c) massive diamictite granding to stratified/laminated diamictite, rhythmite and shale; diamictite with deformed sandstone inclusions; d) marine shale horizons associated

		to thick, poorly bedded diamictites with alignment of clasts.
4	July 14-Thursday 220 km	Start: Curitiba, PR End: Curitiba, PR Principal features: a) contact of diamictite on the Devonian Furnas sandstone; b) cross-bedded sandstone with internal lineations; c) stratified diamictite with diapiric structures; stratified/laminated diamictite overlying basal massive diamictite; d) deformed or slumped sandstone and diamictite; marine shale below fluviatile sandstone with coal.
5	July 15-Friday 390 km	Start: Curitiba End: São Paulo Return to São Paulo. End of Excursion.

Acknowledgements. We thank Benjamin Bley de Brito Neves and Claudio Riccomini, Instituto de Geociências, USP, for their contributions. We are also deeply indebt to Marcello Guimarães Simões and Fernando C. Fittipaldi, Instituto de Geociências, USP, for their assistance with the illustrations and bibliography.

Financial support for the preparation of this guide book was provided by the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq, Brasil, Proc. 404423/87-6.

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REVIEW OF LATE PALEOZOIC GLACIATION IN THE PARANÁ BASIN

Setting of the Late Paleozoic glaciation in the Eastern Paraná Basin

Two recent accounts on the general paleogeographic setting of the Gondwana glaciation in the Paraná Basin are those of Gravenor & Rocha-Campos (1981) and Santos (1988). The comments below were extracted mainly from the first contribution.

The present area of the Paraná Basin is more than a million square kilometers and covers parts of the States of Mato Grosso, Mato Grosso do Sul, Goiás, Minas Gerais, São Paulo, Paraná, Santa Catarina and Rio Grande do Sul in Brazil and parts of Paraguay and Uruguay. The glaciogenic sediments which crop out around the margins of the basin in southeastern Brazil (Fig.7) have been assigned to the Itararé Subgroup of the Tubarão Group (Rocha-Campos, 1967). Although we shall follow this terminology in this study, it is recognized that the stratigraphic hierarchy of the Tubarão/Itararé is under discussion and has been assigned Super Group/Group, Group/Subgroup and Group/Formation status by various authors (for a historical summary of this problem, see Rocha-Campos & Santos, 1981).

In the southeastern part of the Paraná Basin, the rocks of the Itararé Subgroup lie unconformably on Precambrian crystalline rocks and Devonian sediments and are overlain conformably and disconformably by Permian sediments (Rocha-Campos & Santos, 1981). The underlying Precambrian and Devonian rocks were eroded by the overriding glaciers and support striae, grooves, roches moutonnées, modified pre-glacial valleys and molded rock-cored streamlined forms, all of which provide evidence of ice-movement towards the north and northwest (Martin, 1961; Bigarella et al., 1967; Rocha-Campos, 1967, 1972; Frakes & Crowell, 1969; Rocha-Campos et al., 1969; Rocha-Campos et al., 1977). In addition to providing the direction of ice-movement, these features demonstrate that the ice was grounded as it moved across the southeastern platform into the Paraná Basin where it reached sea-level (Rocha-Campos, 1967). As the glaciers moved into the basin, in some areas they remained grounded but in other areas they were either partially grounded of floating. Within the basin, the contact between the lowermost glaciogenic deposits and basement is not well exposed and the upper diamictites and other glaciogenic sediments were deposited on unconsolidated pre-existing glaciogenic and marine deposits (Fig. 2).

Available information suggest that the slope of the basement rocks leading into the Paraná Basin was towards the north and northwest (Rocha-Campos, 1967, p. 88). A trend-surface analysis of the thickness of the Itararé Subgroup (Fulfaro & Landim, 1976) shows that the slope of the lower unit is North 2^{o} West on a regional scale, but it is not known how representative this is on a local scale.

Stratigraphic information and isopach maps of parts of the Itararé show a series of small depressions close to the present eastern margin of the Paraná Basin (Medeiros et al., 1971; Saad et al., 1979). Isopachs of the lower unit show a series of north-northwest and south-southwest trending elongate troughs in the southern and central parts of the State of Paraná (Medeiros et al., 1971). These elongate depressions are roughly parallel to the glacial striae on the basement (Bigarella et al., 1967) and might represent pre-glacial stream valleys or, in some instances, tectonic features which were modified by glacial erosion.

Isopachs of the middle unit in the Itararé (Mafra Formation) show a small northeast-southeast sub-basin in the northern Santa Catarina-southern Paraná area (Medeiros et al., 1971). Widespread existence of marine beds in this area suggests that this feature might represent an engulfment or embayment which controlled marine transgression towards the margin of the basin. Isopach maps of the upper unit of the Itararé in north-central Santa Catarina, including the Rio do Sul area, show a similar sub-basin (Medeiros et al., 1971). (Fig. 10.)

On the basis of the features described above, the eastern margin of the Paraná Basin was a low-lying irregular coastal area and its configuration and distance from the present basin boundary may have been modified by changes in basement features and in response to eustatic and isostatic adjustments.

Sedimentary and paleontologic information from marine sediments intercalated with glaciogenic sediments, which will be discussed in more detail below, suggest that the seas which periodically flooded the margins of the basin were shallow. In addition, the paleoslope leading into the basin was low on a regional scale but locally steep, either as a result of local variations in the basement topography, more rapid subsidence in some areas, relative to others, or by a buildup of sediments being brought into the basin by glaciers and deposition from glacial meltwaters.

Glaciogenic sedimentation in the Paraná Basin

Biostratigraphic information, though not devoid of controversy, suggests that the Late Paleozoic glaciation in the Paraná Basin occurred in the interval from the Late Carboniferous (Stephanian C) to at least the early Permian (Asselian-Sakmarian), from invertebrate/megaplant data or Kungurian, according to palynological investigations (Daemon & Quadros, 1970; Rocha-Campos & Rösler, 1978). Thus, from available information, the Late Paleozoic glaciation in the Paraná Basin lasted from a minimum of 10 m.y. to a maximum of 35 m.y.

The minimum age given above may be incorrect as unpublished preliminary subsurface information suggests that pre-Late Carboniferous (Early Carboniferous?) diamictites may be present in the deeper parts of the basin which were protected from subsequent erosion. It must also be kept in mind that Gondwana was moving northwards during this period and, hence, deposition was probably time transgressive over the length of the Paraná Basin.

The outcrop thickness of the Itararé varies considerably but, in general, is thinner in the south and north than in the central area of the State of São Paulo. Measured thickness of the southern outcrops in Uruguay and the State of Rio Grande do Sul and southern Santa Catarina range from 5 to 280m. In the northern part of the State of Santa Catarina and in the southern and central parts of the States of Paraná and São Paulo, the thickness increases to approximately 1000 m. On the northern margin, the thickness drops off to about 300 m (Rocha-Campos & Santos, 1981).

Isopach maps of the Itararé (Fig.1) derived from subsurface drilling show that, similar to surface outcrops, the Itararé gradually thickens from Uruguay in the south to the area west of São Paulo where the thickness exceeds 1200 m and then thins towards the northern margin of the basin (Northfleet et al., 1969).

The Itararé is composed primarily of sandstone, siltstone, mudstone and diamictites. Sandstones dominates in terms of thickness and volume and, for the most part, its sedimentary structures suggest that deposition took place in subaerial to shallow water conditions. Siltstones and mudstones were deposited under both marine and freshwater conditions. Freshwater conditions are recognized by the presence of varvites (Rocha-Campos & Sundaram, 1981).

Although some thick-bedded sandstones and rhythmites may be marine in origin, true marine conditions and recognized by fossiliferous beds which contain shallow-shelf benthonic faunas consisting of molluscs, brachiopods and arenaceous forams. These marine beds are found at different levels within the Itararé along the eastern margin of the Paraná Basin (Saad, 1977, fig. 7; Rocha-Campos and Rösler, 1978 (Figs. 15, 25, 29). Marine microplankton, including tasmanites (Saad, 1977) and acritarchs are also found within sediments of the Itararé, including the diamictites. In addition to fossiliferous beds, thin beds of coal, possibly paralic, are found in two or three stratigraphic positions within the Itararé in the State of São Paulo (Rocha-Campos & Rösler, 1978).

The marine beds are interpreted as short lived marginal transgressions of the sea that occupied the Paraná Basin during interglacial or interstadial periods. The extent and duration of these transgressions was probably controlled by climatic fluctuations, the physiographic setting, tectonism and isostatic rebound (Leinz, 1939; Rocha-Campos, 1967; Saad et al., 1979).

The presence of thin beds of coal also attests to periodic withdrawal of the glaciers and possible climatic amelioration. Correlation of these "interglacial" beds recorded in terrestrial and marine sediments is difficult because of the lack of detailed stratigraphic information.

In summary, paleogeographic and paleontologic information and the nature of the sediments, all suggest that the Paraná Basin was a shallow gently subsiding basin with localized steeper slopes. The shoreline was probably of irregular configuration and marginal embayments were periodically flooded by marine waters during interglacial periods and by fresh glacial meltwaters during periods of glacial advance and retreat. There is little evidence of subaquatic outwash deposits either at the margins or within the basin. While such deposits, such as those described by Rust & Romanelli (1975) may have been present in the near-shore environment, they were probably eroded by subsequent advances of glaciers into the basin.

Characteristics of diamictites

Diamictites of a variety of types and origin are found in terrestrial and subaquatic environments on the margin and within the Paraná Basin. Although, in some instances, it is possible to differentiate lodgement tills from other supraglacial and subglacial deposits as well as debris flows, in other cases, weathering and poor exposure makes it difficult to determine if certain beds of diamictite represent separate glacial advances.

This difficulty, along with the possibility that some diamictites may have been lost by erosion, may well explain the discrepancy in the number of discrete diamictites and glacial advances reported by various authors who have studied the glaciogenic deposits found in outcrops west of São Paulo. For example, in the state of São Paulo, Frakes & Crowell (1969) reported five to seven distinct diamictites, whereas, Saad (1977, fig. 7) has reported a maximum number of 23 in the central part of the State of São Paulo. Evidence from drill cores shows that in deeper parts of the basin, there may be up to 17 discrete layers of diamictites (Rocha-Campos, 1967). More recent detailed studies in the State of São Paulo by Santos (1979) has shown that there were at least nine glacial advances. This variation in the numbers of diamictites points out the need to categorize diamictites according to origin in order to avoid the possibility that certain supraglacial and subglacial deposits as well as associated glaciogenic debris flows which may result from a single glacial advance are not counted as evidence of multiple glacial advances (Boulton, 1972; Boulton & Deynoux, 1981).

Diamictites found on the eastern margin of the Paraná Basin vary considerably in terms of thickness or boundary conditions and internal structures. For example, some of the diamictites are quite massive, 10 m or more in thickness and, aside from horizontal joints, show little or no evidence of fabric whereas other diamictites are layered and have a preferred fabric in the horizontal plane. Between these two extremes, there are diamictites which are compact, show evidence of shear, preferred fabric and fissility.

The laminated diamictites found within the Paraná Basin are frequently interbedded with sandstone, mudstone and occasional conglomerate and are commonly deformed by flow and, possibly, ice thrusting (Martin, 1961; Rocha-Campos, 1967; Frakes & Crowell, 1969). Additionally, an analysis of drilling records show that, in some cases, the diamictites within the basin appear to be lenses which are not connected to a landward extension of terrestrial glacial deposits (Castro, 1980). It is possible that some of these lenses may have originated from an unstable mass of glacial debris which subsequently moved down a paleoslope or mark locations where the ice was grounded.

Assignement of origins to the different types of diamictites found on the eastern margin of the Paraná Basin is not always easily accomplished because, in many instances, the glaciers were grounded as they passed from a terrestrial to a lacustrine or marine environment (Santos, 1979). Thus, those features associated with terrestrial glacial deposits may interfinger with or pass gradationally into sedimentary features normally associated with marine or lacustrine environments. This problem is further complicated by the lack of outcrops which demonstrate the complete horizontal sequence from terrestrial to lacustrine or marine environment. Despite these difficulties, the diamictites and associated glaciogenic sediments may be assigned a general terrestrial or subaquatic (including glacial-marine facies).

Paleogeographic evolution

A series of four paleogeographic reconstructions showing main lithofacies distributions, position and extension of ice masses and land-sea relationships have recently been prepared bu Santos (1988) on the basis of subsurface data for successive biostratigraphic intervals (G, H, I, and I_2-I_4), of (Middle?) Late Carboniferous to Early Permian age, corresponding to the Itararé Subgroup/Aquidauna Group, Paraná Basin, southeastern Brazil. Main features are synthecized below (Figs.1-4).

Sedimentation during interval G is interpreted as predominantly continental; main depocenters were in the northern part of the basin, and source areas were located along the eastern and northeastern margins. At least three glacial lobes, the Rio Grande do Sul, Paraná and Kaokoveld lobes (Frakes & Crowell, 1972), seem to have reached the eastern Paraná Basin, from the Rio Grande do Sul-Uruguayan shield, the south, and the southeast, respectively. Evidence for a fourth ice-center on the Asuncion

Arch (Frakes & Crowell, 1972) is scanty.

Interval H is characterized by the transgression of a relatively shallow sea into the basin, either from the southwest, around the Rio Grande do Sul-Uruguayan shield, or/and the southeast, via the Rio do Sul depression, with widespread deposition of finer clastic facies; the main depocenters also shifted to locations farther south. Fluviatile-deltaic(?) sand bodies prograded into the subsiding area and probably coalesced at that time and also later on with glacigenic sediments derived from the three main glacial lobes, restricted now to the southern and eastern margins of the basin. The Kaokoveld and Paraná lobes (the latter possibly subdivided into two masses) continued to move towards the northwest and north, respectively, entering the basin at or below sea-level. Intercalations of marine shales, sometimes bearing rafted clasts, with terrestrial/grounded glacier deposits and with continental sediments including coal beds are possibly related to eustatically controlled, periodical (interglacial?) encroachment of the sea eastwards. The coastline was probably very irregular with engulfments and bays where "fjord"-like sedimentation may have occurred.

Maximum sea transgression in the Paraná Basin is recorded during interval I_1, probably coinciding with attenuated glacial activity; fluviatile-deltaic (?) sand bodies prograded into the basin. Sediments of the Paraná and kaokoveld lobes are still recognizable, but some of the other large fluviatile-deltaic deposits with intercalated coal beds in southern Paraná and Santa Catarina are now correlated with the post-glacial Rio Bonito Formation. This deglaciation pattern continues into intervals I_2-I_4. The Kaokoveld lobe, however, seems to have persisted in the northeastern part of the basin, at places moving over fluviatile-deltaic coal-bearing sediments.

Features of the Itararé Subgroup in the area of the excursion

Areal distribution of the Upper Paleozoic strata in that part of the Paraná Basin is influenced by the presence of the Ponta Grossa Arch, an important tectonic uplift of the Precambrian basement, mostly generated during late Jurassic to early Cretaceous time, in association with an important episode of emplacement of basic to acidic dykes and sills and extensive lava flows of the Serra Geral Formation. The eastern outcrop belt of the Gondwana strata bends around the Ponta Grossa Arch and trends SE-NW in the area to be surveyed.

Other important tectonic elements recognized in this part of the Paraná Basin are a series of SE-NW lineaments (faults), the Rio Alonzo and Rio Piqueri faults, which extend from the Precambrian basement towards the basin center. The lineaments are part of a system whose differential behaviour with time seems to have controlled the tectonic evolution of the Ponta Grossa Arch and its influence on sedimentation since the Devonian (Vieira, 1973; Ferreira, 1982; Fulfaro et al., 1982). This is shown, for instance, by the general coincidence between lineament trends and axes of thickest deposition of Upper Paleozoic beds, including the diamictite-bearing sequence.

Upper Paleozoic beds dip gently (1-1.5°), centripetally around the Ponta Grossa Arch, and are essentially undeformed except by faulting and/or dyke and sill-like basic intrusions (Fig. 6).

Upper Paleozoic diamictites and associated sediments in southern Paraná and northern Santa Catarina comprise the Itararé Subgroup. There is presently some controversy regarding the stratigraphic nomenclature of the Upper Paleozoic diamictite-bearing sequence in the Paraná Basin. Rocha-Campos (1967), for instance, utilizes the term Subgroup both for the glacial (Itararé) and the overlying non-glacial (Guatá) units within the Tubarão Group, whereas Schneider et al. (1974) proposed the term Group, both for the Itararé and the Guatá with the Itararé raised to the category of Supergroup. The first usage will be followed in the present text (Fig. 7).

The Itararé Subgroup in the area consists of a maximum of 750 m (in outcrop) of sandstones, diamictites, siltstones/mudstones, shales and rhythmites interpreted as having been deposited under glacial (terrestrial and glacial marine) and marine conditions. Subsurface thickness of the Itararé Subgroup attains a maximum of about 874 m (Petrobrás well, 2-LS-1PR). For a more general discussion on the main characteristics of the Itararé Subgroup in the Paraná Basin, see Rocha-Campos (1967), Frakes & Crowell (1969), Crowell & Frakes (1972), Rocha-Campos & Santos (1981) and Gravenor & Rocha-Campos (1983).

Semi-detailed mapping of the Gondwana sediments in the area by Petrobrás (Brazilian Oil Agency) led to the subdivision of the Itararé sequence into three formations, from bottom to top, Campo do Tenente, Mafra and Rio do Sul (Schneider et al., 1974). (Fig. 7.)

The Campo do Tenente Formation, with the tipe-section located between km 174.5-188 of BR-116, near Campo do Tenente, State of Paraná, has been mapped from northern Santa Catarina (São Bento do Sul), as far as the southern flank of the Ponta Grossa Arch. It is defined as a sequence of brown-red argillite, rhythmite and sandy-matrix diamictite, around 200 m thick. In this area it rests unconformably on Precambrian crystalline basement and concordantly, but in erosional contact, on Devonian sediments of the Furnas and Ponta Grossa Formations of the Paraná Group (Schneider et al., 1974) and is overlain also concordantly (sharp or erosional contact) by the Mafra Formation. This is described as a predominantly sandy unit, made up of whitish, yellow and red fine-grained, well-sorted sandstone, with rippled, thick parallel bedding and medium to coarse-grained sandstones, with channel cross-bedding and cut-and-fill structures, plus subsidiary diamictites, conglomerates, rhythmites, argillites and varved argillites. Thickness of the Mafra Formation is around 350 m in the type-section, between km 188-211 (=present km 6) of road BR-116 to the southwest of Mafra, in Santa Catarina. This Formation has been mapped from central Santa Catarina to northeastern Paraná State. The Mafra Formation is concordantly overlain by the Rio do Sul Formation; in places it transgresses over Precambrian or Devonian basement rocks (Schneider et al., 1974).

The uppermost strata of the Itararé Subgroup in the area constitutes the Rio do Sul Formation. The type-section of this unit is near the homonimous locality in central Santa Catarina, where it is about 350 m thick and rests directly on the Precambrian basement. From there its thickness diminishes both to the south and north, to about 200 m in southeastern Paraná, where it lies in sharp and concordant (disconformable) contact below the Rio Bonito Formation (Guatá Subgroup). Schneider et al. (1974) reported that the unit has been mapped from southeastern Paraná southwards into Rio Grande do Sul. Along this belt the facies change considerably, from a sequence of basal argillites, varved shales and subsidiary rhythmite, diamictite and sandstone, plus an upper section mainly of rhythmite, diamictite and sandstone, in the type-section to a predominantly sandstone and shale section, with numerous diamictite bodies, particularly in its lower half, in the area under study (Canuto, 1985).

Facies of the Itararé Subgroup in the area

The occurrence of a greater number of subaqueous deposits in the Itararé Subgroup, some of them yielding marine invertebrates, and of well-sorted diamictites displaying bedding and deformed sandstones masses, in southern Paraná and northern Santa Catarina, have been pointed out by Salamuni et al. (1966), Rocha-Campos (1967) and Frakes & Crowell (1969).

A better picture of the distribution of the diamictites and the associated beds emerged later, through mapping and measurement of sections by Petrobrás (Tommasi & Roncaratti, 1970; Medeiros,et al. 1971; Schneider et al., 1974).

Tommasi & Roncaratti (1970) favored a glacial terrestrial origin for diamictites in the Campo do Tenente Formation, which in places rests on a striated basement, and a lacustrine environment for the intercalated argillites, The red colour of some of the lithologies was interpreted as primary and due to deposition under a highly oxidizing environments. The basal part of the Mafra Formation, interpreted as mostly fluviatile, is succeeded by marine sediments, including in the middle and upper parts of the sequence a substantial proportion of glacially derived diamictites that have been re-sedimented by mass movement processes. Finally, a marine depositional environment was also postulated for the Rio do Sul Formation, beginning with deep water marine argillaceous strata, with, but mostly overlain by, turbidites and mass-gravity flow deposits (rhythmite, sandstone and diamictite), derived from sediments transported to the basin margin by glaciers.

The stratigraphy and sedimentological features of the Upper Paleozoic diamictites along three roads that cross the outcrop belt of the Itararé Subgroup, in southern Paraná and northern Santa Catarina (BR-116, BR-476, and BR-277; Fig. 6) have been recently studied in more detail by Rocha-Campos & Canuto (1983; 1984), Gravenor & Rocha-Campos (1983) and particularly by Canuto (1985). On the basis of these studies preliminary facies subdivision and paleoenvironmental interpretation of the diamictites and associated rocks have been attempted. The present account is mainly based on these contributions, especially that of Canuto (1985).

Diamictites are common in all three formations of the Itararé Subgroup, but vary considerably both vertically and laterally in number and thickness and, as we will see, in their main structural and textural characteristics.

Diamictites in the area of study include both massive and stratified types. Besides stratification, which is considered a basic structural characteristic of genetic significance, other relevant observable features are: shape, thickness and extention of bodies; texture (matrix: $<$ 2mm), composition, density, shape and fabric of clasts ($>$ 2mm), presence and features of sandstones and other interbeds, stratigraphic relationships with other lithologies or features, nature of upper and lower contacts, association with abraded pavements or clast pavements, presence of fossils, etc. (Rocha-Campos & Canuto, 1983; 1984; Gravenor & Rocha-Campos, 1983; Gravenor et al., 1984). On the basis of these criteria Canuto (1985) subdivided the diamictites cropping out along the three sections into 12 varieties and attempted to interpret their respective mechanisms of sedimentation and possible environmental significance.

The different diamictite facies, according to Canuto's scheme, consist of 4-5 associations that may be more characteristic, but do not occur exclusively in any one of the three formations within the Itararé Subgroup. The subdivision used in the present account is simplified, since we feel that diamictites formed under different environmental circumstances may show similar sets of basic features (textural, structural, stratigraphic, etc.). It is also worth mentioning that the genetic terminology used for the several types of glaciogenic deposits is somewhat loose and does not strictly follow published schemes (e.g., Gravenor et al., 1984), because features utilized for discriminating among the different facies may not be easily recognizable or available in outcrop analysis. Deposits of advancing glaciers formed at the sole of active glaciers are in some instances herein called lodgement tillites, but in most cases the more generic term basal tillite is used. The associations described below include sets of lithologies thought to have been formed during advances and retreats of glaciers over the area of study, but the emphasis will be on deposits of the first phase.

On the basis of the identification of lodgement/basal tillites, some of which are associated with abraded and/or sheared substratum, a maximum of 6-7 glacial advances could be postulated for one of the sections to be examined during the present excursion. Not all of them, however, could be extended laterally to the other sections.

a) Terrestrial/grounded glacier association. This is represented by discontinuous thin veneers of lodgement tillite plastered against ridges or valleys cut in older (Precambrian/Devonian) rocks, or by relatively thin tabular bodies of massive compact basal tillite.

The first type is overlain, with sharp contact, by massive to roughly stratified diamictite (basal tillite?); the latter may be in lateral contact, partially overlying linear bodies (ridges) of conglomeratic/sandstone (of kame/esker type) and be covered, also in sharp contact, by extensive, tabular, stratified diamictite showing undulating, deformed (folded) laminae/beds, slump, normal and reverse faults and lenticular inclusions of the massive basal tillite (supra-glacial flow-tillite?). This association may rest on and/or be followed by thin to thick varvites, sandstones and shale. Marine fossils have not yet been found in lithologies of this association.

b) Internal shelf/grounded glacier association. This association also includes lodgement tillite resting on smooth/polished surfaces on top of linear bodies of intraformational, stratified sandstone with ripple-drift-cross laminae, sheared and faulted in its upper part. More commonly, however, the diamictites form thin to relatively thick tabular bodies, massive to faintly stratified (basal tillite), resting in sharp contact on sandstone or shale, the upper part of which may be sheared.

The lodgement tillite may be followed by a complex of interbedded and mixed, deformed (folded/faulted, disrupted) diamictite and sandstone (flow tillite), conglomerate and fine, cross-bedded sandstone, indicating subaqueous deposition. The sandstone ridge shows features in common with subaqueous outwash. Marine fossils are rare in the flow tillites.

The basal tillites, on the other hand, may rest disconformably below shales, or be truncated by channel-form sandstone. Laterally, as well as vertically, they may show crude lamination and inclusions of deformed sandstone bodies, or even pass upwards to clast-rich (mostly of basinal origin) rhythmite of diamictite/shale and varvite with dropstones. Whereas the lower massive tillites are interpreted as having been deposited from the base of glacier, the disrupted/folded interbeds demonstrate deformation by movements during or shortly after deposition; the clast-laden rhythmites and upper varvites have been clearly deposited subaqueous, probably by dense ("slurry") flows and turbidity currents.

Other stratified types of diamictites in this association and which are probably linked to phases of stagnation/retreat show bedding due to the intercalation of stringers/laminae/lenses of silt/sand, many of which appear to have been sheared parallel to bedding. Additional common associated structures are recumbent folds and "hooks" of silt/sand/diamictite. These are interpreted as flow-tillites. The sandstones bodies, which may predominate at certain levels, exhibit sharp lower and upper boundaries and show deformed cross-bedding or sometimes channel-like structure, ball-like and rare diamictite inclusions. Fluviatile, very long, mappable linear bodies of cross-bedded sandstone, which trend SE-NW or N-S, being thus parallel to striae on the basement, may be laterally equivalent. They also truncate facies belonging to this association. They may represent outwash deposits, but their subaerial or subaqueous deposition is not yet clearly demonstrated.

c) Outer shelf/basinal association. Diamictites belonging to this association form thin to very thick (up to 20-30 m), tabular, sometimes extensive, mappable units, in many ways similar to the bodies described above from the inner shelf association, except for the greater thickness and possibly the absence of evidence of shearing of sediments below. Some may be product of debris flows and occur intercalated with shales with abundant marine fossils, thick varvites containing large dropstones, mudstones and widespread relatively thick tabular bodies of fine sandstone.

Distribution of these facies may be controlled by the presence of deeper sub-basins, surrounded by steeper slopes of the basement. Occurrence of thick varvites indicates the influx of glacial melt-water into such an embayment.

Examples of the above associations will be examined and discussed during the excursion, but their full discrimination in many instances still depends on more detailed work and availability of outcrops, the main difficult remaining the precise recognition of subaerial from subaqueous glaciogenic deposits. As a rough generalization, however, we may say that the terrestrial/grounded glacier association tends to predominate in the basal part of the Itararé Subgroup (Campo do Tenente Formation), which may also include facies of the internal shelf/grounded glacier type. In this regard it is worth mentioning that the isopach map of the lower interval of the Itararé shows a series of narrow SE-NW trending (> 250 m) areas of thicker sediments, which extend from the present eastern margin to the basin center. The features are roughly parallel to striae on the basement and are suggestive of pre-glacial stream valleys or else of tectonic features modified by glacial erosion Medeiros et al., 1971). (Fig.16). The second association is commonly found in the middle, and at places in the upper part, of the Itararé (Mafra and Rio do Sul Formations). The Mafra Formation locally shows sets of facies assigned to the outer shelf/basinal association. Features in sediments associated with diamictites in the Rio do Sul Formation, in the upper part of the Itararé Subgroup, may suggest recurrence of the terrestrial/grounded glacier association.

APPENDIX I

Road logs and stop descriptions

ROAD LOG AND STOP DESCRIPTIONS

1st Day: São Paulo-Curitiba (via BR-116, Rodovia Regis Bittencourt);
Curitiba-vila Velha (via BR-116 and BR-376).

During the morning of the first day, we will be travelling from São Paulo to Curitiba and from there to the first observation points. No stops for observation are planned for this period, but a generalized description of the main geological features along the road may be of some interest. Main geological domains involved in this part of the trip are the São Paulo and Curitiba Basins and the Ribeira Fold Belt (Fig.11).

São Paulo and Curitiba Basins (by C. Riccomini).

The tectonic setting of the São paulo and Curitiba basins is the Serra do Mar Rift System (Almeida, 1976), which also includes the Taubaté, Volta Redonda and Itaboraí Basins (Fig.11).

São Paulo Basin

Geologic and tectonic setting. The rift system was formed within the domain of Precambrian terrains of the Ribeira Folded Belt (Hasui et al., 1975). The final stages of its tectonic evolution during Cambrian-Ordovician times, is related to the Brasiliano Cycle and characterized by an anastomosed network of right-lateral, ENE to EW, shear zones (Hasui & Sadowski, 1976). (Fig. 11).

As a consequence of later processes, related to the Gondwana breakup, the separation of Brazil and Africa, and the opening of the South Atlantic Ocean, these shear zones were reactivated at the begining of the Tertiary, probably up to the Late Eocene-Oligocene; predominantly normal faults were formed, leading to syntectonic continental sedimentation in rift basins (Riccomini et al., 1983; Melo et al., 1985b).

Probably after the Miocene, a right-lateral strike-slip regime, in part transpressional, became active in the region along old faults (Riccomini, 1987).

Stratigraphy. The São Paulo Basin is located in the "Planalto Paulistano" (Paulistano Plateau) a geomorphologic feature younger than the Early Tertiary Japi Surface (Almeida, 1976). It is a semi-graben filled with up to 200 m of sediments (Almeida, 1984).

Two lithostratigraphic units are recognized in the basin, the São Paulo Formation (Pissis, 1842) and the Itaquaquecetuba Formation (Coimbra et al., 1983).

The São Paulo Formation comprises, marginally, a fluvioatile (mainly meandering) sandy to clayey facies; locally, a lacustrine facies is found.

Prevailing paleoclimate during the deposition was probably humid, with possible arid and semi-arid periods, as indicated by caliche-type deposits found in the neighbouring Taubaté Basin (Coimbra & Riccomini (1985).

The sandy fluvial braided deposits of the Itaquaquecetuba Formation reach up to 50 m in thickness. At the type-area, plenty of carbonized fossil trunks and fossil plants in organic-rich clay materials are present in the Formation. Both semi-arid (Coimbra et al., 1983) and humid (Fittipaldi et al., 1987) paleoclimates were proposed during deposition.

Structures. There is clear evidence for tectonic activity during, and after, the deposition of the São Paulo and Itaquaquecetuba Formations, but the latter was probably deposited contemporaneous only with the second rifting event as suggested by the presence of clastic wedges, with flower-structure, associated with the transcurrent faults. The shape of the basin is controlled by two families of faults, on trending ENE to EW, the other with a NNW orientation.

Age. No direct stratigraphic relationships between the São Paulo and Itaquaquecetuba Formation are observable.

The Itaquaquecetuba Formation lies directly over the Precambrian basement; its upper part is truncated by a fossil erosional surface at about 710 m.

Palynological analysis yielded a Middle Eocene to Oligocene age for lacustrine sediments of the São Paulo basin and an Eocene age for organic-rich clays of the Itaquaquecetuba Formation (IPT, 1986). The last sediments have been also paleomagnetically dated as older than 730,000 years BP (Melo et al., 1985a). Evidence of reworking, however, have been found in the samples of the Itaquaquecetuba Formation. This observation plus the indication of a transcurrent movement contemporaneous with the sedimentation of the Itaquaquecetuba Formation, may indicate its correlation with the second event that affected the São Paulo Basin.

Curitiba Basin

The Curitiba Basin is situated on Precambrian terrains that form the "Primeiro Planalto" of Paraná Basin (1st Plateau) levelled off by the Alto Iguaçu Surface (Almeida, 1952) around 980 m.

The sedimentary filling of the Curitiba Basin was referred by

Bigarella et al. (1961a) and Bigarella & Salamuni (1962) to the Guabirotuba Formation. It comprises up to 80 m of clays, conglomerates, sands and marls, predominantly associated with fanglomeratic deposition. Minor fluvial sediments are also present. Bigarella et al. (1961) and Bigarella & Salamuni (1962) suggested a semi-arid paleoclimate during deposition of the Guabirotuba Fm., which is also supported by the presence of caliche-type deposits in the fanglomerates (Coimbra & Riccomini, 1985). Conglomerate and sandstone deposits related to the present drainage system lover the Guabirotuba Formation.

Structure. Bigarella et al. (1961a and Silva et al. (1981) mentioned the presence of reverse faults affecting the sediments of the Guabirotuba Formation, on the other hand, the northwest and northern borders of the basin have boundaries (Fig. 11); the first limit is along the Campo Largo-Barra de Capivari Lineament (Hasui et al., 1978) while the latter is formed by the Rio Capivari Fault, a probable right-lateral strike-slip fault as suggested by drags in older rocks.

Age. The Guabirotuba Formation has been correlated with the Alexandra Formation occurring in nearby coastal areas, adjacent to the Antonina and Paranaguá bays (Silva et al., 1981); it is also probably corretable with the Pariquera-Açu Formation.

Recent tectonic studies on the Pariquera-Açu Formation (Riccomini et al., 1986; IPT, 1987) revealed a set of mesoscopic sin-and post-sedimentary normal faults, probably related to the first tectonic event of the Serra do Mar Rift System, during the Eocene-Oligocene. On the other hand, preliminary palynological data suggest an Early Miocene age for the Alexandra Formation (M.R. de Lima & R. Angulo, pers. comm.). The Guabirotuba Formation is this probably related to Early Tertiary sedimentation.

Ribeira Fold Belt (by B. B. de Brito Neves)

Highway BR-116 crosses the hilly topography of the Serra do Mar (Coastal Range) and follows more or less longitudinally, in a NE-SW direction, the inner portions of the Ribeira fold belt, whose main evolutionary history occurred during the Brasiliano Cycle (700-500 My).

Rocks cropping out from the city of São Paulo up to the border of the State of Paraná (for a distance of approximately 250 km) include meta-volcanic-sedimentary sequences of the Ribeira Belt (Embu Complex) and high-grade rocks which were interpreted as intensively transformed basement sequences ("internides").

These two litho-structural domains are separated by an important NE-SW trending shear zone the Cubatão lineament, that will be crossed by the road south of the locality of Pedro de Barros.

The last 150 km of our trip are along better-preserved high grade terrains of the Ribeira Belt which exhibit structural and geotectonic features typical of the foreland of the so-called Curitiba Marginal Massif. Occurrence of anorogenic sub-alcaline granitic plutons (Guaraú, Alto Turvo, Gracioso, Ilha do Cardoso) are typical of these more external portions of the fold belt, making up the "Serra do Mar Suite" of Proterozoic-Cambrian age, possibly generated by syn-and post-collision taphrogenic processes.

Superimposed an these earlier events are those related to epeirogenic uplift, with emplacement of alcaline intrusions (Jacupiranga, Serrote) and of mafic dyke swarms (Guapiara lineament), all of them associated with the Meso-Cenozoic evolution of the South Atlantic margin.

After leaving the meeting point drive to southwest on Avenida Rebouças and then on its continuation, Avenida Euzébio Mattoso and Francisco Morato, to the entrance of highway BR-116. Distances on Brazilian national highways (BR) are zeroed at each state boundary. For the first part of the trip, however, origin of distances will be the departure point of excursion.

Interval km	Total km	
0	0	Departure point.
20	20	Embú Complex of the Ribeira Fold Belt.
110	130	Shear zone of the Cubatão Lineament.
30	160	Costeiro Complex; reworked basement of the Ribeira Fold Belt (high grade terrains).
50	210	Turvo-Cajati Complex; medium-to high-grade metassediments representing basement of the Ribeira Belt.
39	249	Curitiba Marginal Massif: high grade basement rocks (foreland) intruded by subalkaline anorogenic plutons (e.g. Guaraí, Alto Turvo, Graciosa).
31	380	Cenozoic deposits of the Curitiba Basin.
10	390	Arrival in Curitiba. Proceed southwest through BR-116 up to intersection of Avenida Victor F. do Amaral. Lunch Stop. After lunch we will begin our observations. Return to BR-116 and proceed 12 km to the SW, up to Pinheirinho.

		Take exit at right and travel NW some 13 km to intersection of BR- 376. Turn left and take BR-376 eastwards. Indicated distances are taken with reference to Curitiba.
2.0	25.0	From the intersection with road to Campo Largo, the road runs on metamorphic rocks of the Açungui Group (Prorozoic) and on outliers of the Curitiba Basin, in the area of Campo Largo.
10.0	35,0	Base of the Devonian scarpment. At this point road begins to ascend the front of the cuesta, up to the so called 2nd plateau of the State of Paraná; local outcrops are of Açungui Group rocks.
4.0	39.0	From this point, looking S, one can have a good view of the morphology of the 2nd plateau of the State of Paraná, developed on crystalline rocks. The Serra do Mar (Coastal Range) can be seen in the background. Unconformable angular contact of the sandstone of the Furnas Formation with a slight (1º) SW dip; below, steeper dipping reddish siltstones and sandstones of the Camarinha Formation, locally with a basal conglomerate. The Camarinha Formation is interpreted as a mollase deposits of the Brasiliano orogenic cycle (700-500 My) and has been dated as late Proterozoic-Early Paleozoic (Fragoso Cesar et al., 1985).(Fig.12.)
3.4	42.4	STOP 1. Furnas Formation. This is an stop is to see abundant and well preserved trace fossils on an extensively exposed bedding plane of the Furnas sandstones, on the right side of road. The Furnas Formation is a sequence, up to 340 m thick, of whiteish/purplish, medium to coarse grained, moderately sorted sandstones with a kaolinitic matrix, interbedded with buth thin conglomerates and micaceous fine sandstones and silty shales. Lenses of conglomeratic of subrounded to rounded quartz and quartzite claste (5-20 cm in size), in a sandy-clayey matrix, are intercalated in the sandstones. Rounded clasts of quartz may also occur at the base of cross strata. The environment of deposition, as well as the stratigraphic relationships with the marine Ponta Grossa shales, is still a matter of some debate. Trough cross-bedding associated with clay-pebbles is predominant over planar and plane-parallel cross-bedding, particularly in the basal part of the unit; this structure, together with the existence

of kaolinite matrix are evidences mentioned by Schneider et al., 1974 in favour of a fluvial origin for this largely unfossiliferous sandstone. Other arguments point to a shallow marine environment, dominated by strong currenty, such as the low percentage of fine particles, the possible transitional stratigraphic relationships with the marine Ponta Grossa shales, and the extensive erosion plain on which the deposits rest (Bigarella & Salamuni, 1967a; Petri & Fulfaro, 1976). Additional sedimentological and paleontological evidence for a shallow marine environment for the Furnas Fmt. is reported by Ciguel (Personal communication) who identified a sequence of mutually truncating sigmoidal structures in sandstones, on top of which a diversified ichnofauna was found. Ciguel (in preparation) recognized the ichnogenera: *Didymaulichnus* (= *Fraena*), *Palaeophycus* and *Rusophycus*. The latter is a cosmopolitan trace fossil, found in Cambro-Devonian sediments and interpreted as a tribolite resting mark. The Furna Fmt. is found almost everywhere in the Paraná Basin below the Ponta Grossa Formation, which carries a rich marine fauna of brachiopods and other marine invertebrates with Malvinokafric affinities (Clarke, 1913; Lange & Petri, 1967; Popp, 1986 ; Mello, 1986). The Ponta Grossa shales have been paleontologically dated on the basis of chitinozoans and of spores as of Emsian-Frasnian age (Devonian). The contact between the two units is interpreted either as disconformable (Zalán et al., 1987) or transitional (Lange & Petri, 1967). Therefore, the age of the Furnas is differently interpreted as either the same as that of the basal Ponta Grossa (Emsian) or as slightly older (Pre-Early Devonian) (See, for instance, Zalán et al. 1987).

3.4 45.8 Entrance of Tamandaré at left. Optional stop to see striated ("fluted") sandstone of the Itararé Subgroup. Itararé sediments in the area correspond to the lower Campo do Tenente Formation. From the last point to here outcrops of the Furnas sandstone and of the disconformably overlying Itararé Subgroup can be observed. Striated surfaces of two ages related two successive advances of ice in this part of the Paraná Basin have been recognized by Fuck et al. (1967), Fuck & Bigarella (1967) and Bigarella et al. (1967) during detailed geological mapping in this area. Sandstone of the present locality is interpreted as "periglacial" sediments of the first "glaciation" (Rio do Salto) representing the first glacial advance in the area. We will return to this topic later when discussing the striated surface at wittmarsun.

1.6	47.4	Exit to BR-277 on the left. We have passed by sediments of the Itararé Subgroup on the road side.
3.3	49.7	Cross-bedded Furnas sandstone.
3.4	54.1	The characteristic landscape of the rolling hills of the so called "Campos Gerais" of Paraná State, a grass land developed mostly on top of the Furnas sandstone, on the 2nd Plateau may be observed.
	65.4	STOP 2. Entrance to Colônia Witmarsun at left. Striated pavement on the Furnas sandstone. Drive some 8 km on secondary road towards the main building of the Cooperativa to examine the striated pavement. The feature, now partially covered by road fill is still beautfully exposed (Bigarella et al., 1967). (Figs. 13-14). As mentioned before glacial striae have been recorded in many localities of this area, in the Quero Quero, Contendas, Campo Largo and Porto Amazonas. Striated outcrops (some 22) with a total area of 2,500 km,developed on the Furnas sandstone and on sandstones of the Itararé Subgroup have been mapped. On stratigraphic basis Bigarella et al. (1967) recognized two different erosion surfaces. The older one, cropping out in the Rio do Salto valley, is preserved on the Furnas sandstone and assigned to a first advance of the ice in the area, associated with the "Rio do Salto glaciation" A second and younger group of striae was formed both on the Furnas sediments, as well as on the overlying sandstones interpreted as "periglacial" sediments of the Rio do Salto glaciation, is related to a second glacial advance, the "Cancela glaciation". This is mostly based on the fact that the diamictite which rest on top of the abraded surface was formed as stratigraphically younger than the glacigenic sediments assigned to the Rio do Salto advance. Striae at Witmarsun and in all other localities in this general area are

strikingly parallel. They consist generally of alternating grooves and crests of variable dimentions and distances between crests. No other type of structure have been yet found associated with the striae. Average direction of the striae is N2°W, but no direct evidence of sense of movement of ice can be interpreted from the pavements. Fabric studies of diamictites performed by Bigarella et al. (1967) furnished the following results: a) striations: N2°W; b) clast long axis direction: N38W; c) clast long axis dip direction S20°E; the deduced sense of ice movement was N20°W. One interested result reported was that the sense of ice movement deduced from fabric study (dip of clast long axis) was opposite to that obtained from paleocurrent study of cross-bedded sandstone. Bigarella et al. (1967) considered the diamictite as a true tillite or "ground moraine" mostly on the basis of its sedimentological properties, lack of stratification, fabric and position on top of the pavement. Section overlying the pavement is not well exposed on the flanks of the hill, but show alternating decimetric beds of silty-clayey diamictite and of stratified or massive, medium sandstone. Limonitization is extensive. Sesimentological features of the sandstone are similar to that of the underlying Furnas basement (and have been taken as Furnas by some). A "ground moraine" (basal till) origin for the diamictite seems thus less probable. Extension of the area covered by the glacial striae and features in the basal part of the Itararé (Campo do Tenente Formation), however, speaks in favour of a glacial terrestrial environment. Form the striae locality will well return to BR-376. Turn left on the highway and proceed northwestwards.

14.2	73.6	Bridge over canyon of the Tibagi River cut into the Furnas sandstone. From the last point the highway runs mostly on the Furnas sandstone and scattered areas of Itararé Subgroup sediments.
1.0	74.6	Contact between the Furnas Formation and Itararé Subgroup. This is an optional stop. In the lower part of the road cut, on the right side of the highway, the Furnas sandstone shows both through cross-bedding and plane-parallel stratification and ripple-drift cross-lamination. The overlying section is apparently made up of two (?) diamictite horizons both grossly stratified, with clasts with long axes

		oriented more or less parallel to bedding, overlain by coarse conglomeratic, poorly stratified sandstone. Flow tillites.
9.0	83.6	Weathered Ponta Grossa Formation shales.
08.	84.4	From this point one may start to see the Vila Velha sandstone, a member of the basal Itararé Formation, with its typical ruinform morphology.
3.6	88.0	STOP 3. Vila Velha sandstone. Entrance to the Vila Velha state park on the right side of road. A short stop will be made here for cursory examination of the Vila Velha sandstone and some relaxing walk. The Vila Velha sandstone is an extensive mappable, lobate deposit, about 190 m thick (Fuck & Bigarella, 1967) overlying basal diamictites and rhythmite of the Itararé Subgroup (Campo do Tenete Formation), but also transgressing over the Furnas and Ponta Grossa Formations. In the park area the sandstone shows beautiful examples of residual weathering features basically controlled by joints. The sandstone is predominantly medium to coarse grained, poorly sorted and conglomeratic, but may include thick intercalations of laminated sandy siltstone, which is also pebbly. The origin of this member of the Itararé is not completely understood in great part due to the lack of recent detailed research. Though outcrops within the main area of the park show only poorly developed plane-parallel, more or less discontinuous bedding, medium-scale trough-cross bedding and lamination in fine-grained interbeds have been described elsewhere in the Vila Velha park area. The sandstone thus has been at least in part deposited subaqueouslly by currents. A "sand-flow" mechanism for deposition on this body in a large outwash plain has been proposed by Bigarella & Salamuni (1967 a,b).

<u>2nd Day</u>: Curitiba - Rio Negro - Mafra - Itaiopolis (via BR 116).

The route to be followed will serve as a general introduction to the stratigraphy and main characteristics of diamictites of the Itararé Subgroup of southern Paraná and northern Santa Catarina, and includes examination of the type sections for two of the formations of the Subgroup (Campo do Tenente and Mafra Fmts.)

The road runs more or less normal of the outcrop band (and to the depositional strike?) of the Itararé Subgroup in the area south from the Ponta Grossa Arch (Fig. 7), (Fig. 15) is a generalizes stratigraphic section measured along BR-116 and demonstrates the gross arrangement of the main exposed sediment types. Notes for this part of the trip, as well for the sections to be examined in the next to days have been based mostly on Canuto (1985).

Diamictites and associated sediments along this section seem to involve a variety of facies interpreted as representing glacial-terrestrial (or grounded-glacier) and glacial-marine sedimentation (Canuto, 1985). Both megascopically massive to faint bedded and stratified diamictites will be examined, related to these environments. Massive and compact diamictite cropping out usually as discontinuous bodies, plastered against the smooth crystalline basement (Fig. 16) or sandstone bodies of Itararé Subgroup (Fig. 20) are interpreted as lodgement tillites. Other types of diamictites that may represent deposits formed at the sole of active glacier (basal tillite) are more extensive (tabular?) bodies resting on erosional smooth surfaces, on top of faulted/folded sediments (shearing?) (Fig. 21) reccur at several horizons in the Campo do Tenente, Mafra and Rio do Sul Fmts. and may indicate multiple glacier advances.

Diamictite and other rocks assigned to a glacial-marine origin tend to form regionally extensive thick mappable bodies in the Mafra Formation (Canuto, 1985), that include massive to faintly stratified tabular bodies, fossiliferous shale/siltstones/fine sandstone, and varvites with rafted clasts. These are mostly circunscribed to a sub-basin in the Rio Negro-Mafra area (Fig. 9).

Other interesting features found along the section are deformations as folds in fine sediments, found between horizontal strata, that have been differently interpreted as load structures, convolution or cryoturbation (glacial involutions) (Canuto, 1985). (Fig. 22) At the top of the section, facies associated with the passage from the diamictite bearing sequence to the fluvial-deltaic Rio Bonito Formation will be examined.

In general terms, the Campo do Tenete sediments are considered as glacial-terrestrial, the Mafra Formation predominantly glacial-marine, while both glacial-marine and terrestrial grounded-glacier facies characterize the Rio do Sul Formation.

On the basis of recognition of basal tillites, some associated with an abraded or sheared substratum, 6-7 glacier advances were inferred in this part of the Paraná Basin by Canuto (1985). The marine nature of some of these is paleontologically documented by the presence of arenaceous forams, brachiopods, mollusks, etc. in siltstones and shales closely associate with the diamictites.

Direction of movement of ice, as deduced from striae on the basement and on Itararé sediments was roughly N-S or WNW-SSE thus consistent with that of the striae on the Devonian basement of the Witmarsum area. Evidence for sense of movement has not been found. This regional trend of the area South of the Ponta Grossa Arch is paleogeographically associated with the location of the Paraná glacial lobe (Frakes & Crowell, 1972); Santos, 1988). The direction is also roughly coincident with that of small elongated depressions depicted in the isopach maps of the Campo do Tenente Formation (Fig. 8) that may correspond to pre-glacial depressions or valleys modified by the ice (Gravenor & Rocha-Campos, 1983).

The stratigraphy of the Itararé beds in the area is characterized by the inclusion of several regionally extensive strata, some of them forming mappable units or key or marker beds. This, so to speak, more organized "layered-cake" type of stratigraphy contrasts with the generally complex lithostratigraphic arrangement that characterizes the Itararé elsewhere beds, and seems to correspond to a particular geologic setting of the Rio Negro area. As noticed by Canuto (1985), these features plus the higher incidence of marine or subaquatic deposits beds, the ubiquitious evidence of ressedimented glaciogenic materials, etc., speakes in favor of a sizeable body of water in an embayment or gulf-like deeper area occupying this part of the basin, corresponding to the thicker Mafra Formation shown in the isopach map of Fig. 9.

Interval (km)	Distance (km)	
0	112.0	Departure point is in front of hotel in Curitiba (= km 112 of BR-116). We will leave the hotel in downtown Curitiba and drive SE to Highway BR-116. Turn right at intersection and proceed SW on the road.
62.0	174.0	STOP 1. Contact between the Itararé Subgroup (Campo do Tenente Formation) and Precambrian basement. From Curitiba until this point the highway crosses again sediments of the Curitiba Basin and Precambrian rocks of the Ribeira Fold Belt. At this point we enter into the Paraná Basin. Small ridges and valleys carved in Precambrian schist filled and overlain by medium to coarse-grained conglomeratic sandstone and diamictites are seen on the right cut. Polished and finely striated basement surfaces on sides of valleys are directly overlain by very compact thin, discontinuous diamictite (lodgement tillite), coarsely stratified conglomeratic sandstone (fluvio-glacial) and massive, but less compact diamictite (basal tillite?) with

		abundant faceted and striated clasts; conglomeratic sandstone lenses are present. The sequence represents deposits of the (first?) advance of ice in the area (Fig. 16).
2.0	176,0 - 177,0	The ridge seen at a distance (1.5 km) on the right side of the road is formed by the Lapa sandstone, a linear discontinuous body of fluviatile sandstone which is interpreted as part of the Mafra Formation, but mostly included in the Campo do Tenente Formation. The sandstone will be more closely observed near the town of Lapa, on Day 2 (Fig. 25).
2.0	178.0	STOP 2. Massive diamictite (Campo do Tenente Formation. Silty-sandy diamictite, mostly massive, with clasts rare to common, up to 30 cm in diameter, overlying a bed of shale with centimeter sized dropstones. Contact between the two units is sharp with the surface smooth ("polished") with faint lineations oriented N130°. Slabs of diamictite are circumscribed by shale along the contact (shearing?). The diamictite is interpreted as a basal tillite and may document a second ice advance in the area.
6.0	184.0	STOP 3. Massive diamictite (Campo do Tenente Formation. The outcrop is again of a massive, silty-sandy diamictite in sharp contact with shales, but some 40-50 m above the last locality (Stop 2). The contact surface is also smooth and undulating, but bears no clear lineation. The diamictite may be an upper basal tillite, in this case representing a readvance of the ice in the area.
1.0	185	Exit to Campo do Tenente at right.
3.0	188,0	Flow-diamictite and fluviatile sandstone (Mafra Formation). Bands of stratified, light gray-yellowish, sandy diamictite with small centimeter sized clasts oriented parallel to bedding, interbedded and mixed with fine-medium sandstone, deformed (contorted), showing recumbent folds and slump faults, on the NE face of the cut. Irregularly stratified sandstone predominates in the upper part of the outcrop and along the two parallel road cuts. Sandstones exhibits medium-scale, trough and tabular cross-bedding, ripple-marks and irregular strati-

fication, all deformed. The outcrop is a good example of flow-tillite (glaciogenic subaqueous debris flow), which seems to characterize the Mafra Formation, as it can be observed on the next several road cuts. No marine beds have been found in this part of the Mafra Fmt that seems to represent a fluvio-glacial sequence.

3.5 191.5 STOP 5. Massive basal below stratified flow tillite. Outcrop on the left (SE) side of the road shows two superposed diamictites. The lower one is massive to sandy, compact, faintly stratified and includes horizontal streaks, thin lenses and bands of clasts, silt, and sand undulating, apparently sheared and displaced by intraformational faults. The upper body is sandy-silty, stratified into cm-dm, irregular and discontinuous beds. Concave upward surfaces cutting the bedding may be slump faults. Clasts (up to decimeter in size) are rare-common and some have been found with longer axes normal to bedding (dropstones?). Contact between the two diamictites is sharp and undulating (loading?). Lower diamictite may correspond to a basal tillite overlain by flow tillite.

5.5 197.0 STOP 6. Stratified flow-tillite. This excellent section displays a lower diamictite (about 4 m thick), silty-clayey, crudely bedded as a result of the intercalation of thin sandstone layers, with clasts rare to common, many of sedimentary rocks, passing upwards to alternating laminae of diamictite, siltstone and shale. The diamictite is overlain, with sharp contact, by a coarse sandstone (2-3 m thick, with conglomerate and siltstone interbeds. The top of the sandstone is plane and bears parallel striae and furrows oriented N145°(Mg). It is overlain by a rhythmite of silty-clayey diamictite and shale, and by laminated clast-laden diamictite bearing abundant shale clasts, many oriented parallel to bedding (exposed thickness is about 4.5 m). Features of lower and upper diamictite suggest that they may have been deposited by a combination of debris and "slurry" flow. Parallelism, persistence and dimensions of the striae and furrows on top of the sandstone suggest their origin by glacial erosion.

If so, they may be associated with a later episode of ice-advance in the area.

6.0 203.0 Exit to Rio Negro.

0.8 203.8 STOP 7. Glacial marine deposits, Pedreira (quarry) da Prefeitura, Rio Negro. Enter at right and proceed some 1.1 km SW to quarry. This will be a longer stop for examination of a series of excellent outcrops of mid Mafra Formation beds exposed at a local quarry. A composite section of the sedimentary sequence exposed in the quarry and adjoining areas is shown on Fig.18. A geological sketch map of the Rio Negro-Mafra area is shown on Fig.17. (Salamuni et al. 1964). The lowermost sediments exposed are two beds to dark silty-clayey diamictite, about 80 cm thick, overlaying dark mudstone/shale bearing centimeter sized clasts. Diamicties show crude bedding marked by horizontal alignment of small clasts of shape (rip up?) diamictite, as well as of crystalline rocks up to 15 cm in diameter. They may also contain infilled animal burrows normal to and parallel to bedding. The upper diamictite bed is followed by interbedded diamictite and shale, with a sharp boundary below the upper shales. This surface represents a sedimentary hiatus marked by abundant animal trails and contain several emerging clasts. Shales with rare lonestones about 2 m thick, above this boundary grade upwards to typical thin varvites with abundant dropstones, up to 40 cm in diameter. Continuation of this section may be seen on the main quarry face, a few hundred meters away from the first locality, where some 25 m of varvites, with dropstones up to 2 m in diameter, overlie the dark shale. Along a lateral trail climbing up the hill from the first locality, the varvite section is seen to be overlain by mudstone (60 cm), and laminated and deformed fine sandstone (1.5 m). The uppermost Itararé unit exposed in the area is a thick section (over 30 m) of mostly massive diamictite, with an intercalation of laminated sandstone and siltstone at the base of bearing faing evidence of bedding higher up. This unit, as well as the lower varvite, seem to form extensive tabular bodies in the Rio Negro - Mafra area. Elsewhere, some 2.5 km north from Rio Negro, they are overlain by the thick massive siltstone with marine fossils and fine sandstone (Fig. 18). Intercalation with shale beds, superposition by thick varvite and the presence of fossils indicate a subaqueous environment for the lower diamictites in the quarry section. On the basis of their sharp boundaries, textural homogeneity, possible polymodal size distribution and poor clast alignment, they have been interpreted as debris flows. The upper thick diamictite shows, at least in part, the same set of features and may correspond also to a widespread debris flow. Influx of glacial meltwaters in a depositional sub-basin has been postulated to account for the presence of the thick varvite section of the quarry. A detailed study of the Rio Negro rhythmites was performed by Rocha-Campos et al. (1981) 601 couplets have been counted and measured along the quarry face. The represent, however, roughly a third of the section exposed and the total number of couplets may be at least 3 times larger. Couplets in this locality are very thin, varying from 2 to a maximum of 52 mm. No general trend of variation could be established by visual inspection and, except for the intercalation of a few exceptionally thicker pairs, the maximum and minimum thicknesses seem to remain about the same along the examined section. Granulometrically, all the couplets seem to be made up mostly of silt (lighter bands) and clay (darker bands). Except for the plane parallel bedding very few other sedimentary structures could be identified in the rhythmite. Microclasts of different lithologies, pellets of sandstone and diamictite (iceberg dump?) and very thin partings of clay and sand are widespread inside the couplets. Rafted clasts up to 2m in diameter are relatively frequent within the rhythmite. Marine influence during the deposition of the Itararé sediments of the Rio Negro area is indicated by at least two intercalations of shales containing marine fossils (Salamuni et al., 1965). Non-varved dark-gray shale bearing isolated clasts probably rafted immediately below and in transitional (?) contact with the rhythmite at the quarry yielded poorly preserved marine microplankton; elsewhere in the Rio Negro area a marine shale was found to occur intercalated within a rhythmite stratigraphicaly higher in the section (Salamuni et al., 1965). Marine fossils though have not been recorded in the rhythmite. A glacial marine origin for the diamictites and associated sediments of the Rio Negro area is thus likely. The occurrence of numerous contorted and disrupted beds and flow structures in the diamictites of the area is consistent with this interpretation. Since experimental and geological evidence indicates that formation of typical clastic varves is normally restricted to fresh water conditions, due to the flocculating effect of salt, under marine conditions, occurrence of varve intervals within a marine sequence would thus be possible only during periodically drastic reductions of salinity in the marine water body, a situation that might theoretically occur in the proximity of a glacier front sporadically discharging large volumes of melt water near the coast (Carey & Ahmad, 1961). Such an environmental picture is envisaged to explain the formation of the Rio Negro rhythmites. The relatively frequent occurrence of rafted clasts indicates that floating ice was present in the basin of deposition. Parts of the Rio Negro rhythmite (160 pairs), sequence have also been sampled for paleomagnetic analysis (Rocha-Campos et al., 1981). Paleomagnetic data is summarized in the right column of Fig.19 where magnetic inclination and declination are represented for each couplet in the sequence sampled. For comparison, data on thickness of the couplets are also shown. Tables I and II summarize results of application of maximum entropy technique to paleomagnetic and thickness data. A good agreement of periods was found both in the thickness and paleomagnetic spectra what may indicate seasonal-nature of the rhythmite, since close correspondence would be improbable if each pair would represent a variable member of years. Another set data shown in the Tables refer to results of sunspot number spectrum that are also consistant with the thickness and paleomagnetic spectra. After visit to the quarry, we will enter the town of Rio Negro where lunch will be taken. We will then return to BR-116 and proceed SW.

2.4 205.4 Bridge over the Rio Negro. Paraná and Santa Catarina border. Distances will now be counted from the bridge.

0.3 0.3 STOP 8. Marine shale of the Mafra Formation. Silty shale, dark-gray with thin (cm) intercalations of diamictite. Bedding planes of this rock are full of arenaceous forams (*Ammodiscus*, *Hiperammina*). These beds have been informally called "Mafra beds". A little before towards the bridge, along the flank of the hill to the hight of the road, the shale is found to overlie, with sharp contact, a sequence made up of a thick (over 20 m) lower massive diamictite correlatable with the upper one at the quarry, bearing deformed sandstone/diamictite masses, passing upwards to superposed, mutually truncating lobes of pebbly-sandstone/diamictite, some showing basal concentration of clasts, deformed sandstone interbeds, recumbent folds and faults. Features of the diamictite here are indicative of its deposition through mass-gravity flow. It shows a gradation from more to less viscous flow including some channelization.

3.7 4.0 STOP 9. (optional). Flow tillite with deformed sandstone intercalations overlying ridge of sandstone. The lower ridge of compact, fine to medium sandstone with plane-parallel bedding and ripple-drift cross lamination is overlain by stratified-laminated diamictite interbbeded with deformed and disrupted sandstone masses, at places complexely mixed, both in turn truncated by inclined beds of chaotic conglomeratic sandstone and fine stratified sandstone better seen of the left side of the road (Fig. 20). On the southern flanck of the left cut (Canuto, 1985) identified a wedge-shaped body of massive and compact sandy diamictite plastered again not the sandstone. The contact surface between the two rocks is smooth (polished?) and the lower sandstone is deformed folded and faulted near its top (shearing?). This is a relatively complex outcrop whose detailed interpretation is not entirely clear. Canuto (1985) compared the features of the sandstone ridge and the associated sediments with those of Quaternary subaqueous outwash formed by melt water confined in subglacial tunnel debouching at ice front within a water body (e.g. Rust & Romanelli, 1975). The shape of the sandstone ridge could have been modified by active ice as indicated by the lower diamictite apparently compacted against the ridge (lodgement tillite?), internal deformation and "polishing" at the top. According to this scheme the overlying diamictite, could represented a subaqueous-flow of glacigenic sediments possibly associated with retreat of ice.

0.4 4.4 Exit to Mafra at hight.

1.6 6.6 Marine siltstones at Vila Nova. These are basal beds of the Rio do Sul Formation, the uppermost unit of the Itararé Subgroup. The strata are correlated with the Lontras beds near Rio do Sul. Santa Catarina (some 120 km) S and to the Guaraúna shale of southern and central Paraná.

5.0 9.4 STOP 10. Basal tillite on sandstone. A road cut on the right-hand side shows fine, yellowish sandstone, very compact, forming a boss or round topped ridge, being overlain with erosional contact by massive diamictite, which is in turn truncated by a large channel-form sandstone body. The lower sandstone shows internal deformation in the form of folds and faults. These may separate slabs of sandstone and diamictite along the contact. The top of the sandstone boss is smooth and bears faint lineation trending NS. Canuto (1985) interprets the features above as indicating that the diamictite may have been deposited under an active glacier as basal till, associated with the shearing and abrasion along the contact with the local sedimentary basement (ice advance?). Evidence of some mass movement after deposition on the diamictite is shown by the deformed mass of sandstone included in it (Fig. 21). The channel-like sandstone in erosional contact with the diamictite is probably fluvio-glacial.

11.5 Fine, stratified, reddish sandstone in sharp contact below silty-clayey diamictite, with rare clasts up to 40 cm in diameter. Numerous small, low angle reverse faults in the sandstone and along the contact, and slabs of sandstone circumscribed by diamictite suggest shearing. As in the other cases, this type of massive diamictite is interpreted as a basal tillite documenting a recurrence of glaciation. The lower sandstone may correlate with the upper unit in the next outcrop.

12.0 STOP 11 (Optional). Confortions in fine sandstone (exit to Canoinhas at right). On the left side of the road, a bed of fine-clayey sandstone mixed with clay, is intensively contorted, fragmented and cut by numerous faults (mostly high angle or vertical normal). The unit is overlain by non-deformed, thick stratified fine sandstone. Zone of separating of the two beds in marked by a decimeter band of intensely jointed sandy layer (soil?). Geometry of the folds and apparent upward trend of the material involved in the movement is reminiscent of glacial involution (cryoturbation) of periglacial sediments or convolutions (Fig. 22 e 23).

126 STOP 12 (optional). Several outcrops of a sequence of fine to medium sandstone beds, cross-bedded, overlain by a mostly massive, silty diamictite, in parts showing subparallel faint foliation, with centimeter to decimeter clasts, some with long axes parallel to bedding. The boundary between the two units is sharp, with the upper part of the sandstone cut by several low angle faults and folded (shearing?). The diamictite may change laterally (and vertically) to faintly bedded, due to inclusions of streaks of microclasts, or discontinuous (sheared) thin beds of sandstone or conglomerate, being truncated by channel-like, cross-bedded sandstone. This is again another possible and probably the uppermost basal tillite of the Rio do Sul Formation overlying fluvial-glacial sediments.

From this point excursion returns to Curitiba for overnight stop.

3rd Day: Curitiba - km 102 of BR-476, via Lapa.

Outcrops along this road demonstrate some variation of facies within the three formations of the Itararé Subgroup. Most information for this section derives from Canuto (1985). (Fig. 24.)

Lodgement or basal tillites similar to the ones examined along road BR-116 have not been clearly identified yet. Most of the diamictites cropping out along the section, though at a first view apparently massive, may exhibit faint stratification due to inclusion of laminae or zones of silt/sand, alignment of small or large clasts, sometimes forming discontinuous boulder pavements. They may also display discontinuous deformed beds, laterally disrupted and balls, "hooks" and complexly folded sandstone bodies and dykes. Though some of the above units may resemble basal tillites, the nature of their lower contact could not be always examined. There is only one instance where a massive diamictite was clearly found to rest in sharp contact over folded and faulted (sheared?) shale.

Massive diamictites may pass upwards, abruptly or gradationally, to stratified ones. In the first case, the diamictite may show even and thin beds or laminae, undulating to folded, cut by slump and normal faults and enveloping long lenses of massive diamictites. They are interpreted as a type of flow tillite, which may be overlain by sandstone and varvite. The second case involves upwards grading to grossly stratified beds marked by stringers of silt/shale, clast-laden rhythmite of diamictite/shale and varvites with dropstones attributed to "slurry" and turbidity flows in a subaqueous environment.

In addition to those included in the diamictites, other larger sand bodies associated with the diamictites may be examined along this section. They may form channel-form deposits cutting down into diamictites and other lithologies, or in other cases forming slumped (contorted, disrupted and faulted) masses. The already-mentioned Lapa sandstone, beautifully exposed along the road and in the vicinity of Lapa, is a long, sinuous though discontinuous relatively thick body of cross-bedded, fluviatile sandstone stratigraphically correlated with the Mafra Formation, but which cuts down into diamictites of the underlying Campo do Tenente Formation (Fig. 25). Another large body, also of probable fluviatile origin, occurs higher up in the section, in erosional contact with diamictites of the Mafra Formation. Slump structures, rolled up masses of sandstone intermixed with diamictites and drag-lineation are commonly seen at the base of the thick cross-bedded sandstone and denotates loading.

As in the case of the section along BR-116 a terrestrial environment seems likely for the Campo do Tenente and great part of the Mafra Formation.

The upper part of the section (upper Mafra, and Rio do Sul Formation) is marked by the frequent occurrence of shale beds, including a thick intercalation of marine shale ("Guaraúna shale") which is taken as the base of the Rio do Sul Formation and correlative with the marine beds in the Mafra - Rio Negro area.

0 0 Departure point (Curitiba). From downtown Curitiba drive south to Avenida Estrutural Sul to highway BR-476 SW. Up to the first observation point the road runs on Curitiba Basin sediments and Precambrian rocks.

62.0 62.0 Lapa sandstone. Outcrops of thick bedded, fine to medium grained sandstone appear on road cut, on left side of road. Better exposures, however, may be seen along secondary road on left side of road, some 200 m to NE from this point. The Lapa sandstone forms a long, discontinuous and sinuous, rougly SE-NW and N-S trending ridge with width of up to 2 km and up to 60 km of length (Fig.25), extending from the Precambrian basement in the SE, NW towards Vila Velha. In this area the ridge-like body disappears having been either eroded or concealed under younger sediments (Medeiros, 1971). Alternatively, the Vila Velha sandstone, which is a lobate deposit at the base of the Itararé Subgroup, may represent the northern extension of the Lapa. The sandstone with a basal conglomerate, is a channel-like body in erosional contact on diamictite of the Campo do Tenente Formation. The sandstone body has been mapped as part of the Mafra Formation to the southeast of BR-116; from there the channel cuts down into sucessively older beds towards NW. The sandstone exhibits trough cross-bedding and conglomeratic zones with clay pebbles. Parting lineation and cross-bedding measurements show currents flowing roughly parallel with the channel axes (SE-NW) and also with the glacial striae on the basement. Characteristics of the Lapa are thus of a fluviatile (fluvio-glacial) body, probably associated with a phase of stagnation of retreat of ice in the area.

25

62.5 Exit to Lapa at left.

1.5 63.5 STOP 2. "Laminated" tillite (flow tillite?). Excellent exposure of stratified diamictite of the Campo do Tenente Formation along the left and right cuts of the road, immediately after the railroad bridge. The outcrops show zones of massive diamictite near the base overlain by finely "laminated" diamictite. Laminae are undulating or folded, and cut by slump fault and inclined and vertical normal faults, an bend around elongated elliptical zones of massive diamictite or of sandstone balls. Stratification is shown by more or less regularly distributed discontinuities (joints) not clearly associated with any textural variation. Clasts in the diamictite are relatively small and many occur with their longest axes parallel to bedding. The diamictite grades upwards to shale, which is in turn overlain, with erosional contact, by sandstone and rhythmite. Nature of stratification is not entirely clear. A post-depositional origin through sheeting, for instance, does note seem probable in view of the pattern of distribution of the structures and their confinement to the diamictite bed. An origin associated through flow was pointed out by Canuto (1985). He considered the lower massive diamictite as a basal tillite, overlain by the flowed diamictite (supra-glacial) and partially reworked by it, during a stagnant or retreat phase, that involved also the formation of a small lake where the rhythmite accumulated (Fig. 26).

2.0 65.5 STOP 3. Massive to stratified diamictite at the DER quarry. Take entrance of quarry area at right, proceed some 400 m to near the quarry face. Stratigraphically, the glaciogenic sediments exposed in the quarry correspond to the middle part of the Campo do Tenente Formation (Fig. 27) The lower ten meters of the section are composed of massive, highly indurated, diamictite which is used for road metal. The upper metre or so of the massive diamictite contains stringers of sandstone and siltstone which appear to have been sheared and slightly contorted during post-depositional movement. These stringers of sorted materials impart a crude lamination to the otherwise megascopically structureless diamictite. This poorly laminated zone may represent a transition zone between the lower massive diamictite and the overlying stratified sediments. The sediments overlying the massive diamictite are composed of laminated diamictites interbedded with rhythmites, all of which contain numerous intrabasinal clasts and a few extrabasinal clasts. A thin section of the thinly-bedded clast-rich rhythmites shows that most of the clasts are angular and composed of intrabasinal material. The fine matrix in the rhythmites appears to flow around the larger fragments and there is a fining upward within each rhythmite towards a very thin clay band which separates one rhythmite from the next. But there are thin layers of silt within each unit which are similar in some respects to storm lamination or microturbidites in varves. Most of the long axes of the clasts are parallel to the bedding planes but there are a few which have their long axes inclined to the bedding planes. The small intrabasinal clasts do not deform or pierce the bedding planes but the bedding planes are disrupted and pierced by large extrabasinal clasts which are dropstones. The clasts in the more massive but still faintly laminated diamictites found within the thin clast-laden varvites also have their long axes parallel to the bedding planes. Most of the clasts are composed of intrabasinal mudstone, siltstone and fine sandstone which were contorted and stretched out during movement and compaction. The above evidence suggests that the clast-laden rhythmites and interbedded more massive, poorly laminated, diamictites represent the product of turbidity currents which ripped up the soft underlying sediments and had a sufficient density to support the clasts during transport. During periods of quiescence, clay was deposited to give a resultant varve appearance. These laminated sediments are probably varvites in the sense that they may be annual deposits and the clay layer was deposited when the water body was ice-covered. The thicker faintly laminated diamictites probably represent periods of greater influx of material into the basin and the bedding was disturbed by the large number of intrabasinal ripped-up clasts being carried within each flow. The sediments that overly the clast-laden varvites of the Lapa quarry are varvites composed of couplets of silt and clay with occasional dropstones. The stratigraphic position of those varvites and the obsence of associated marine beds in this part of the Itararé section suggest that the clast-laden varvites, poorly laminated diamictites and varvites found above the massive diamictite may have been deposited in a lake (Canuto, 1985; Gravenor & Rocha-Campos, 1983). The section would represent an advance and retreat of ice-sheet into a water filled basin. Results of paleomagnetic analysis of samples of the basal massive diamictite of the Lapa quarry suggested that the original diamicton underwent syn-or porst-depositional deformation, which also is indicated by the contorted inclusions of sediments (Gravenor & Von Brunn, 1987).

From the quarry we will return to Lapa for lunch.

9.7 75.2 STOP 4. Fluviatile sandstone of the Mafra Formation. A large body of fluviatile sandstone in erosional contact on Mafra Formation diamictite. On the map the sandstone is less linear in shape, though also roughly oriented

SE-NW as the Lapa. The body is about 30 km in length and 10 km wide, with an estimated thickness of at least 90 m. Its internal features may be observed on the large area quarried on the left side of road. The sandstone is medium to coarse grained, conglomeratic, quartz-feldspathic, includes clasts of underlying diamictite and shale, and has predominantly planar plus trough cross-bedding and ripple-marks. Paleocurrent orientation is roughly SE-NW and parallel to axes of the body. Contact between the sandstone and underlying diamictite may be seen on road cuts, a few hundred meters north from this locality. The erosional contact zone is marked by intermixing of complexely folded, cigar-shaped bodies of sandstone and diamictite showing numerous drag-lineations probably associated with loading of the large sandstone body on a soft substratum of diamictite. As in the case of the Lapa sandstone the characteristics of the body point to a fluviatile (fluvio-glacial) origin.

22.1 97.3 STOP 5. Marine shale of the Rio do Sul Formation. Thick section of dark silty shale with, plane-parallel lamination, bearing concretions, which is taken as the basal part of the Rio do Sul Formation (Guaraúna shale). The unit seems to form an extensive body correlative with similar shales in the Mafra - Rio Negro area. Arenaceous forams have been recovered from these rocks. Shale intercalations become more frequent in the upper part of the Mafra Formation, but particularly in the Rio do Sul, thus denotating a predominant subaquatic/marine environment.

0.7 100.0 STOP 6. Several outcrops of megascopically massive, silty-clay diamictite of the Rio do Sul Formation exposed in abandoned quarries on the left side of road. The diamictites form a relatively thick (over 15 m) and extensive, apparently structureless unit, buth which occasionally shows crude bedding, marked by thin laminae (streaks) of silt/sand. At some places elongated or spherical bodies of sandstone occur sunk into the diamictite; clasts (up to 20 cm) are relatively rare to common and may form discontinuous horizontal layers or "pavements". Characteristics of the diamictites are remindful of the basal massive body examined at the Lapa quarry.

Return to Curitiba from this point for overnight stop.

4th Day: Curitiba - Palmeira - Rio da Areia (via BR-277)

Similarly to the section along BR-476, diamictites are commonly faintly to clearly stratified, through either the intercalation of beds/laminae and/or elongated lenses or streaks of sandstone/siltstone, or else by vertical textural variation. Sandstone intercalations are commonly disrupted and folded (recumbent, "hooks"). Clasts are rare to common and typically have their long axes parallel to bedding. Other bodies of diamictite are apparently more massive, but contain balls or irregular, laterally disrupted masses of sandstone. Evidence of mass-gravity flow is thus ubiquitous and some of these flow tillites may be associated with complexely folded sandstones.

Lodgement tillites of the type examined along BR-116 have not been identified in this area. Some of the massive diamictites form relatively extensive tabular bodies and may correspond to basal tillites, though the nature of their lower contact could not be examined anywhere. One of these was found in lateral contact with a ridge of conglomerate sandstone which is possibly a type of fluvio-glacial deposit being overlain by stratified diamictite similar to the flow-tillite described at Stop 2 near Lapa. This bed is in turn locally overlain by shale and sandstone. The uppermost dark marine shale of the Itararé Subgroup Passinho shale) related to a post-glacial transgression will be examined at the end of section disconformably below cross-bedded fluviatile sandstones of the Rio Bonito Formation, with thin coal beds.

Distances along this road are marked from its initial point in Paranaguá, some 84 km E from Curitiba. Reference point for this log, however, is again Curitiba.

0 0 Departure point. From downtown Curitiba travel westwards and take highway BR-277. Up to São Luis do Purunã, 28 km W from Curitiba, the route is the same as in Day 1st.

74.0 74.0 STOP 1. Contact of Itararé Subgroup (Campo do Tenente Formation) and the Devonian Furnas sandstone. The outcrop on the left side of the road, though rather poor, is the only available showing the contact between patches of massive diamictite of the Campo do Tenente Formation filling shallow depressions in the Furnas Formation. Though glacial striae have note been found in this locality, other outcrops of the Devonian sandstone in the surrounding area have been glacially abraded.

1.0 75.0 STOP 2. Diamictite with deformed sand inclusions. Outcrop of sandy diamictite containing small clasts, intercalated with

		deformed sandstone laminae/beds. The diamictite is faintly bedded and shows clasts oriented parallel to stratification. Recumbent (sheared) folds and faults occur in the sandstone (Campo do Tenente Formation).
5.4	74.6	STOP 3. Striated sandstone (Campo do Tenente Formation?). Striae on the upper surface of sandstone,on left side of road correlates with the ones on sandstone surface at ground level on the right side. Striae are relatively long, parallel, and oriented roughly N-S. Other striated surfaces occur in the outcrop on the left. Striae on a lower surface on the right side of outcrop continue internally into the sandstone. The sandstone fine, feldspatic and relatively well sorted with trough cross-bedding and bearing rare isolated clasts of coarse, feldspatic sandstone (Furnas Fmt.?) has been mapped as part of the Furnas Formation. Similar sandstones, however, are also found in the Itararé Subgroup. A drag lineation origin for the internal striae has been suggested, but coincident orientation is not easy to explain.
0.4	75.0	Exit to Lapa at left.
		STOP 4. (optional). Outcrop on the right side of the road to Lapa shows a lower massive sandy diamictite cut by discontinuous horizontal joints and succeeded transitionally by rhythmite of diamictite and shale. Both are loaded with intrabasinal sedimentary clasts, most of which parallel to bedding, and also contain rare dropstones. The outcrop is very similar to the one at Lapa quarry and may also represent a subaqueous basal tillite followed by deposits of density currents.
5.0	80.0	STOP 5. Massive and stratigraphic diamictite. An excellent, thick and relatively continuous outcrop of Campo do Tenente beds along the ravine and the road cut on the right side of road. The sequence exposed includes basal clast-laden (mostly intrabasinal) rhythmite of diamictite and shale and varvite (± 20 m) intercalated with thick massive sandstone beds upwards. The stratified subaqueous deposit passes transitionally to a zone of fragmented and disorganized blocks of sandstone mixed with crenulated shale, which apparently rest below a ridge-like body of coarse conglomeratic sandstone with slumped (faulted) blocks on its flanks. The sequence exposed on the southern flank is also made up of fragmented blocks or thick beds of massive diamictites which is better exposed along the road cut

(Fig. 29). The long cut (± 300 m) shows a basal zone of massive, very compact diamictite, cut by normal faults and overlain by stratified diamictite with beds/laminae, undulated/folded and enveloping lenticular masses of the massive lower diamictite. Clasts in the stratified diamictite often lie with longer axes parallel to bedding. This is marked by a series of parallel irregular to regularly spaced joints. The upper diamictite is overlain disconformably by shales. The diamictites have been interpreted as representing a basal (massive) tillite, overlain by flow-tillite resting against a fluvio-glacial body of conglomeratic sandstone. Canuto (1985) compared this outcrop with models of development of supraglacial sequences of till and outwash as discussed by Boulton (1972).

2.5 82.5 STOP 6. Massive and stratified diamictite. A relatively long outcrop of Campo do Tenente beds on the left side of road shows a lower diamictite, silty-sandy, massive to faintly stratified with clasts parallel to bedding laterally cut by normal faults and overlain with gradational contact by alternating diamictite and laminae/beds and lenses of sandstone and conglomeratic sandstone, associated with drag-lineations. The section is disconformably overlain by shale with dropstones. The sequence is interpreted as including a lower basal tillite overlain by flow tillite.

1.1 83,6 STOP 7. Stratified diamictite. A relatively thick exposure along valley flank on right side of road (Campo do Tenente Formation). Stratified sandy diamictite (30-40 m thick) with abundant structures denoting gravitational mass flow, such as folds and "hooks" and many clasts oriented parallel to bedding, and intercalated with beds of graded, coarse to conglomeratic sandstone, with sharp basal contacts, which tend to predominate towards the top of section. Diamictite corresponds to a flow tillite, whereas the sandstone beds are probably deposits of dense currents, which alternate with the debris flows, and later becoming the predominant depositional process (Campo do Tenente Formation).

1.4 85.0 Exit to Palmeira at right.

3.0 88.0 Exit to Palmeira at right.

1.2 89.2 STOP 8. Slumped sandstone of the Mafra Formation. Intensely (chaotically) deformed fine sandstone and interbedded laminated diamictite (Mafra Formation). Slump

		structures are relatively common in sandstones and associated diamictites in this part of the section, suggesting local steeper slopes.
40.8	130.0	Exit to Rio da Areia at right. Outcrops of fine, fossiliferous marine sediments of the upper Rio do Sul Formation occur locally.
45.8	135.5	STOP 9. Contact of the Itararé Subgroup (Rio do Sul Formation) and the Rio Bonito Formation. Marine shale (Passinho shale) at the top of the Rio do Sul Formation is disconformably overlain by fluviatile sandstones of the Rio Bonito Formation (Permian). The Passinho shale is a regionally extensive bed identified from southern to northern Paraná State. It is associated with the post-glacial transgression that followed cessation of the glaciation.
		End of excursion. Return to Curitiba for overnight stop and to São Paulo on next day.

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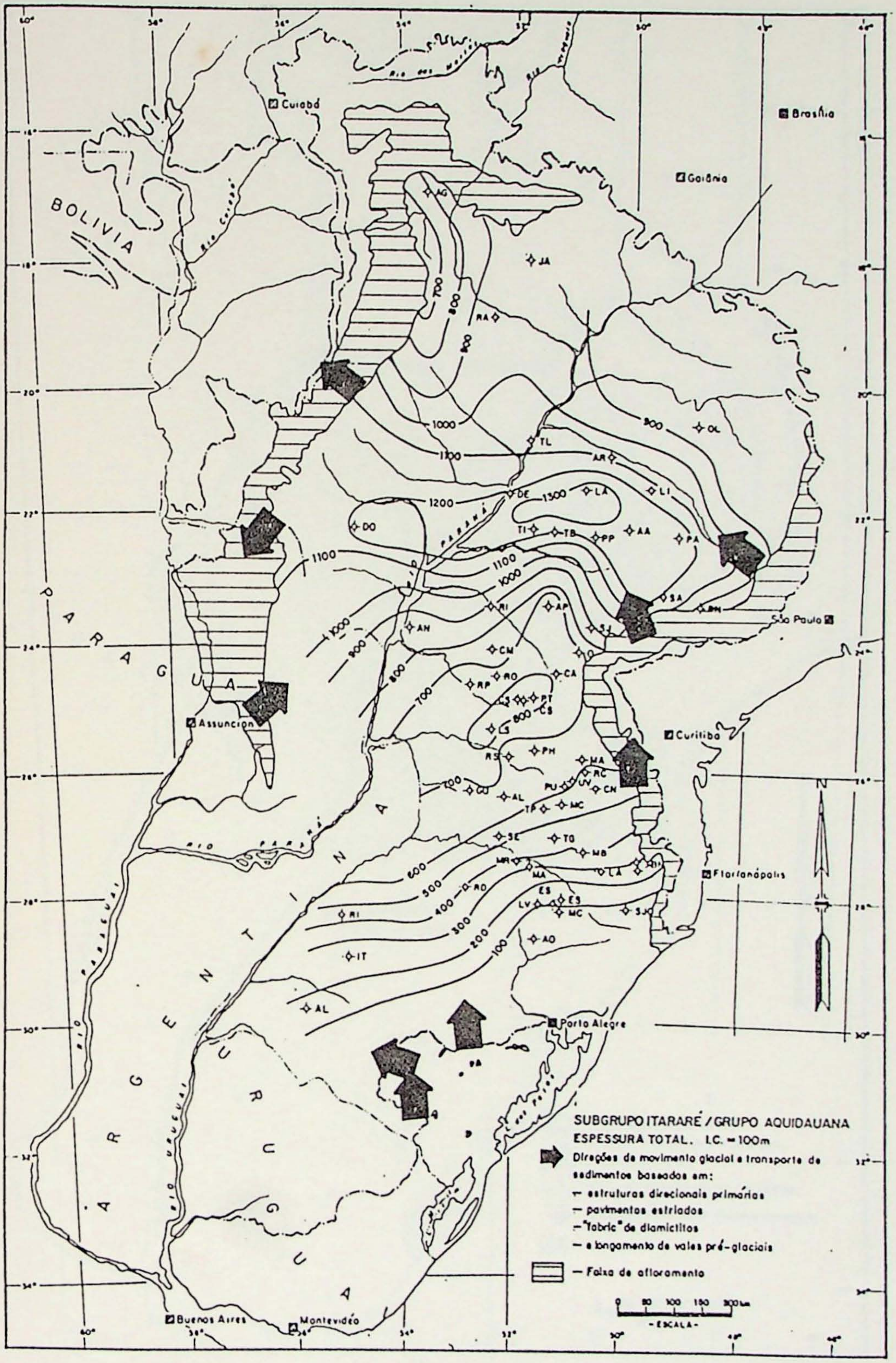


Fig.1 - Isopach map of the Itararé Subgroup and equivalent beds, Paraná Basin (SANTOS, 1988).

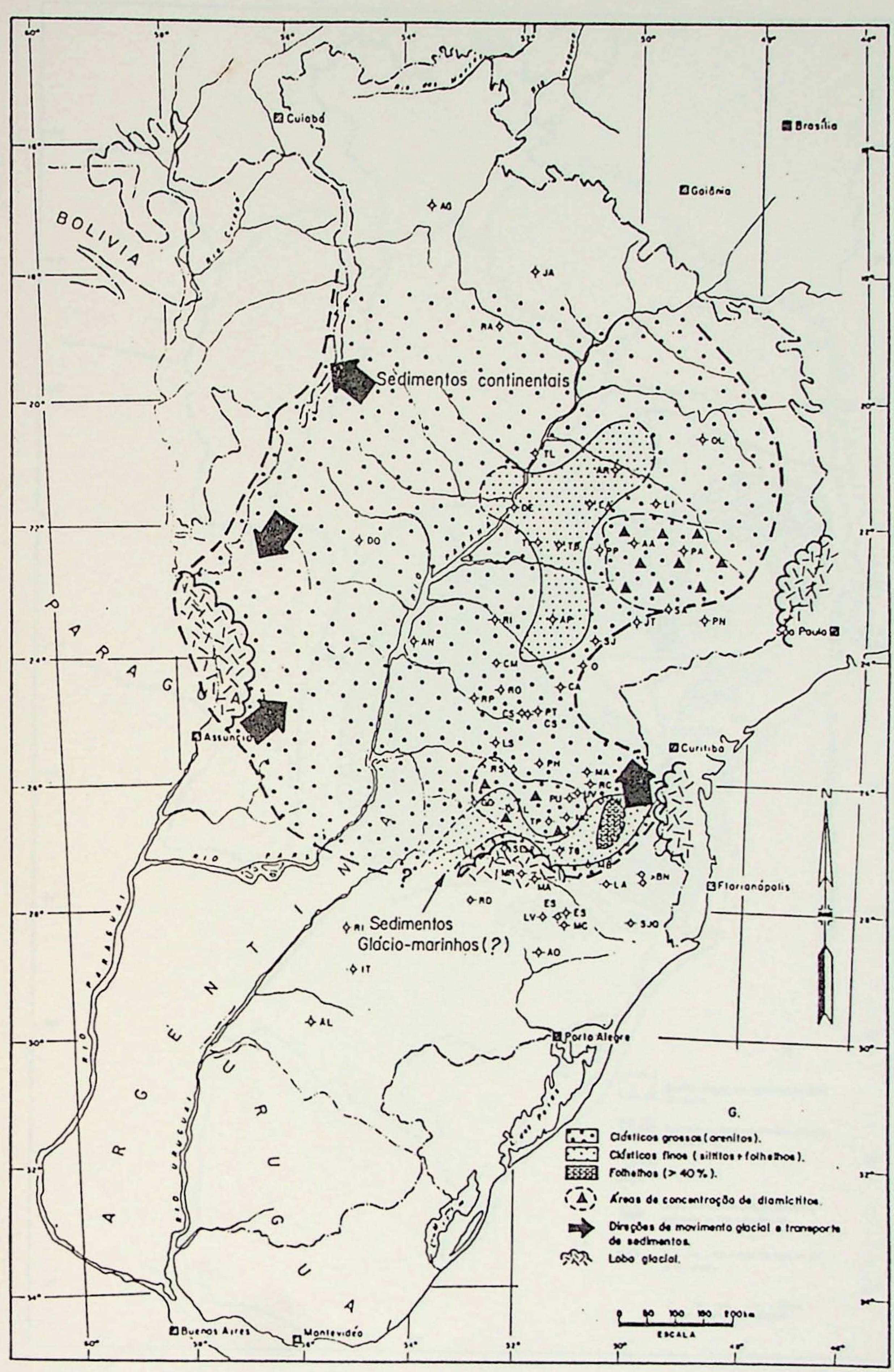


Fig.2 - Paleogeographic map of interval G (SANTOS, 1988).

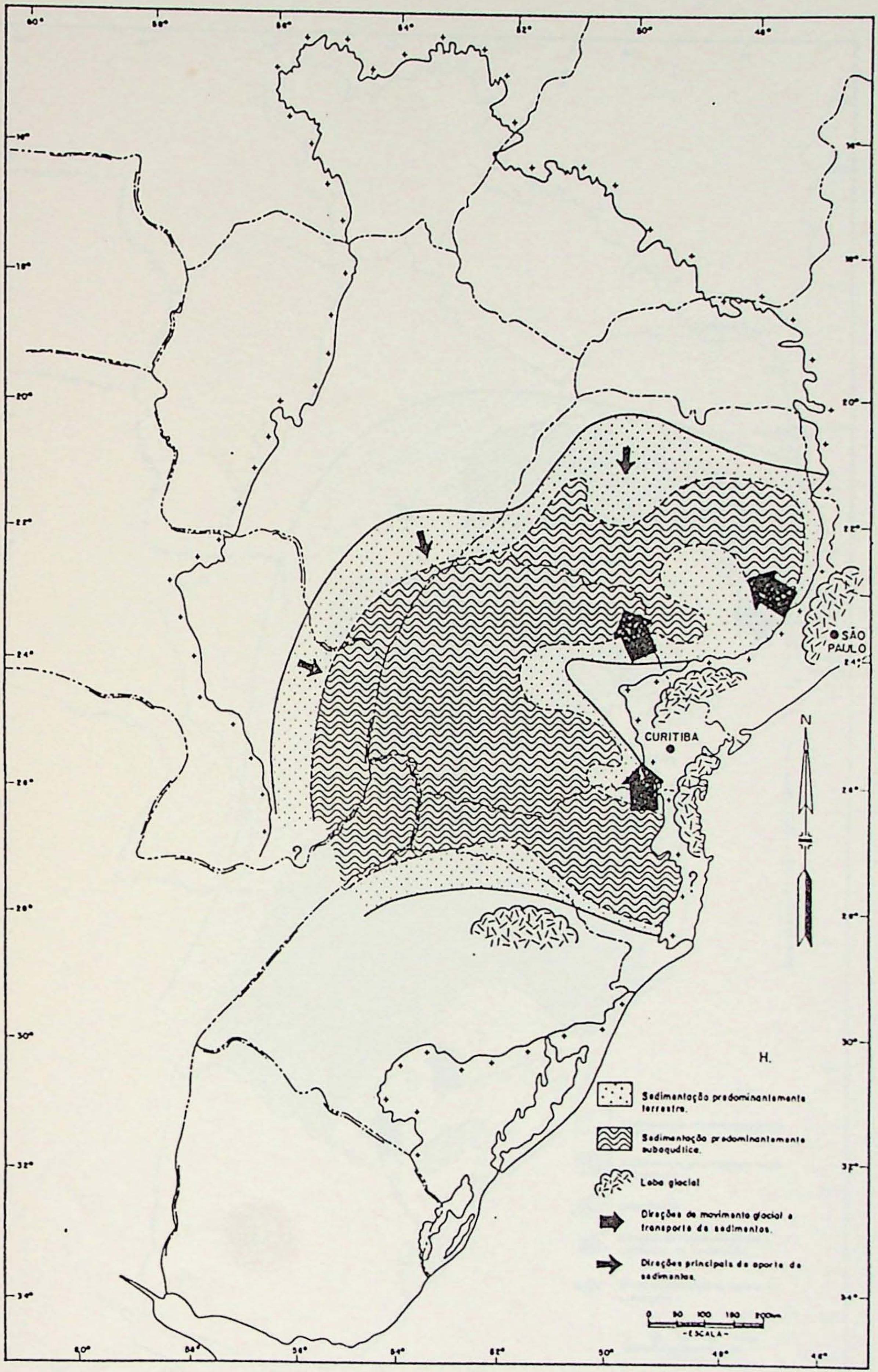


Fig.3 - Paleogeographic map of interval H (SANTOS, 1988).

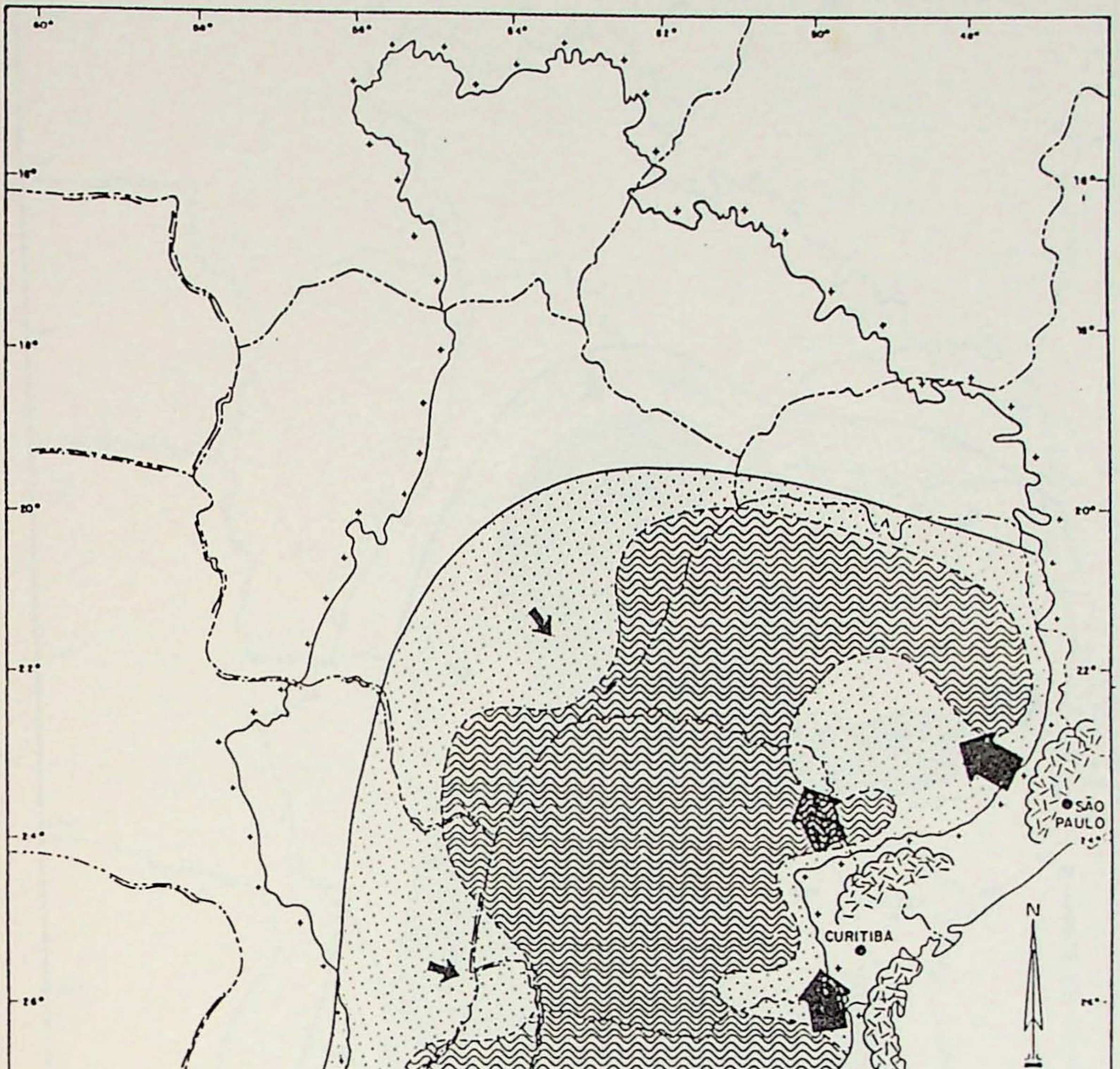


Fig.4 - Paleogeographic map of interval I (SANTOS, 1988).

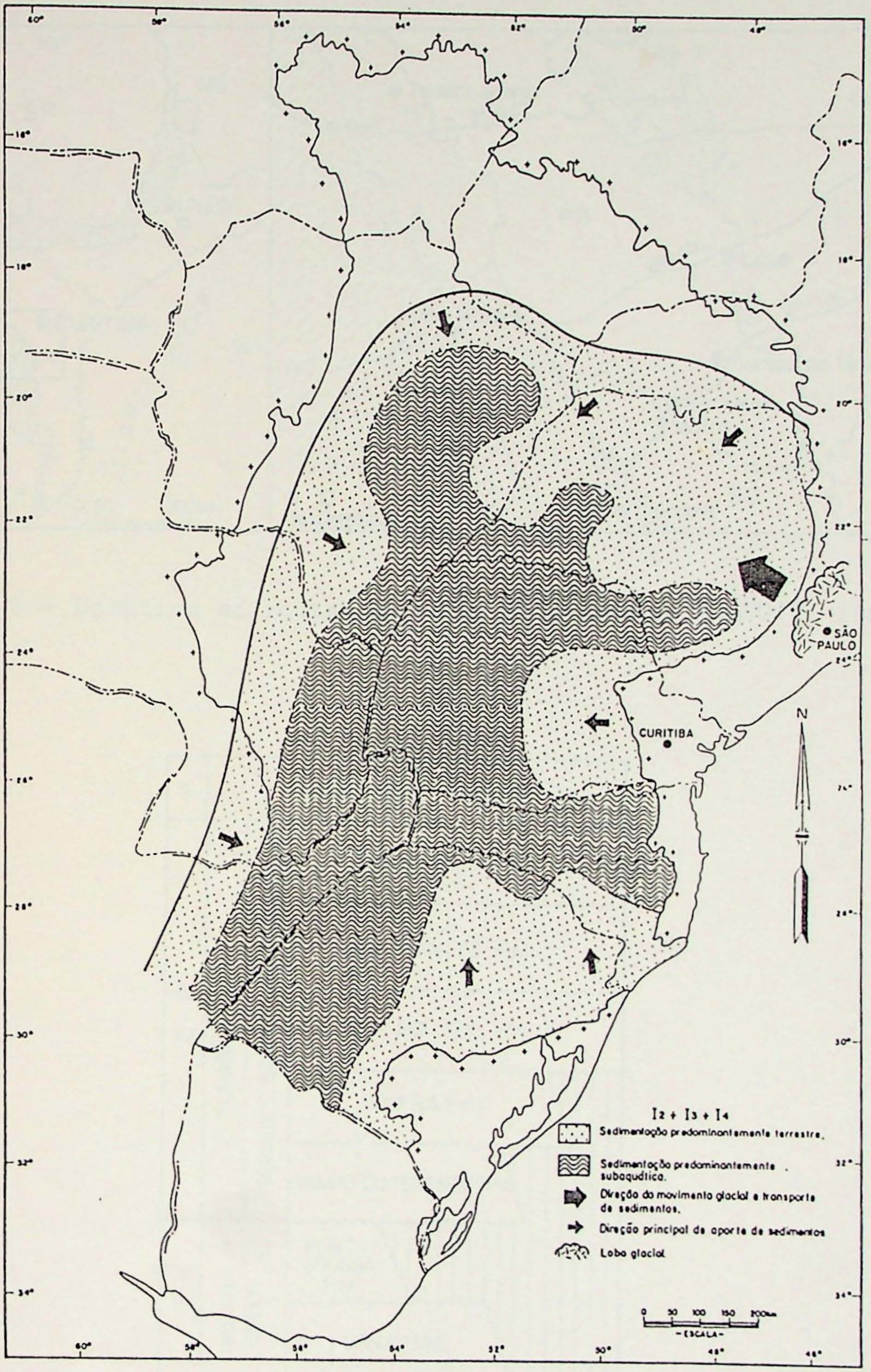


Fig.5 - Paleogeographic map of interval $I_2+I_3+I_4$ (SANTOS, 1988).

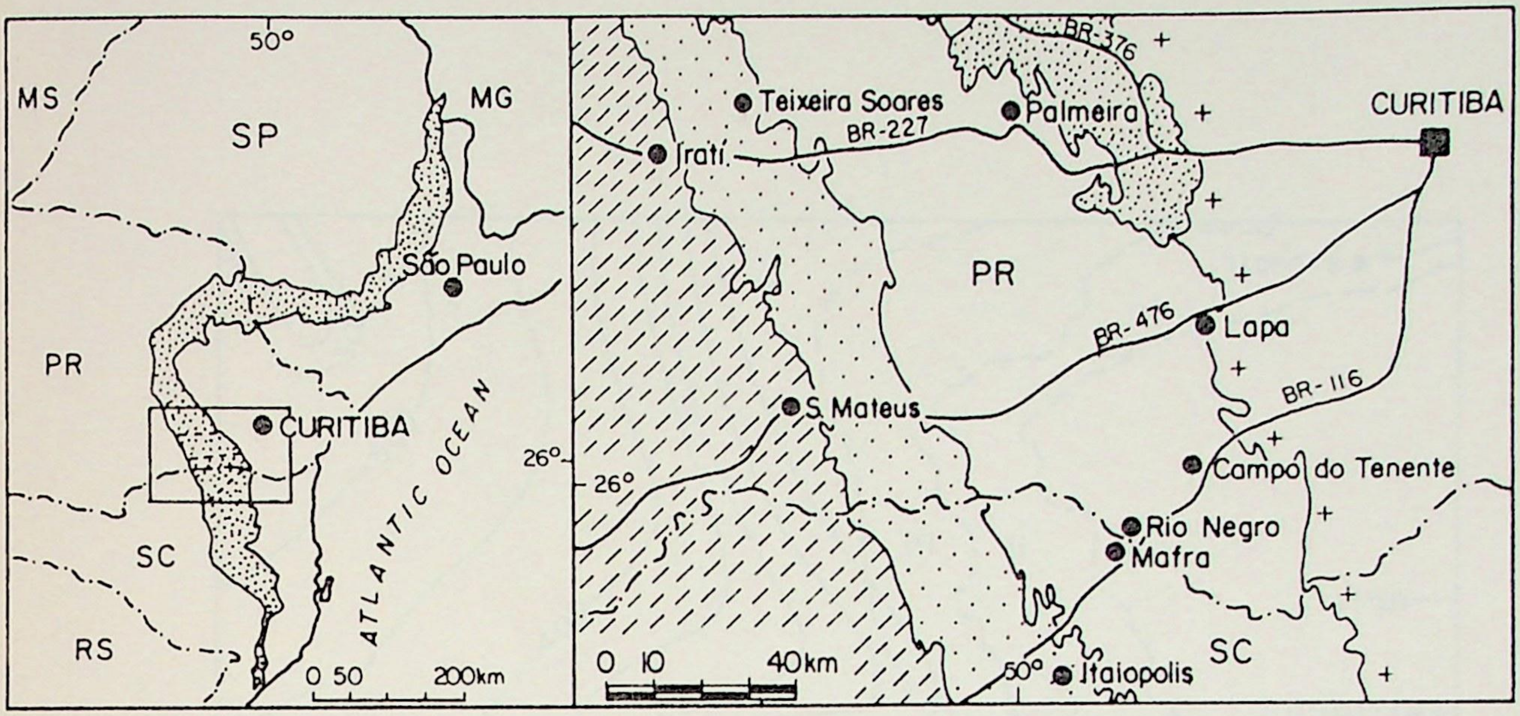


Fig.6 - Location of routes and area of excursion (CANUTO, 1985).

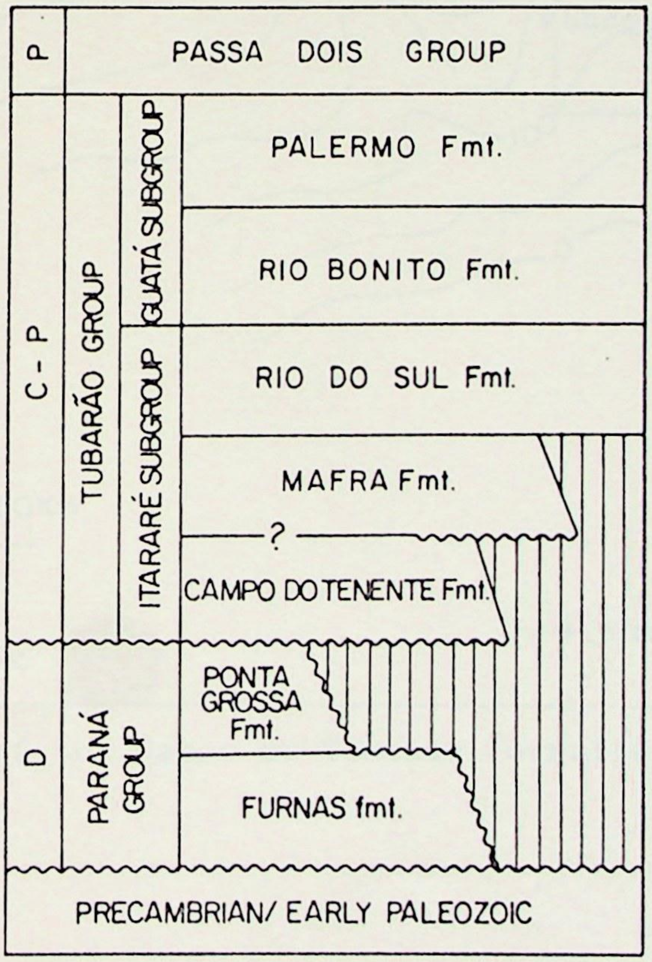


Fig.7 - Stratigraphy and nomenclature of the Itararé Subgroup (CANUTO,1985).

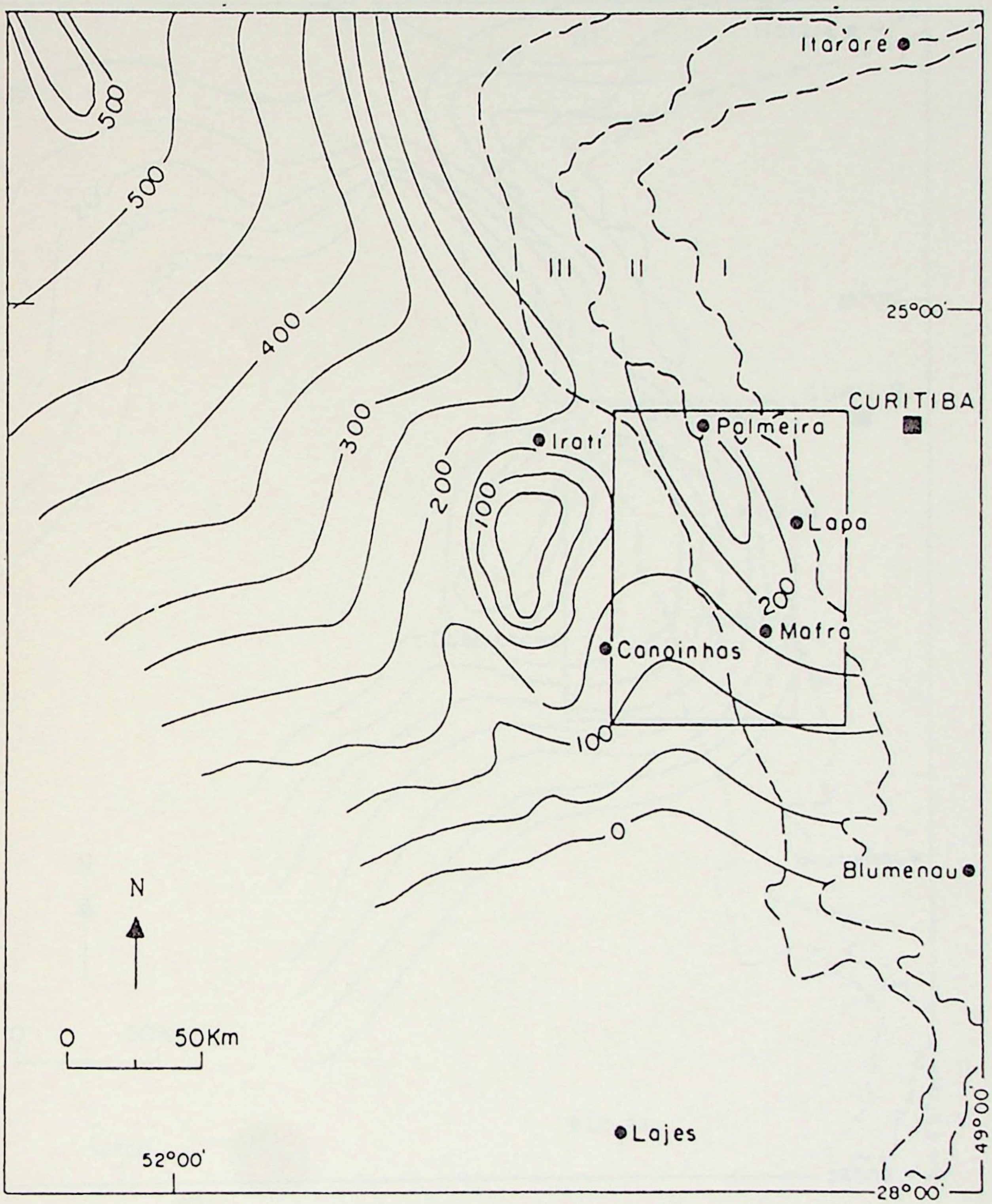


Fig.8 - Isopach of the Campo do Tenente Formation (MEDEIROS et al., 1971).

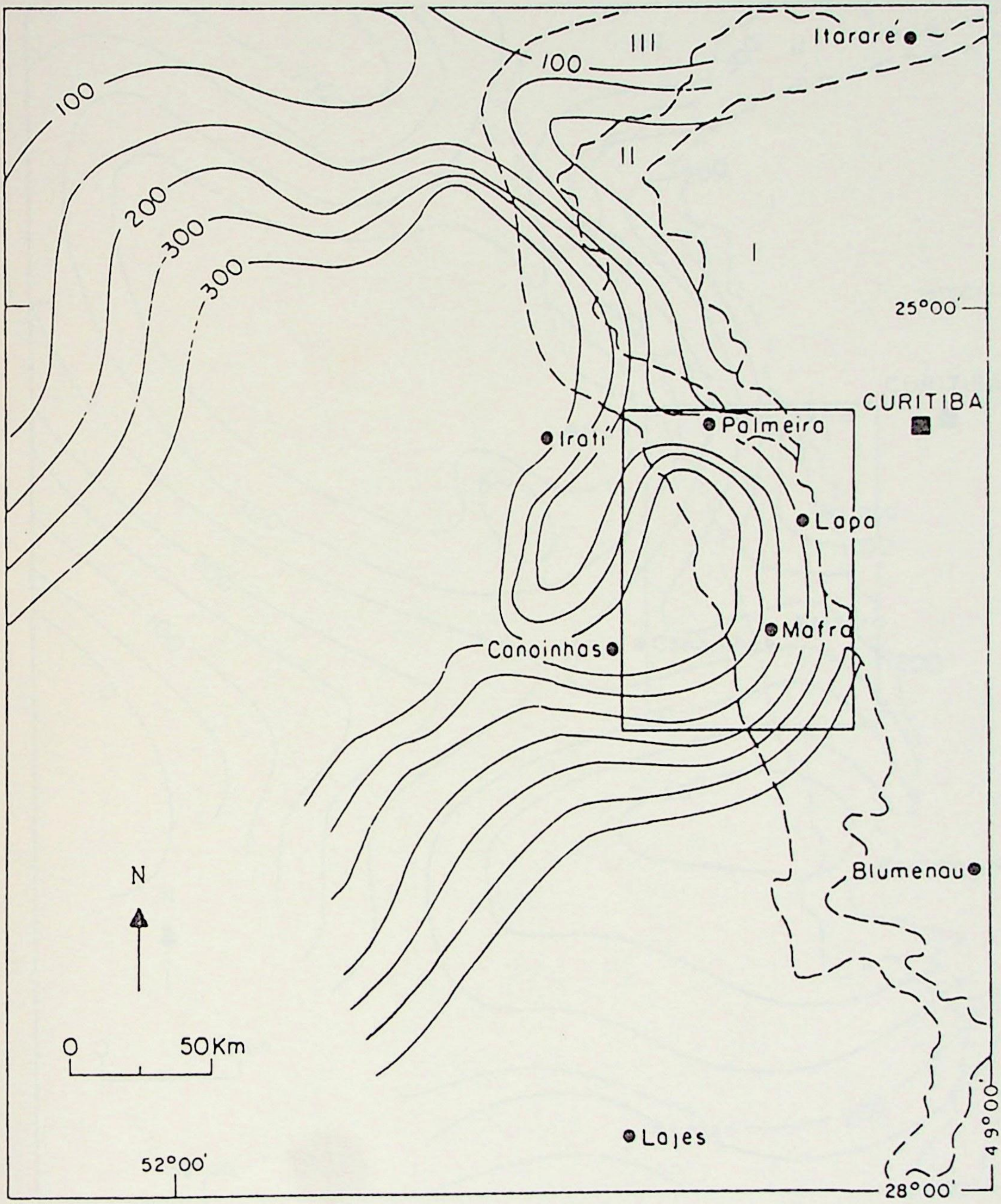


Fig.9 - Isopach of the Mafra Formation (MEDEIROS et al., 1971).

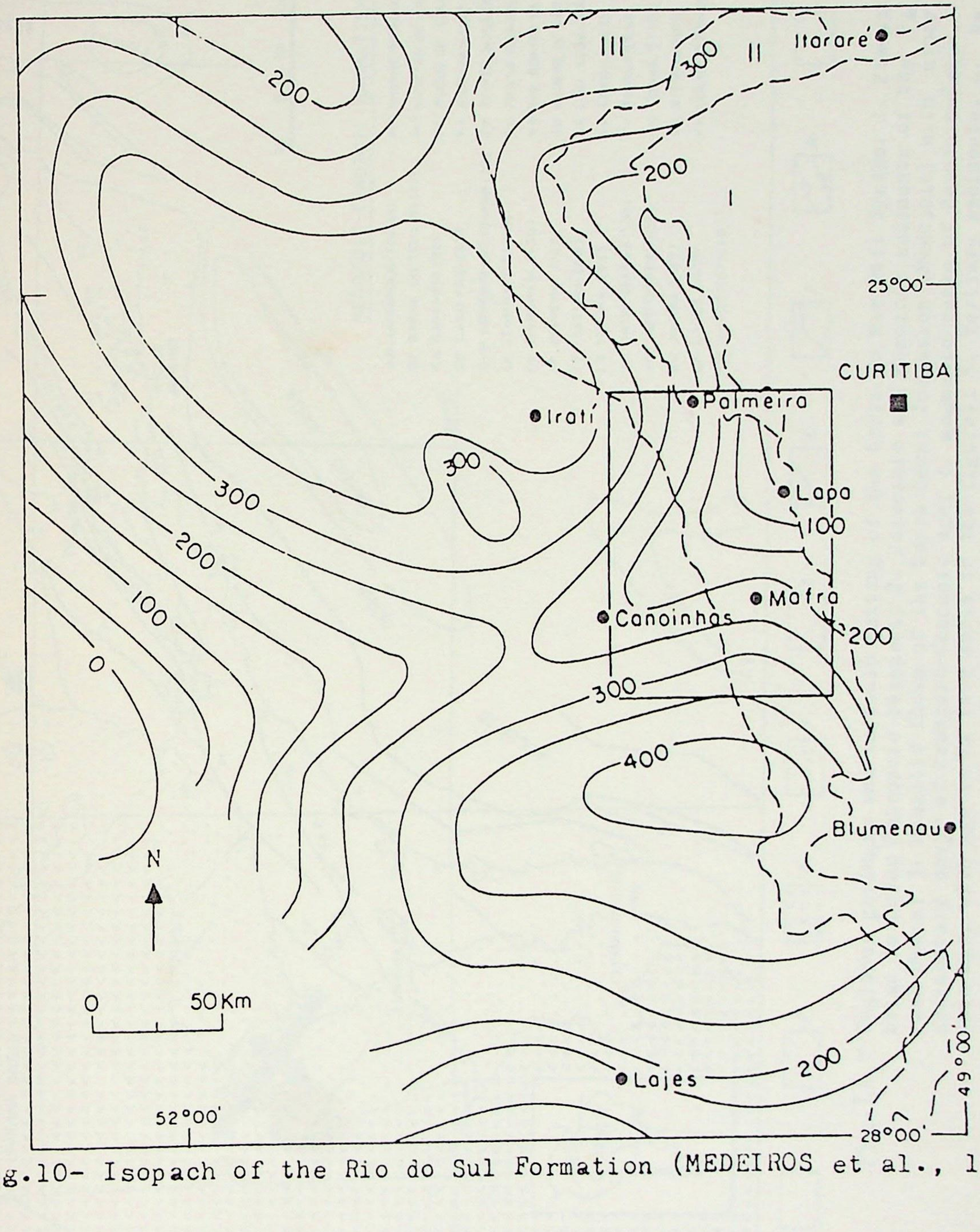


Fig.10- Isopach of the Rio do Sul Formation (MEDEIROS et al., 1971).

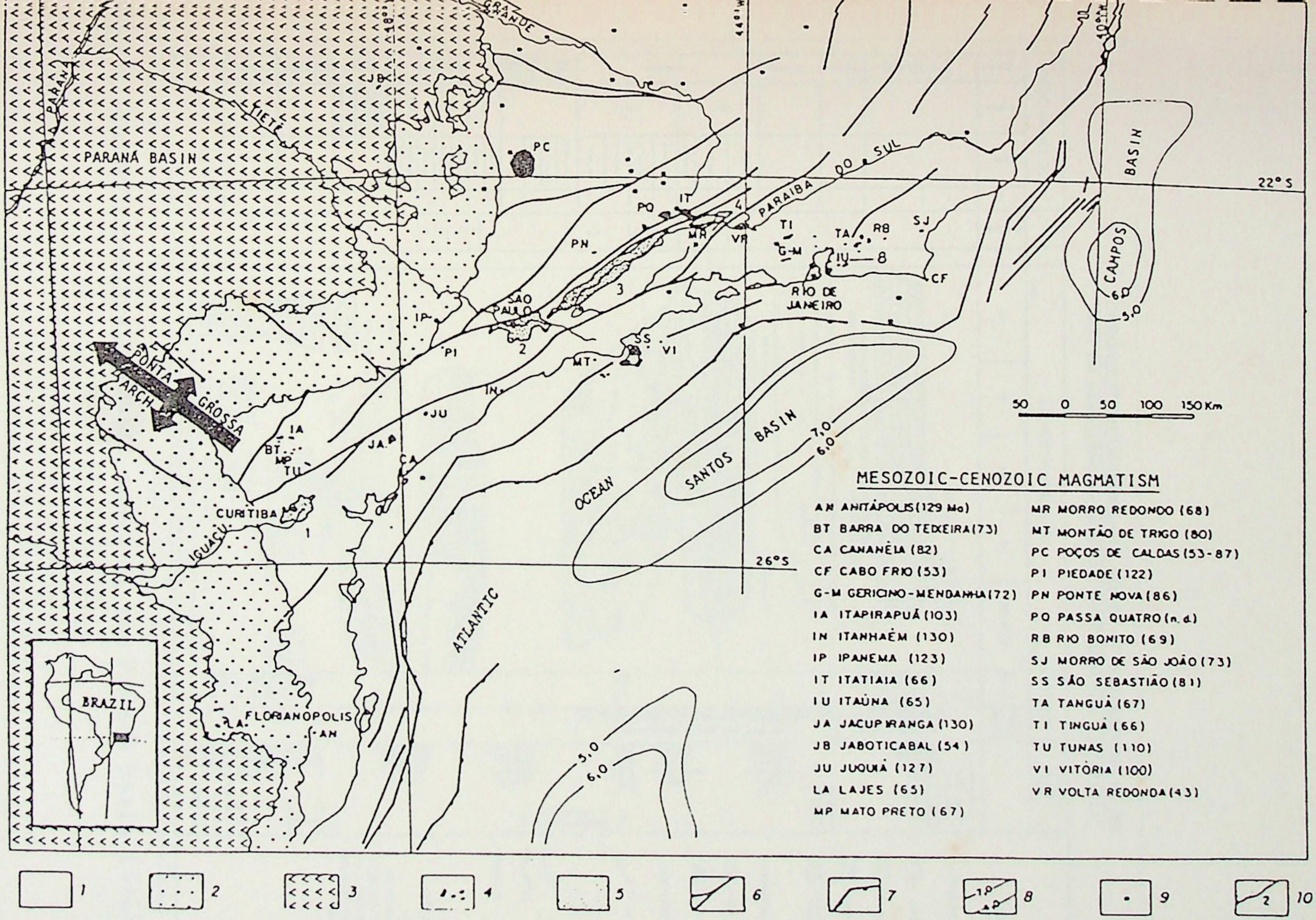
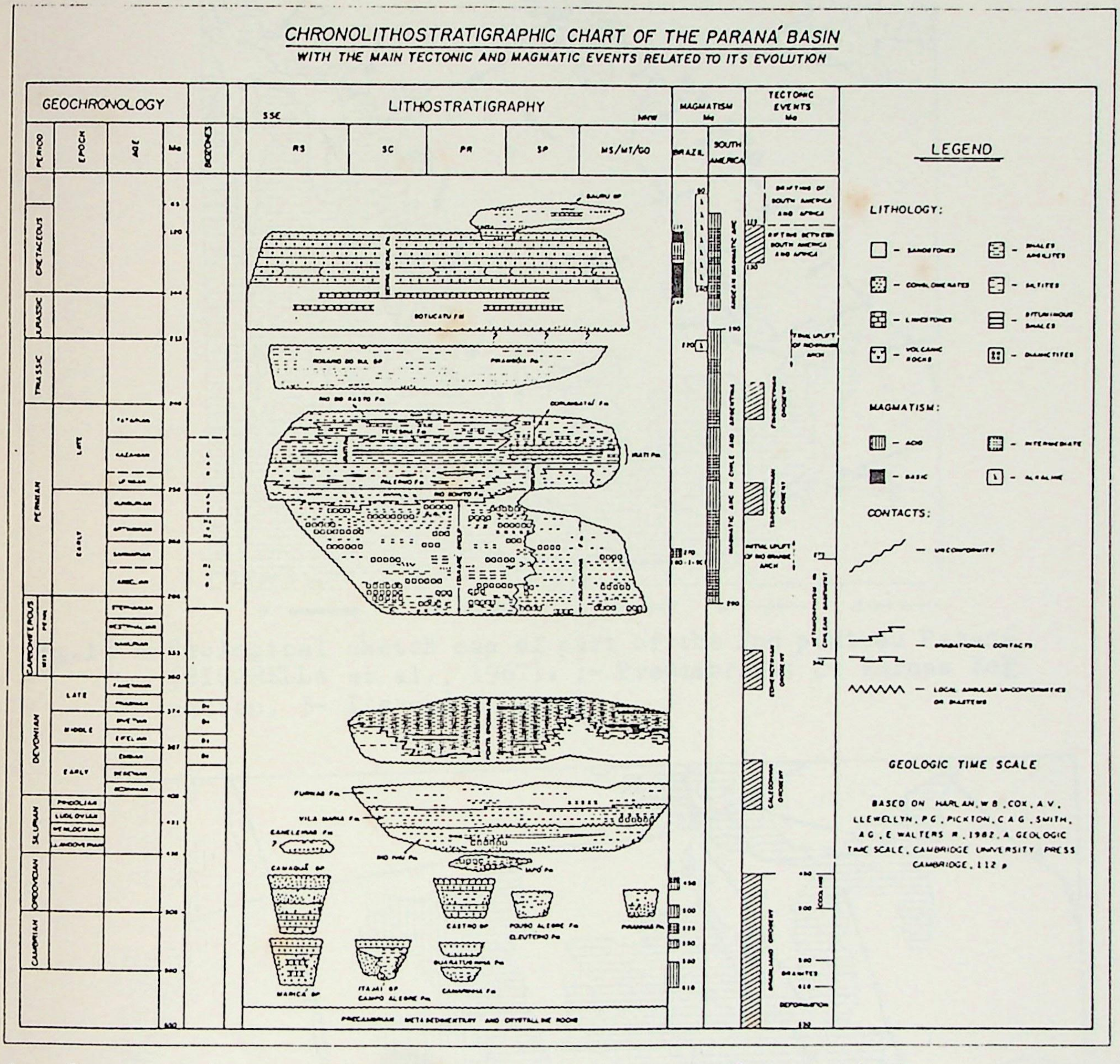


Fig.11 - Regional geologic and tectonic setting of the Serra do Mar Rift System: 1. Precambrian to Lower Paleozoic basement; 2. Paleozoic and Mesozoic sediments of the Paraná Basin; 3. basaltic flows of the Serra Geral Formation (Mesozoic) with minor sedimentary cover of Mesozoic-Cenozoic age; 4. magmatic rocks of Mesozoic-Cenozoic age, with age in Ma (see table in the figure); 5. Tertiary sediments; 6. basement shear zones; 8. isopachs (in Km) of the marginal basins; 9. Earthquake epicenters; 10. basins of the rift system: 1- Curitiba; 2- São Paulo; 3- Taubaté; 4- Resende; 5- Volta Redonda. Itaboraí Basin is located close to the Itaúna (IU) alkaline, and the Pariquera-Açu deposits are located within the triangle JA (Jacupiranga), CA (Cananéia) and JU (Juquiá) alkalines. Map compiled after ULBRICH & GOMES (1981), MELO et al. (1985b) and RICCOMINI et al. (1986).



.12 - Chronolithostratigraphic chart of the Paraná Basin (ZALAN et al., 1987).

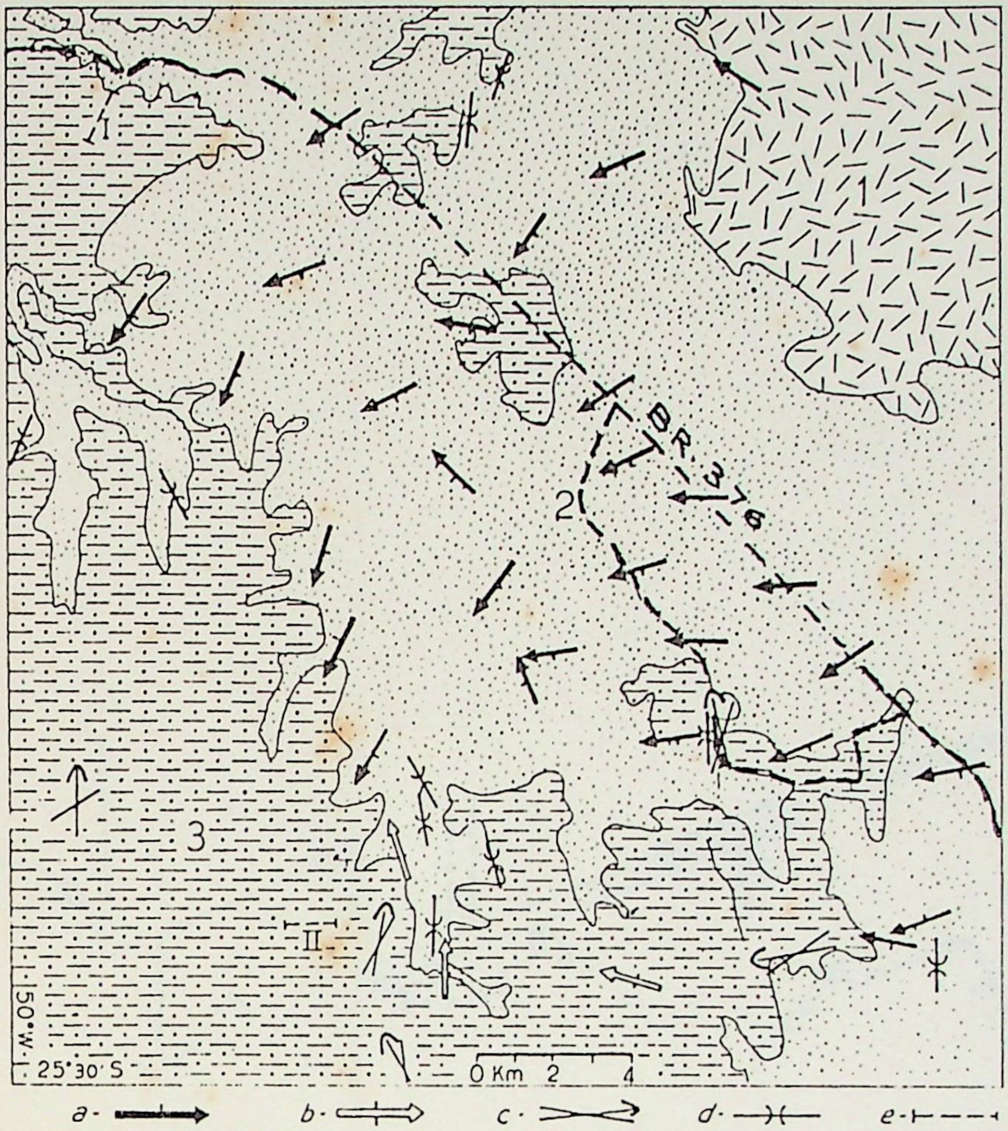


Fig.13 - Geological sketch map of part of the 2nd plateau Paraná (BIGARELLA et al., 1967). 1- Precambrian; 2- Furnas Formation; 3- Itararé Subgroup.

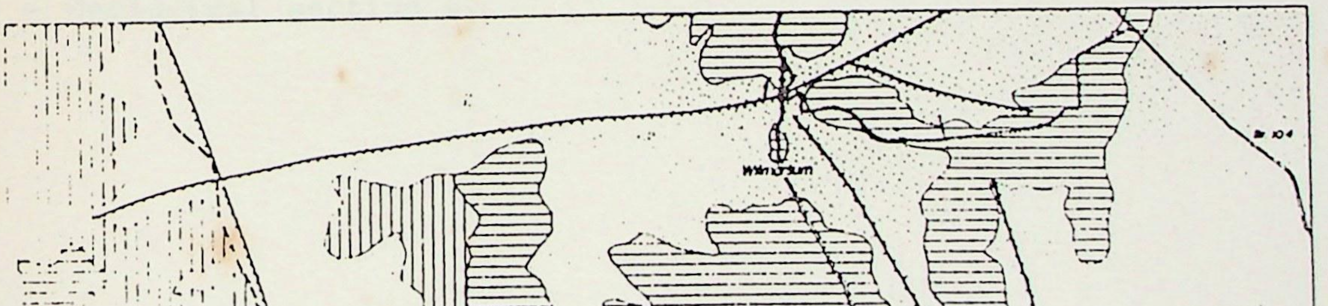


Fig.14 - Geological sketch map of Witmarsum area (BIGARELLA et al., 1967). A - Furnas sandstone; B - Cancela glacial and periglacial deposits; C - Rio do Salto glacial and periglacial deposits.

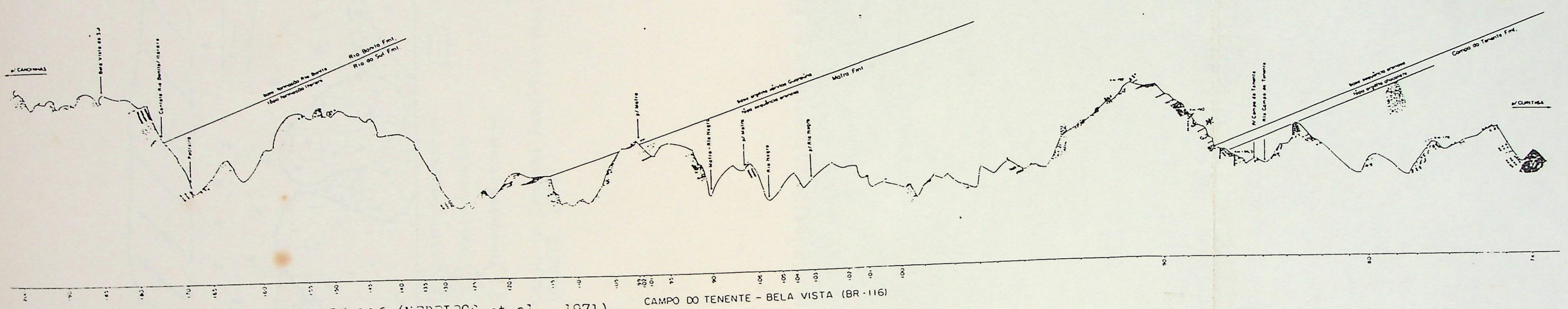


Fig.15 - Geological section along BR.116 (MEDEIROS et al., 1971).

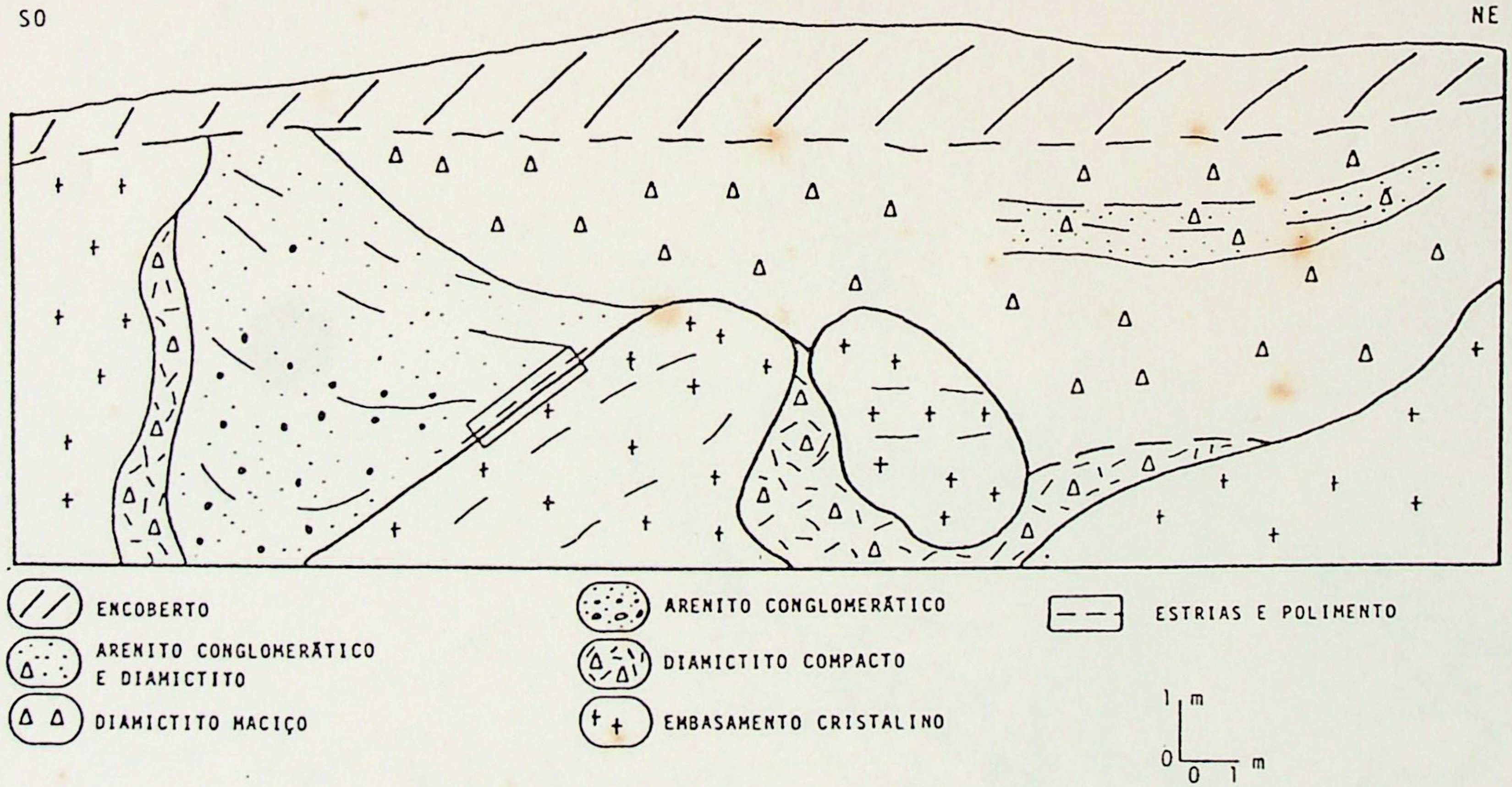


Fig.16 - Contact between Campo do Tenente Formation and basement rocks (BR-116 km 62), (CANUTO, 1985).

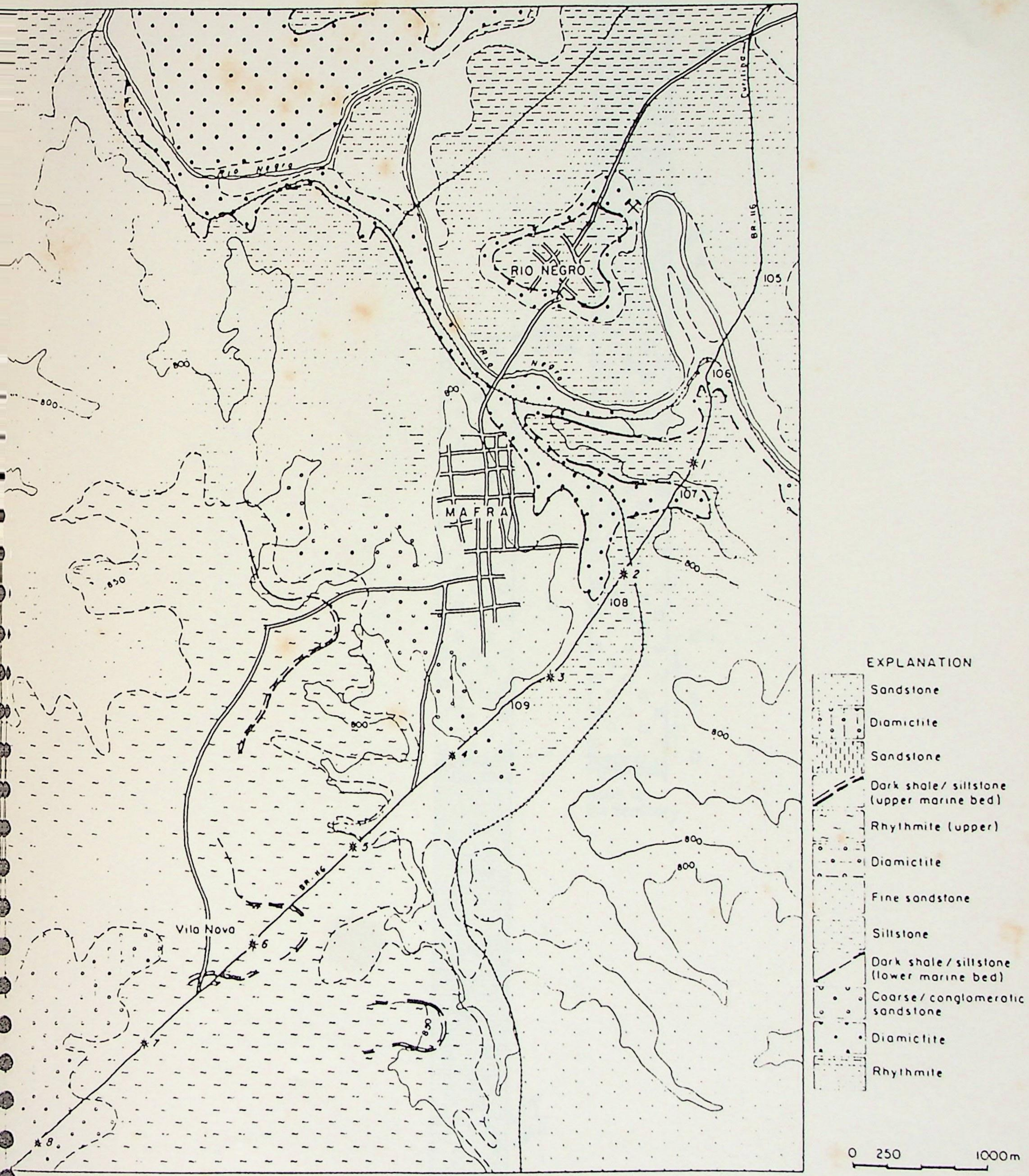


Fig.17 - Geological map of the Rio Negro-Mafra area (SALAMUNI et al., 1964).

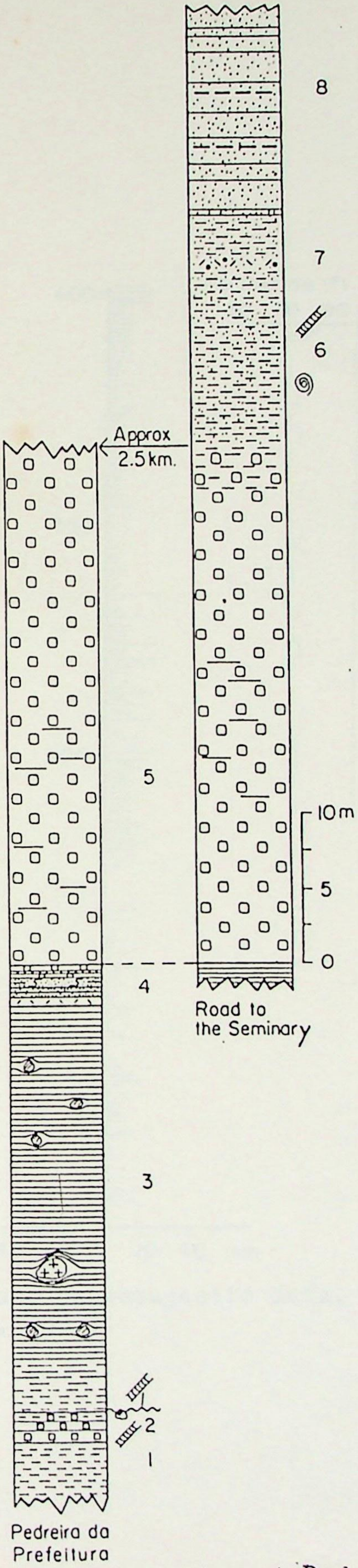


Fig.18 - Columnar section of the Mafra Formation at Pedreira da Prefeitura, Rio Negro,PR (CANUTO, 1985).

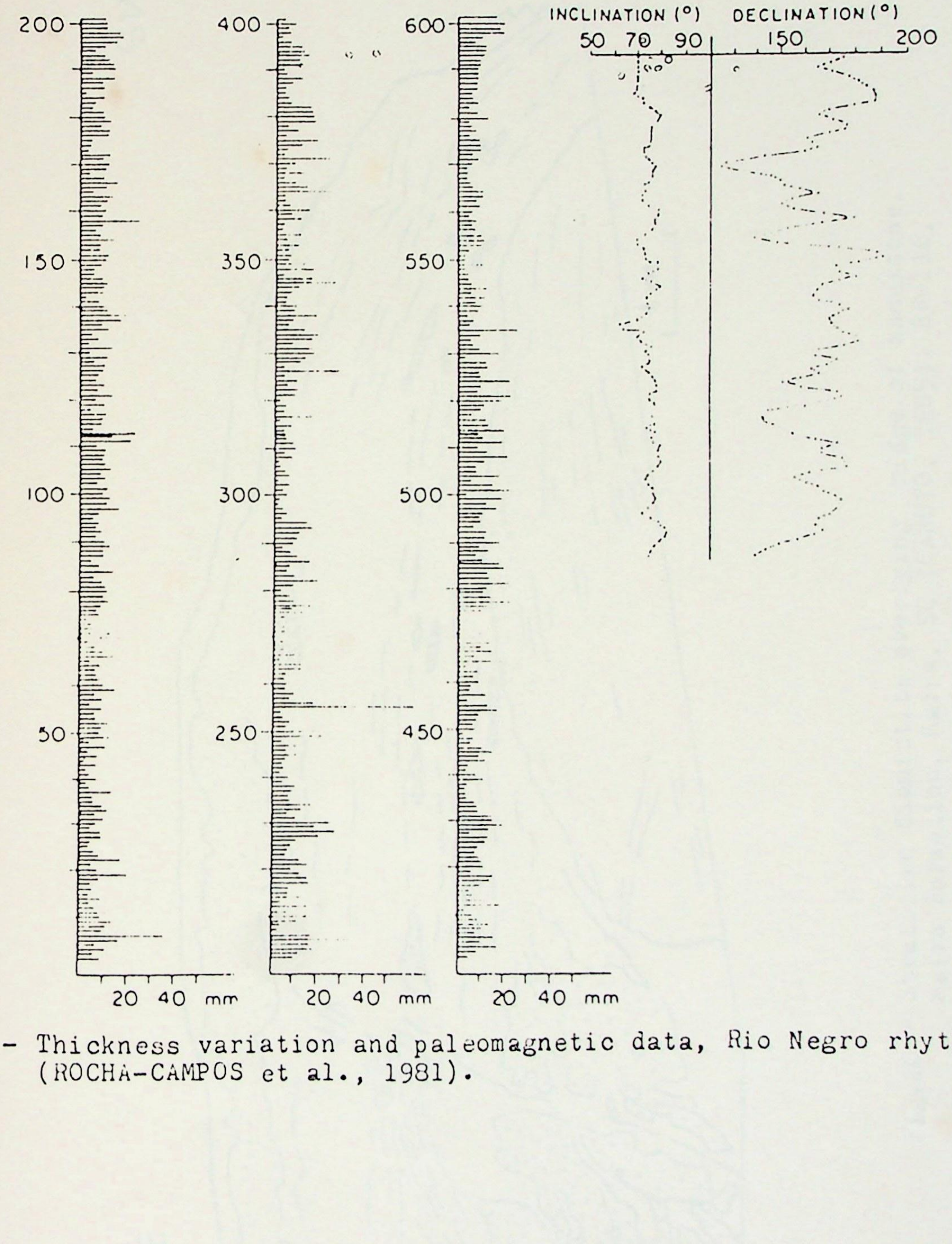


Fig.19 - Thickness variation and paleomagnetic data, Rio Negro rhythmites (ROCHA-CAMPOS et al., 1981).

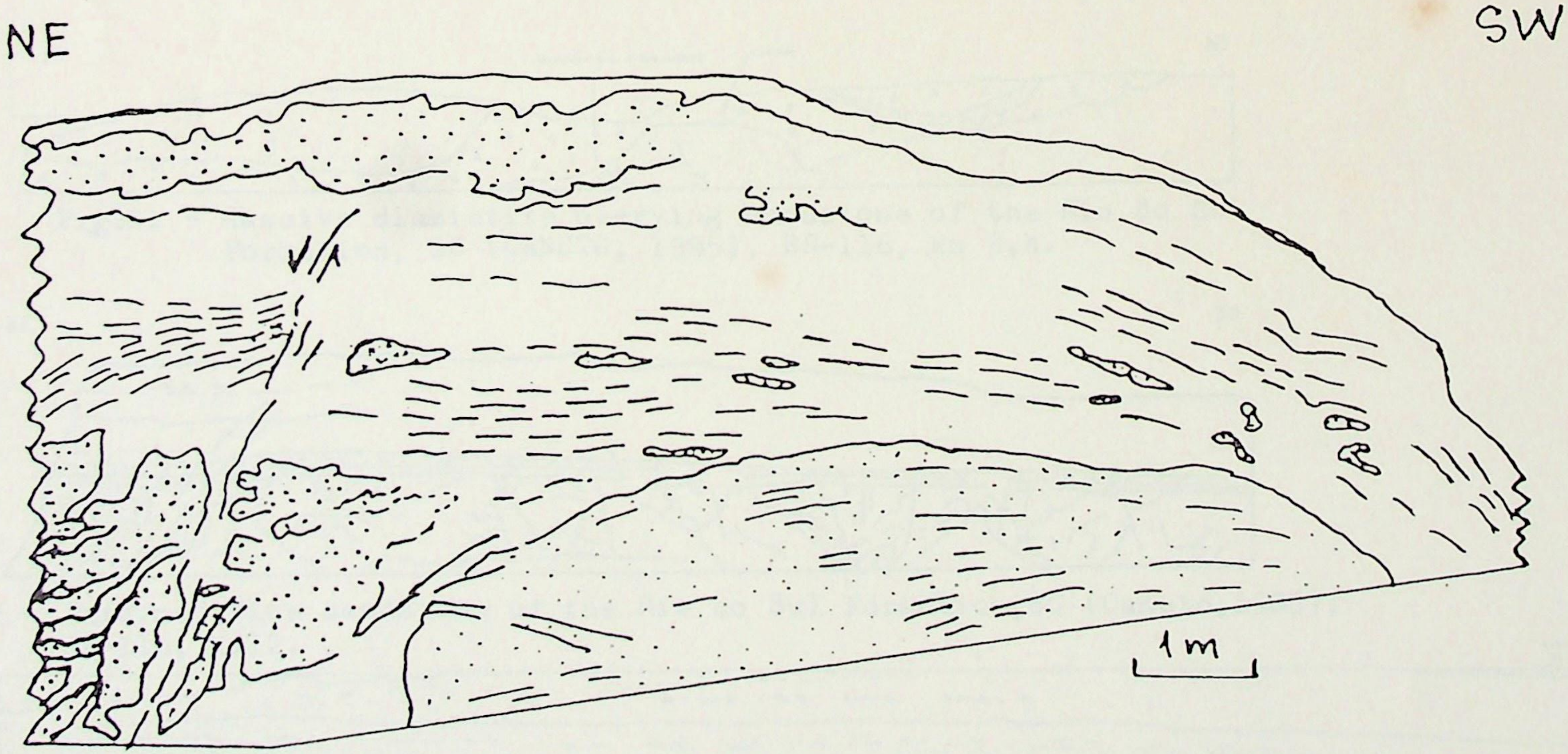


Fig.20 - Stratified diamictite overlying ridge of sandstone, Mafra Formation, Mafra, SC (CANUTO, 1985). BR-116, km 4.

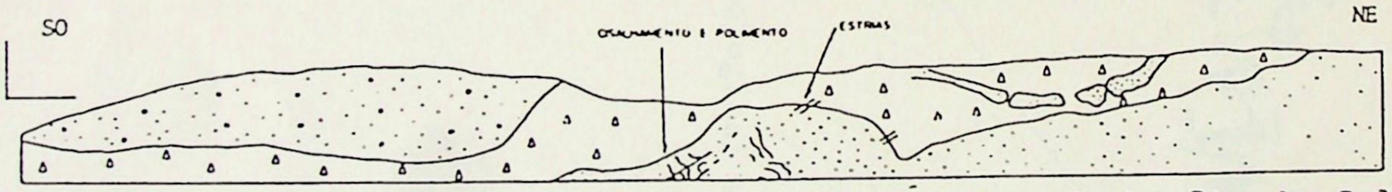


Fig.21 - Massive diamictite overying sandstone of the Rio do Sul Formation, SC (CANUTO, 1985), BR-116, km 9,4.

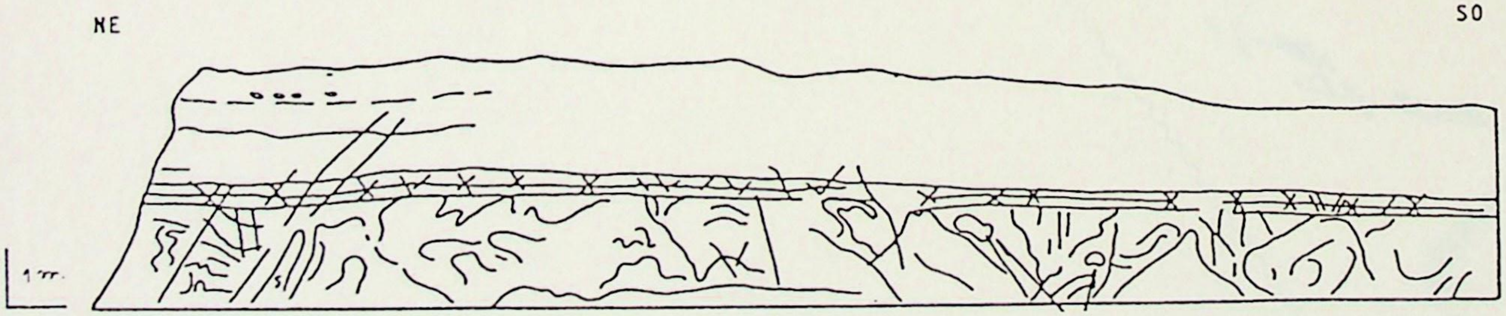


Fig.22 - Deformed fine sandstone of the Rio do Sul Formation,SC (Canuto,1985), BR-116, Km12.

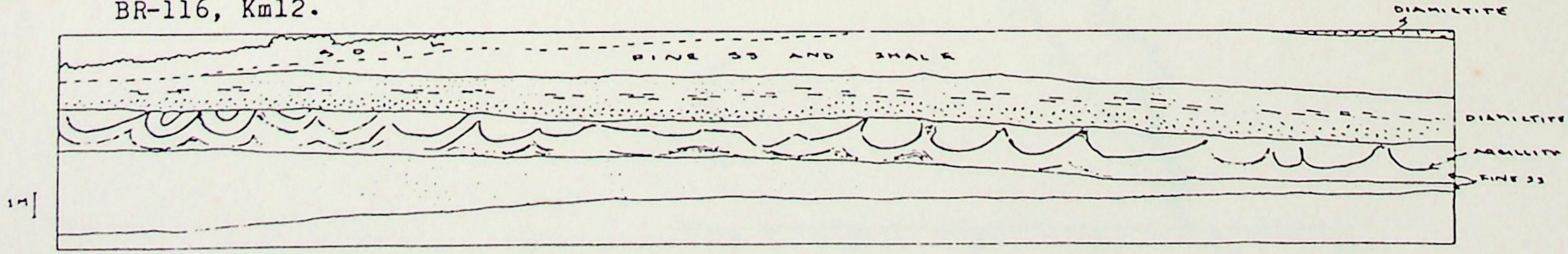


Fig.23 Deformed fine sandstone of the Rio do Sul Formation, SC, road to Canoinhas, some 300m W from BR-116, km12.

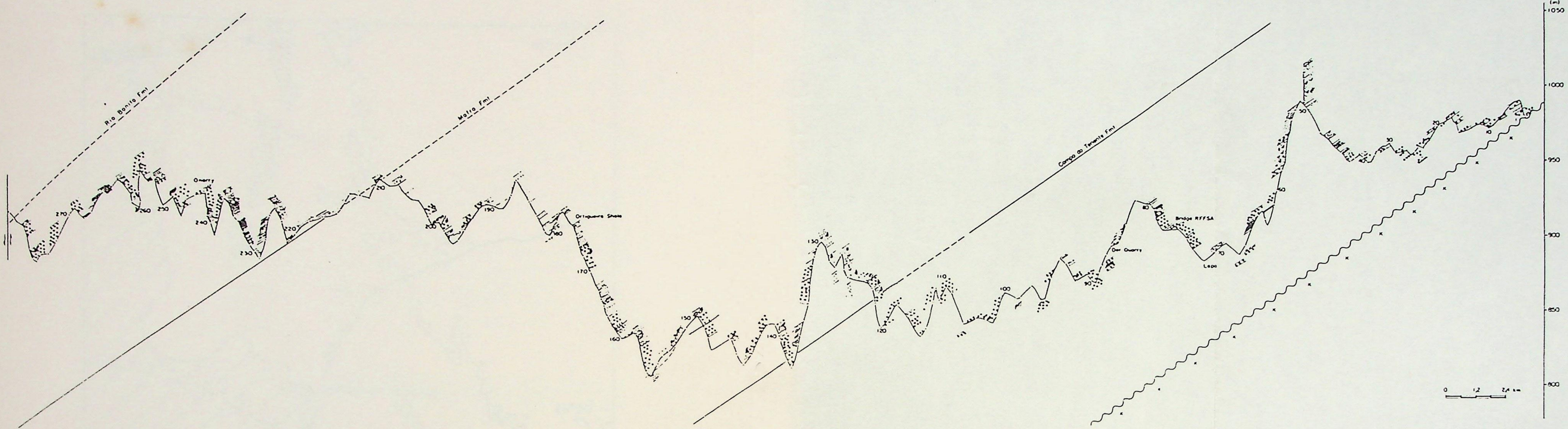
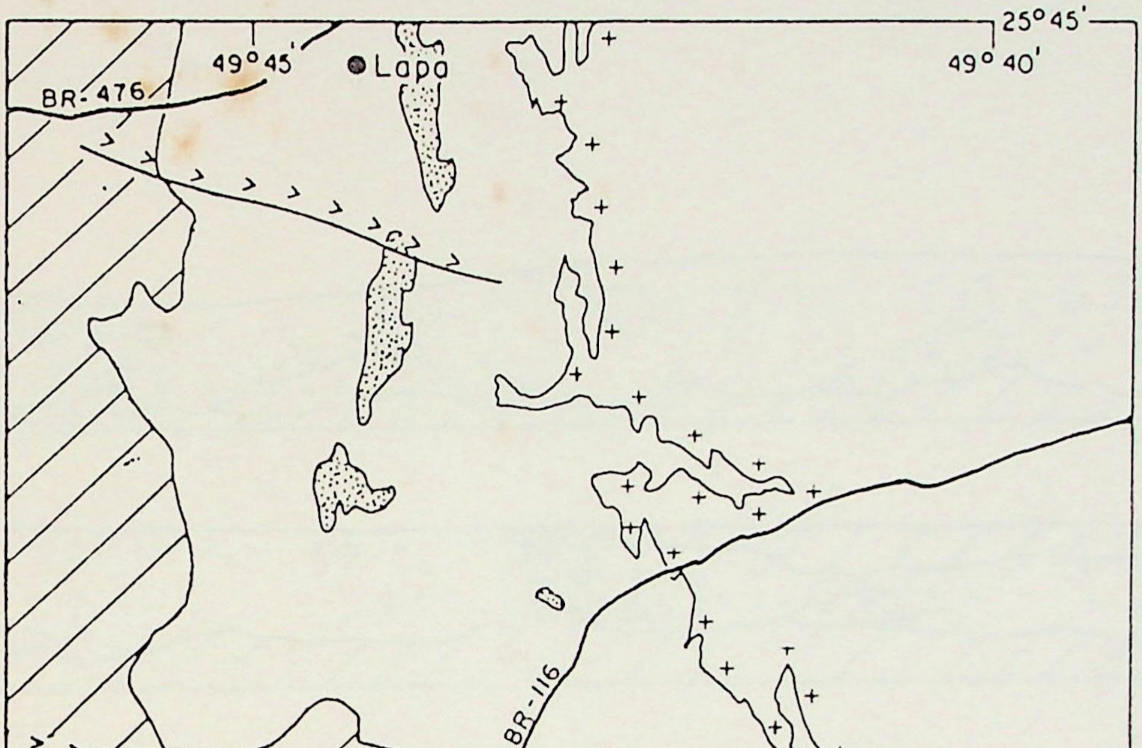


Fig.24 - Geological section along BR-476 (MEDEIROS et al., 1971).



g.25 - Geological sketch of the Lapa sandstone (MEDEIROS, 1971).

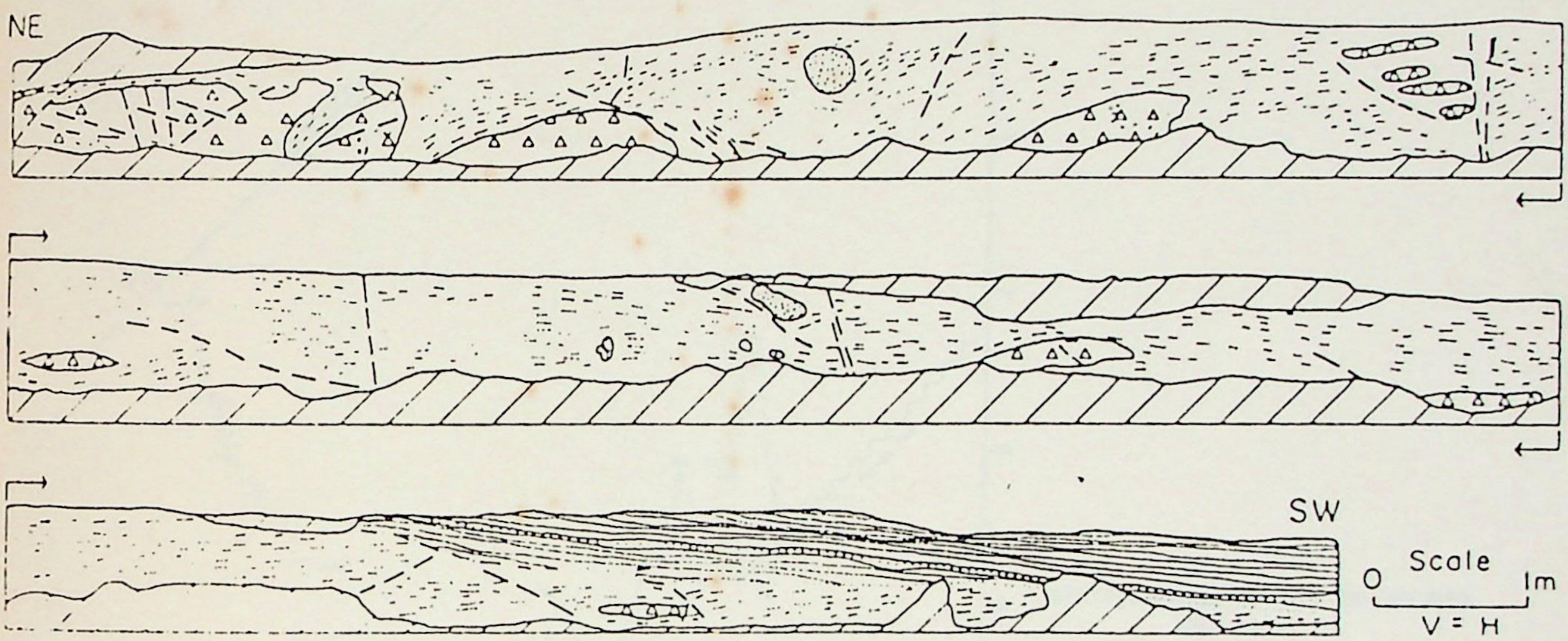


Fig.26 - Laminate and massive diamictite, Campo do Tenente Formation, Lapa, PR, BR-476, km 63,4 (CANUTO, 1985).

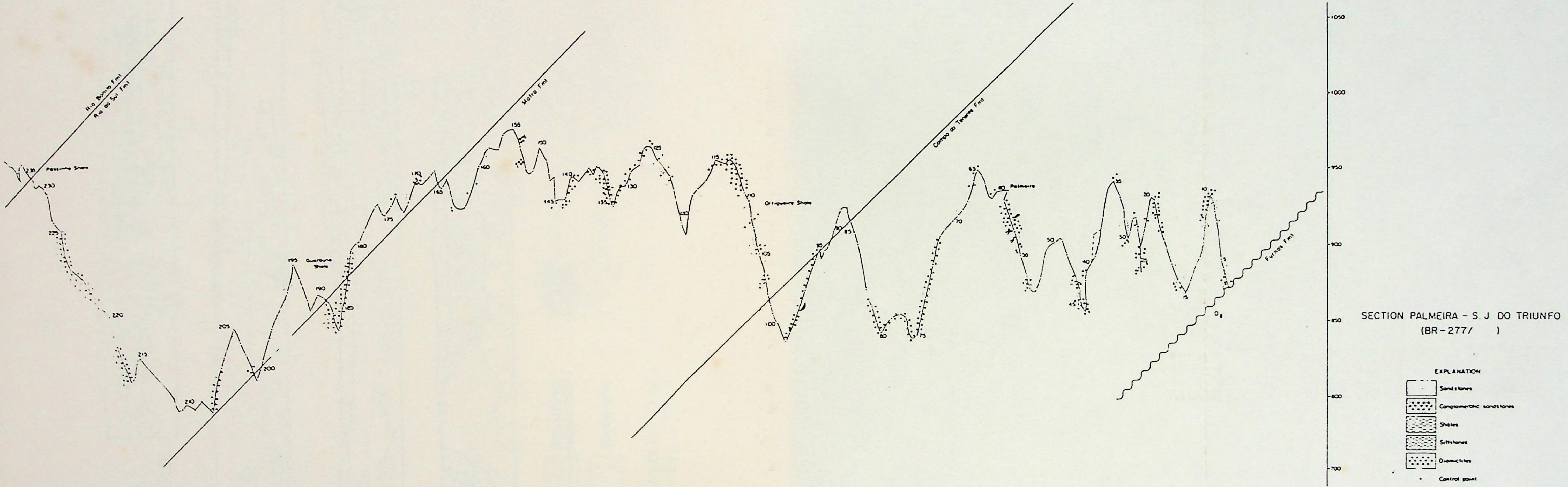


Fig.28 - Geological section along BR - 277 (MEDEIROS et al., 1971).

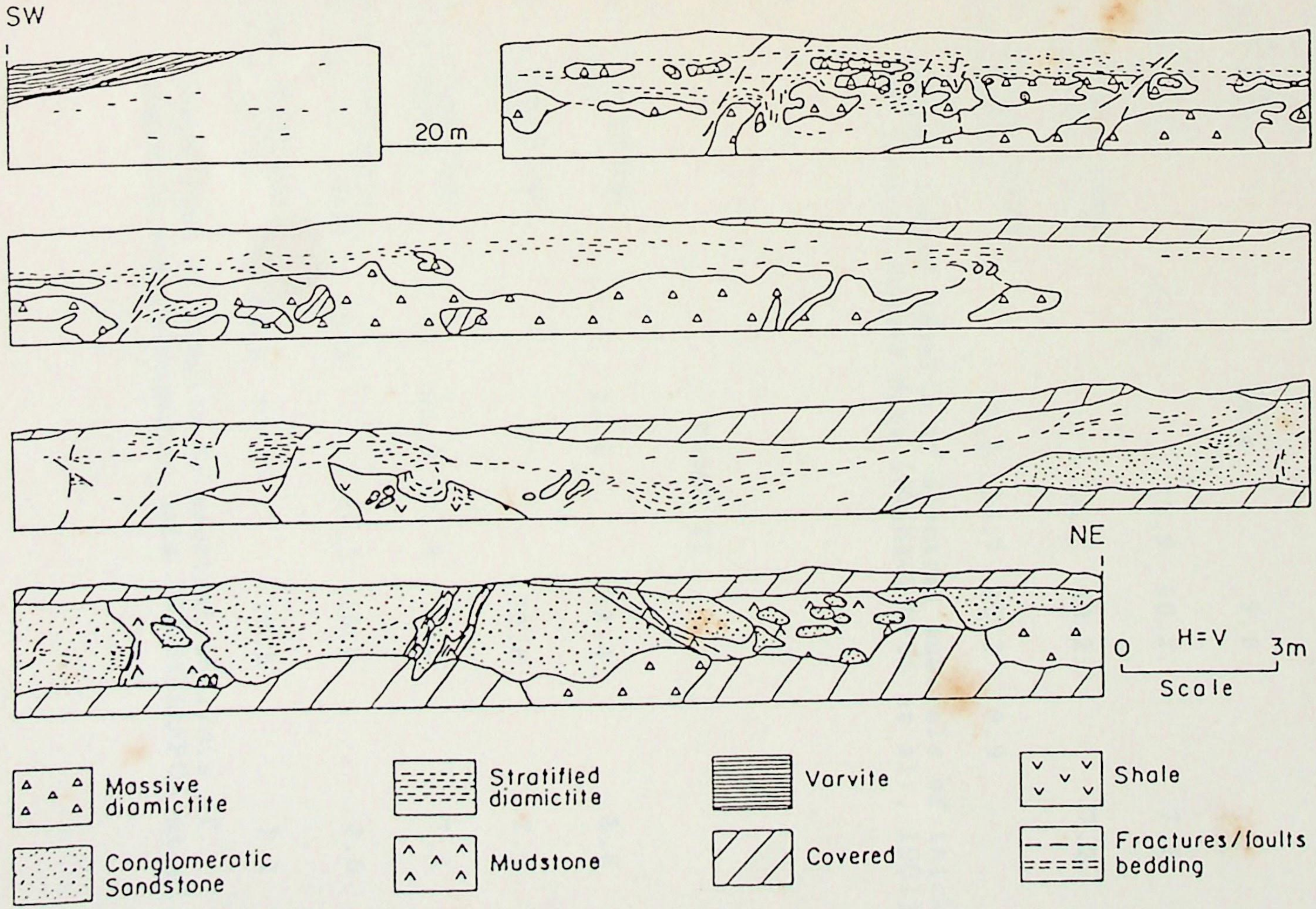


Fig.29 - Massive and stratified diamictite, Campo do Tenente Formation, BR-277, km17o(CANUTO, 1985).

TABLE I

						Period(years)		
ITU THICKNESS	40.0			11.5		8.3	6.5	5.6
POTREIRO GRANDE THICKNESS	43.5			12.0		8.6		5.5
ITAÚ THICKNESS		20.4		9.6			6.1	
RIO NEGRO THICKNESS	47.6		15.9	10.2		7.8	6.1	
SUNSPOT NUMBER DATA (Fraser-Smith,1972)			16.2	10.2		7.2	6.8	5.3
SUNSPOT NUMBER DATA (Currie,1973b)		23.6	14.7	11.2	9.9			

Comparison of results of spectral analysis of thickness and sunspot number data (ROCHA-CAMPOS et al., 1981).

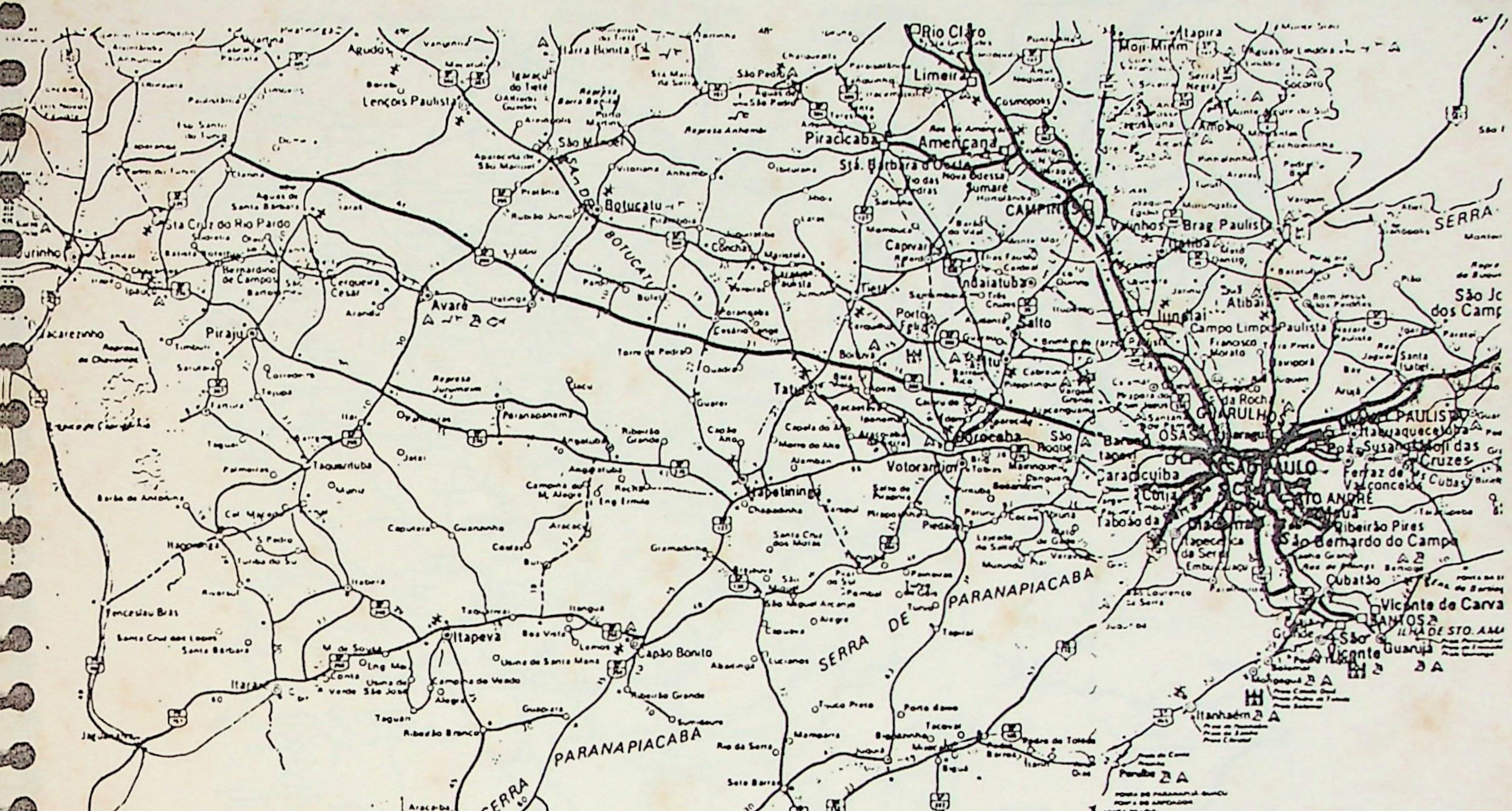
TABLE II

MAGN. DIRECTION ITU		24.4		12.4		8.6	6.7	5.5
MAGN. DIRECTION ITAÚ				10.6		7.9	6.5	
MAGN. DIRECTION RIO NEGRO		21.3	17.9	9.5		7.1		5.3
GEOMAG.SPECTRUM (Fraser-Smith,1972)	35.2		16,1	10.2		7.0		5.1
GEOMAG.SPECTRUM (Currie,1973a)	60.5	21.4		10.5		7.1	6.07	5.15

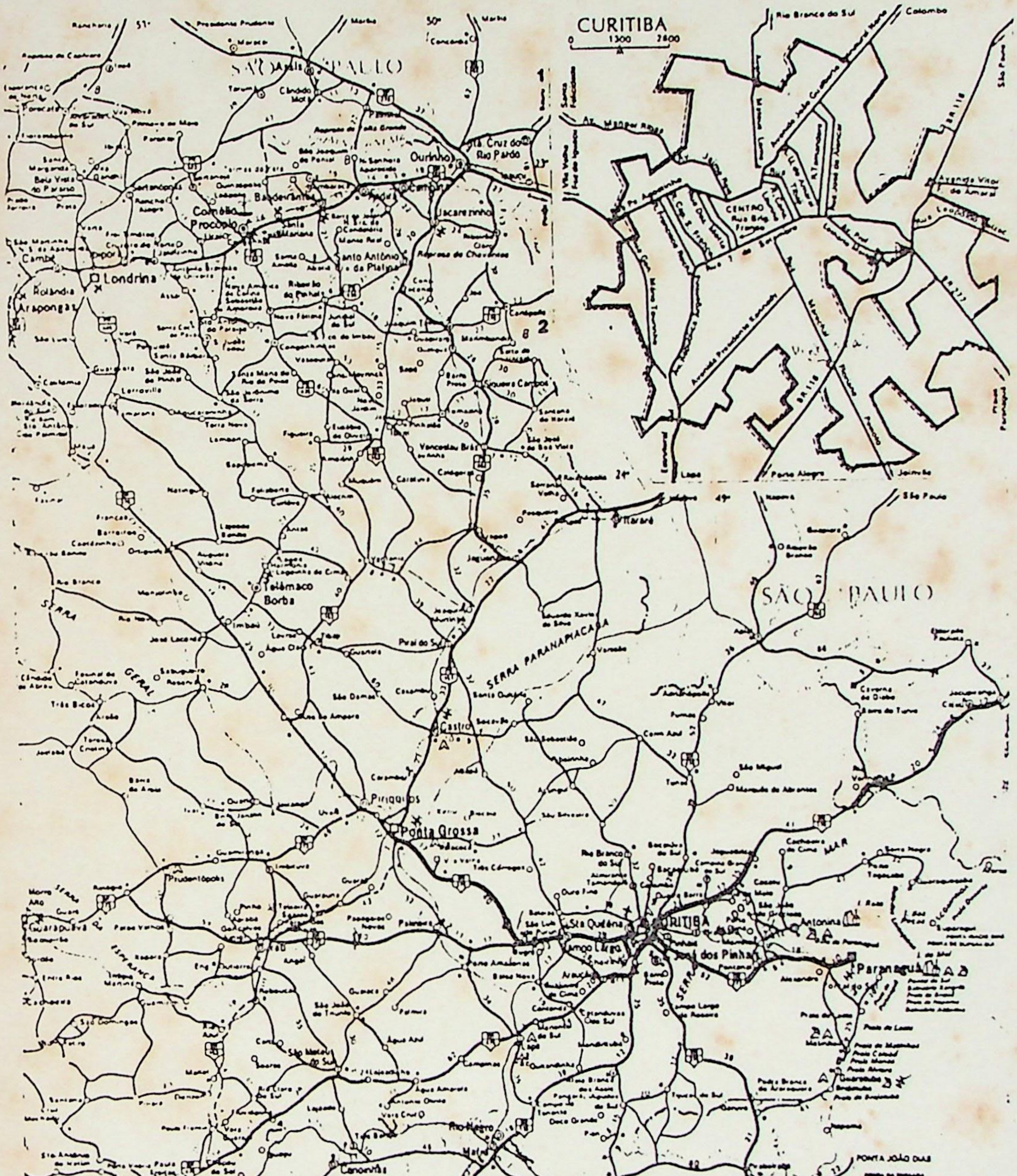
Comparison of results of spectral analysis of paleo magnetic and geomagnetic data (ROCHA-CAMPOS et al., 1981).

APPENDIX II

Road Maps



Rio Claro
Agudos
Barra Bonita
Igaraçu do Tietê
São Pedro
Limeira
Moji-Mirim
Lençóis Paulista
Piracicaba
Americana
Cosmópolis
São Manuel
Sta. Bárbara d'Oeste
Nova Odessa
Sumaré
Campinas
Botucatu
Vinhedo
Brag. Paulista
Atibaia
Sta Cruz do Rio Pardo
Bernardino de Campos
Cerqueira César
Avaré
Conchas
Capivari
Indaiatuba
Salto
Jundiaí
Campo Limpo Paulista
São José dos Campos
SERRA
Piraju
Tietê
Porto Feliz
Itu
Francisco Morato
Tatuí
Sorocaba
Guarulhos
Osasco
Barueri
Carapicuíba
São Paulo
Itaquaquecetuba
Mogi das Cruzes
Poá
Suzano
Ferraz de Vasconcelos
Santo André
Ribeirão Pires
São Bernardo do Campo
Taboão da Serra
Cubatão
Vicente de Carvalho
Santos
São Vicente
Guarujá
Ilha de Sto. Amaro
Votorantim
Itapetininga
Paranapanema
Taquarituba
Piedade
Itapeva
Capão Bonito
Itararé
Wenceslau Brás
SERRA DE PARANAPIACABA
SERRA PARANAPIACABA
Itanhaém
Registro
Eldorado
Iguape
ILHA COMPRIDA
Cananéia
Ilha do Cardoso
PARANÁ
Castro
Oceano Atlânti
SERRA DO MAR
CURITIBA
Campo Largo
Paranaguá
Ilha do Mel
Baía de Guaratuba


CURITIBA
0 1300 2800
SÃO PAULO
SÃO PAULO
SANTA CATARINA
SERRA PARANAPIACABA
SERRA GERAL
SERRA DO ESPIGÃO
CENTRO
Ourinhos
Sta. Cruz do Rio Pardo
Bandeirantes
Cornélio Procópio
Londrina
Rolândia
Arapongas
Cambé
Jacarezinho
Santo Antônio da Platina
Siqueira Campos
Wenceslau Braz
Itararé
Telêmaco Borba
Castro
Piraí do Sul
Piriquitos
Ponta Grossa
Prudentópolis
Guarapuava
Palmeira
Campo Largo
CURITIBA
S. José dos Pinhais
Antonina
Paranaguá
São Mateus do Sul
Lapa
Rio Negro
Mafra
Canoinhas
União da Vitória
Porto União
São Bento do Sul
Joinville
São Francisco do Sul
ILHA DE SÃO FRANCISCO
PONTA JOÃO DIAS
Jaraguá do Sul
Rio Branco do Sul
Colombo
1
2
51°
50°
49°
24°

)