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INTERGLACIAL AND EARLY POST-GLACIAL, LOWER GONDWANA COAL SEQUENCES IN THE PARANÁ BASIN, BRAZIL

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ABSTRACT

Upper Carboniferous to Lower Permian Gondwanan coals of the Paraná Basin occur both in interglacial/interstadial and post-glacial sequences. The first ones are found exclusively in the northeastern part of basin, in the State of São Paulo, included in the Itararé Subgroup. They are usually thin (max. 50 cm), dull, rich in mineral matter and silt intercalations. They are associated with pre-Gangamopteris (Monte Mor coals) and Gangamopteris (Cerquilho coals) floras, abundant exotic-bearing diamictites, striated boulder pavements and synsedimentary foldings in part related to glacier action. The post-glacial coal measures are found in the Lower Permian Rio Bonito Formation of the states of Santa Catarina and Rio Grande do Sul where the coals are thick enough to be mined. They are characterized by Glossopteris floral assemblages. Many coals in Rio Grande do Sul State derive from limno-telmatic peatlands developed in paleovalleys, others are associated with deltaic and barred coastal plains. In Santa Catarina and Paraná States coals are associated with upper deltaic to fluvial sequences.

INTRODUCTION

Objectives

The objectives of this paper are to review briefly the settings of the Permo-Carboniferous coals of the Paraná Basin in Brazil and establish whether any of the coal layers are of interglacial origin or whether they all are of post-glacial times (Fig. 1). Such a query impinges on the difficulty of recognition of the glacial-post-glacial transition. The focus of the paper is on the analysis of the coal-bearing sequences of the Cerquilho area in S. Paulo State which best exemplify the dilema (Fig. 1).

Paleoclimatic and glacial conditions are in many cases hypothesized on the basis of recognition and interpretation of diamictites and associated sequences as sedimentary facies of glacial origin (Landim and Frakes, 1968; Landim and Barros, 1972). Recognition of such glacial origin is not a trivial matter, because sediment gravity flows that affect them may occur also in non-glacial settings (Eyles and Eyles, 1983; Drewry, 1986).

Theoretically, paleoclimatic conditions could be established from fossil plants. Fossil plant associations have been interpreted linking, for instance, the Botrychiopsis association with a tundra-equivalent setting, the Gangamopteris association with a boreal-equivalent setting, and the Glossopteris association with a cold-temperate or temperate setting (Retallack, 1980). Unfortunately, these interpretations suffer from circular reasoning as many are based on the characteristics of the host rocks, for instance, presence of diamictites, rather than on independent, purely physiological evidence from the fossils themselves. Few of these plants have ring structures and cortex features which support seasonality, but not necessarily cold climate (Guerra-Sommer, pers. comm.; Bernardes de Oliveira, 1977, 1978; Mussa, 1982).

Methods of study

A review of the literature dealing with the Lower Permian of the Paraná basin was conducted first. Then, sedimentary facies analysis was applied to key outcrops and cores from coalfields of Rio Grande do Sul and, particularly of the Cerquilho area in São Paulo State. Most of the best exposures of the Paraná and S. Catarina states were visited as well, particularly those which show the transition between the Itararé Subgroup and the Rio Bonito Formation (Fig. 2).

THE PARANÁ BASIN

Geology of the coal-bearing Paleozoic sequences

The Paraná Basin is located in southwestern Brazil and extends into Argentina, Paraguay and Uruguay (Fig. 1). It covers 1,400,000 km^2 and it is filled by up to 3,500 m of Phanerozoic sedimentary rock.

The stratigraphic units of interest in this paper belong to the Tubarão Group, which is subdivided into a lower sub-group (Itararé Subgroup, Middle(?)-Upper Carboniferous to Lower Permian) and an upper subgroup (Guatá Subgroup, Lower Permian) (Fig. 2; Rocha-Campos, 1967). Coal measures are found primarily in the Rio Bonito Formation of the Guatá Subgroup, and only a few thin coal layers have been described from the Itararé Subgroup (Bortoluzzi et al., 1978; Correa da Silva, 1980). The Tubarão Group rests unconformably and onlaps on the Precambrian shield along all the eastern margin of the basin, except around the Ponta Grossa arch where the Group lies disconformably over Devonian sedimentary rocks (Daemon and Quadros, 1970; Schneider et al., 1974; Correa da Silva, 1978).

Local and global considerations indicate that the eastern edge of the Paraná Basin has been glaciated, that the basin was located at the margin of glaciers some of which originated in southern Africa, and that glaciers affected differently the various states of eastern Brazil (Martin, 1961; Rocha-Campos, 1967; Frakes and Crowell, 1969).

In S.Catarina and southern Paraná states, glaciations are recorded in striated pavements on Precambrian rocks, and on rocks of the Itararé Subgroup which include subglacial diamictites, "varvites", and glacio-marine deposits, which alternate with normal marine sediments (Canuto, 1985; Santos, 1987, Machado, 1988; Rocha-Campos et al., 1989). The sedimentary sequence shows overall upward coarsening as the basin was filled by prograding deltas and shores (Castro, 1980; Lopes et al., 1986; Machado, 1989).

The appearance of the first coarse winnowed coastal or fluvial sand identifies the base of the coal-bearing sequence ascribed to the Rio Bonito Formation (Castro, 1988). Glossopteris floral associations characterize this unit (Bortoluzzi et al., 1978; Correa da Silva, 1980; Rösler, 1978, 1979; Bernardes de Oliveira, 1977, 1978).

In Rio Grande do Sul, the lowest Permian unit cropping out around the Rio Grande do Sul - Uruguay shield in Rio Grande do Sul is equivalent to the upper Itararé Subgroup of the other states (Daemon and Quadros,1970) and consists mainly of diamictites and varvites and shows some glacial fluted surfaces. The glaciers flowed out from a centre on the shield and were funneled northward through structurally controlled valleys (Tomazelli and Soliani, 1982). The coals are of post-glacial times, and are found in the Rio Bonito Formation. Most of them derived from limno-telmatic peats formed in valley floors, others are associated with fens of barred coasts. The coals are found onlapping directly the Precambrian, on lacustrine sediments and, in some instance, they are associated with alluvial fans (Mendes-Piccoli et al., 1985; Mendes-Piccoli et al., 1986). Many coal layers are associated with an arkosic pebbly sand (locally called "pedra areia") which has been interpreted as debris flow (Gamermann and Coulon, 1975), but could also be considered a flash flood deposit.

The coal measures are overlain by marine units (Daemon and Quadros, 1970) (Fig. 2.)

In S. Paulo and northern Paraná State, the uppermost Carboniferous to Lower Permian sequence is complex and represents conditions proximal to the glacier, as indicated by striations, roche moutonnée, true subglacial tillites, striated boulder pavements, and numerous reworked subaqueous and subaerial diamictites (Rocha-Campos, 1967; Soares, 1972; Santos, 1987). Similarly to Rio Grande do Sul, structural valleys were filled with glacial, lacustrine, marine and fluvial deposits (Soares and Cava, 1982). Different from the Rio Grande do Sul, the S. Paulo region has experienced greater glacial deposition over a longer period of time from the Upper Carboniferous to the upper part of the Lower Permian (Santos, 1987; Rocha-Campos and Santos, 1981). There is some controversy, however, on whether the topmost part of what is called Itararé Subgroup in figure 2 belongs instead to a post-glacial unit (Tietê Formation) which would be equivalent to the Rio Bonito Formation (Fulfaro et al., 1984). Such controversy has to do with whether the topmost part of this sequence has been influenced by glaciers, and whether the thin coals that occur at Monte Mor, Buri and Cerquilho are interglacial/interstadial or post-glacial.

An interglacial setting for the Monte Mor coal-bearing sequence is established by its Late Carboniferous age, a time of glaciation in the region, and its pre-Gangamopteris flora (Taphoflora A of Rösler, 1978) (Figs. 2, 3; Millan, 1975, 1987). Although their correlation is debated, the coals of the Buri area may be of similar age and origin (Fig. 3; Cabral et al., 1983; Ciantelli et al., 1983; Cabral and Motta, 1985; Cabral et al., 1988).

Thicker and better studied coals are found in an alluvial floodplain sequence at Cerquilho (Figs. 1, 4). Considerable debate exists on the origin of these coal-bearing sequences, hence our analysis has concentrated on them.

Coal-bearing sequences of Cerquilho

The coal bearing rock sequence of the Cerquilho area is approximately 70 m thick and underlies the transgressive shallow marine siltstones and carbonates of the Tatuí Formation (Nagalli and Consoni, 1984; Fulfaro et al., 1984). Floristically the sequence is characterized by a "transitional tafoflora" which contains Gangamopteris. To date, no true Glossopteris has been found in it (Rösler, 1978; Millan, 1987). Core samples show a rich assemblage of spores (40-50%) and pollens (30-40%) associated with these coals. The subdivision of palynomorphs are approximately: triletes 40-45%; monosaccates 10-15%; non striated bisaccates 10-15%; striated bisaccates 20-25%; others 0-5%; and few Tasmanites which, however, may be reworked Devonian material (Rocha-Campos, unpublished data). This information suggests existence of continental wetlands surrounded by dry uplands. Lithologically, the coal-bearing silty and sandy units of the Cerquilho area are associated with diamictites. Many diamictites are massive, others show lamination or partings, and deformation, and are most likely formed by sediment gravity flows. Some authors (Nagalli and Consoni, 1984; Rocha-Campos et al., 1986) contend that these diamictites are glacial in origin, others (Fulfaro et al., 1984; Stevaux et al., 1985) that they were formed during post-glacial times.

In cores we have studied, four major facies associations succeed each other up to the coaly horizons (Figs. 5,6)

a. Rhythmites. They are characterized by sand and silt alternances which show internal grading, cross-laminations, some deformation structures, flame structures, pillows, pseudonodules. They are most likely of turbiditic, possibly hyperpycnal flow origin.

b. Well sorted silt and sand units. They consist of fine sand and silt, well sorted, light gray. They show faint horizontal lamination, ripple cross-lamination and flaser, deformation structures such as pseudonodules. Few burrows are present, some very large (order of 20-30 cm deep and 2-3 cm wide). This facies represents lower shoreface deposits.

c. Diamictite units. They are characterized by sandy matrix with disseminated granules and pebbles, some of which have exotic composition. Some diamictites have laminae of fairly well sorted sand and silt, others show contortions, microfaultings, diapires, load structures, irregular lamination. Occasional bioturbation occurs.

These diamictites are, for the most part, subaqueous debris flows developed in prograding marine shores/deltas, but in cores there is no unequivocal evidence to decide whether periglacial or post-glacial conditions prevailed.

d. Coal bearing units. They are characterized by fine to coarse sand, with some intercalations of silty sand, coal and carbonaceous silt. Most layers show horizontal lamination, ripple cross-lamination and occasional cross-beds. Fine grained conglomerates to pebbly coarse sands occur, and some contain intraformational silt clay pebbles. These units represent alluvial environments ranging from alluvial plains with wetlands and shallow lakes.

The coals are rooted, thin (maximum 50 cm), dull and rich in inertite. They are underlain and overlain by pebbly sandstones (some resembling diamictites), seldom by intraformational breccia and conglomerate, and fairly well-sorted sand.

The information obtained from a few key outcrops in the Cerquilho and Jumirin areas complements the evidence from the cores, by allowing analysis of large scale features (Rocha-Campos et al., 1986).

a. Near Cerquilho, the sequence show coal-bearing, thinly interbedded silts and sands, locally folded, faulted and jointed, and truncated by an undulating, sub-horizontal surface (Fig. 7). A large (approximately 1.5 m in diameter), exotic granitic boulder rests directly on the surface, included between a triangular slice of massive, sandy diamictite on one side and deformed conglomeratic, poorly sorted sandstone on the other. This polymictic sequence is capped by a massive, sandy diamictite (about 2.5 m thick) with floating exotic clasts. This diamictite is in turn overlain by two superimposed sequences (about 4 m thick each) separated by a fine clay lamina, and characterized by relatively well sorted sand and silt showing fining upward trends with cross-beds at the base and laminated to cross-laminated layers above. These two sequences are of probable fluvio-lacustrine origin.

The top part of the uppermost fluvio-lacustrine sequence shows structural deformations and shears. It is overlain by a massive, heavily weathered, silty sandy diamictite (about 1.5 m thick) containing floating coarse sand grains and few pebbles.

b. Another important outcrop is found along a railway cut near Jumirim, approximately 20 km northwest form Cerquilho. The outcrop shows a lower, tightly isoclinally folded, thick sandstone, sharply overlain by a silty-sandy, gray, indurated massive diamictite. The diamictite contains cobbles and boulders primarily of quartzite and granite dispersed throughout and locally concentrated in a boulder pavement (Fig. 8A). The clasts are rounded to subrounded, and many show iron shapes, facetting and striations (Fig. 8B). These and other features such as thin, irregularly distributed sorted sand layers and veins found above and below the boulder pavements have been interpreted by Rocha-Campos et al (1968, 1969) to record glacial action and frozen ground conditions.

DISCUSSION

The thin, inertite rich coals of São Paulo State indicate that active alluvial clastic sedimentation did not allow ancient peatlands to persist for long time at any one location. The determination of paleoclimatic conditions under which the coal measures developed and whether glaciers had some direct or indirect effect on it, rests, for the most part, on the interpretation of the origin of the diamictites and associated sedimentary features. Two interpretations exist of the coal-bearing sequences of the Cerquilho area. One is based on the semi-regional analysis of the cores of the Cerquilho area, and suggests that the diamictites underlying the coals and those overlying them are related to advancing and retreating glacial lobes which reached this marginal area (Figs. 4, 9A; Nagalli and Consoni, 1984). The second interpretation is based on detailed analysis of cores from a smaller local area, and suggests that the sequence developed as a post-glacial prograding delta and alluvial plains (Fig. 9B; Stevaux et al., 1985).

The deposits in the local area where the best coals are found, could be indeed readily explained as prograding fluvial and shoreface sedimentation with material contributed from exposed crystalline basement, and/or from reworked pre-existing glaciated terrains. However, when the overall region is taken in consideration, questions must be raised about the significance of the recurring coexistence of abundant exotic materials, faceted particles with various types of striations and crescentic marks, massive exotic-bearing diamictites showing variable structures and composition, intraformational folds and shear zones, and a taphoflora which is transitional between a colder climate older Botrychiopsis one of the lower Itararé Subgroup and the temperate climate Glossopteris one of the overlying Rio Bonito Formation in southern states of Brazil. To explain such a variety of sediments and sedimentary features, a very active sedimentation regime is required under variable climatic conditions and presence of reasonable slopes. Then, either the tectonics of the area was much more active than evidence would indicate, or glaciers were still present in the area to produce similar effects, or a combination of the two occurred.

What was happening along the western margin of the Paraná Basin at large during the lower Permian time ? Perhaps a basin-wide regional view can help in understanding the local problems of the Cerquilho area.

Relative steep slopes were present in parts of Rio Grande do Sul, where some are being exhumed. Slope deposits were present both during the deposition of the possible glacigenic Itararé Subgroup and the post-glacial coal-bearing Rio Bonito Formation. In S. Catarina and parts of Paraná State steep slopes and possible reactivation of normal faults occurred during the deposition of the Itararé Subgroup, but the sedimentation of the coal bearing layers of the post-glacial Rio Bonito Formation occurred on regularly prograding alluvial, deltaic and coastal sequences. In São Paulo and parts of Paraná State , the morphology of the depositional surface has not been completely clarified. For instance, the highlands west of the city of São Paulo do not show evidence of glaciation on them, but they have undergone considerable erosion, weathering and are now heavily covered by vegetation. These highlands grade westward into a "transition zone" with valley fills containing tillites (Cerquilho is located about 50 km west of this zone). This zone in turn grades westward into the fully developed marine Paraná Basin. Perhaps valleys existed throughout the deposition of the Itararé Subgroup in the areas marginal to the main basin and glaciers were funnelled through them first. Later marine embayment developed, and finally coal bearing strata formed on the prograding alluvial systems.

Furthermore, tectonic movements may have occurred during Permian times in the Paraná Basin, affecting sedimentation through shift of basinal depocenters or, locally, through growth fault reactivation which may have been one of the mechanisms triggering debris flow. Although the eastern flank of the Paraná Basin was located at the margin of large ice sheets, extending from Africa, some glacier-induced isostatic readjustments, similar to those we see in the Quaternary of North America (Martini and Bowlby, in press), may have occurred and been influential in reactivating older faults. Such structures may have affected local sedimentation, but alone would not justify the variation in sedimentary features observed in the Cerquilho area.

The sedimentary features described in the Cerquilho area can be more readily explained by the influence of glacial lobes which advanced and retreated locally, at times overriding some sequences, in places reaching the sea and entering marine embayments aground or floating in them. This setting would explain the interstratification of glacigenic-like deposits, particularly the abundant exotic-bearing diamictites, with marine and alluvial sediments. The intraformational folds involving the coal-bearing strata and diamictites, the evidence of shearing, the large isolated granitic boulder and the associated complex distribution of diamictite and contorted conglomerate of the Cerquilho outcrop may record ice push action of a surging glacial lobe. Similarly, the development of an intrastratal boulder pavement at Jumirim can be associated with lodgement processes at the base of a glacial lobe.

If this latter interpretation is correct, the Cerquilho coals are interglacial/interstadial deposits and they belong to the Itararé Subgroup, as this is identified as the glacially affected stratigraphic unit, rather than the post-glacial Rio Bonito Formation. The Cerquilho occurrences should be comparable to Quaternary analogues of the Northern Hemisphere. A preliminary search has revealed that only few well-developed interglacial peats are preserved in Quaternary glaciated areas of North America, and they consist of lacustrine to telmatic deposits or transported organic material in shallow lakes (Fulton, 1984). One of the best examples of buried fen (low moor) peat occurs in the Hudson Bay Lowland, on the west coasts of James Bay (McDonald, 1969). The buried ancient peat developed on top of an offlap marine sequence in an alluvial setting. The peat is highly deformed and is covered by tills of the last glaciation. These tills are in turn covered by a second offlap sequence capped by the modern, very extensive peatland. In Europe, particularly in Holland and northern Germany, well-developed interglacial peats (Eemian in age) are found in stratigraphic sequences entirely formed by ice-proximal, fluvial deposits, that is, they have not been overridden by glaciers (Fig. 10; Ter Wee, 1983). The interglacial/interstadial position of such peats is established by their age and by the presence of nearby, laterally equivalent diamictites associated with glacial lobes surging along certain valleys.

The Quaternary examples indicate that interglacial and interstadial peats form and can be preserved both in areas overridden by glaciers and in ice-marginal zones. Similar settings may have existed in the Cerquilho area. The Quaternary examples show also that the peatlands formed in interglacial and post-glacial times only after climate had ameliorated to boreal conditions (Martini and Glooschenko, 1985). In the Holocene, the transition from a glacial to a boreal climate occurred in about 5-6,000 years, an almost instantaneous geologic event.

CONCLUSIONS

1. Except for those of S. Paulo State, the coals of the Paraná Basin are all of post-glacial times.

2. Fossil plant, microflora, and climatic non-diagnostic trace fossils and marine invertebrate fossils are available in the Permian sequence of the eastern side of the Paraná Basin. Although there is evidence of seasonal climatic changes (ring and cortex plant structures), there is no evidence of very cold climate during the deposition of the peats. This is consistent with what we know about Quaternary boreal conditions.

3. Whichever interpretation is given for certain diamictites (till, flow-till, or non-glacial debris flow), such interpretation carries certain implications about the paleogeographic (types of slopes), climatic (semi-aridity) and structural settings, which needs addressing and may require re-interpretation of the geology of the region. It is likely that tectonic rejuvenation of slopes, glacial activities and changing climatic conditions have all contributed to form the variable Permo-Carboniferous sedimentary sequence of the Paraná Basin.

4. Coals of Monte Mor are intercalated within the glacial sequences of the Itararé Subgroup, and have pre-Gangamopteris flora and are considered interglacial. Although the stratigraphic position on the coals of Buri is controversial, they too may be considered interglacial deposits.

5. The coal-bearing sequences of the Cerquilho area were formed on prograding coastal and alluvial environments. However, the recurrent association of diamictite carrying exotic materials, faceted and striated pebbles, boulder pavements, large scale intraformational deformation and shear zones and similar features, indicate active and variable sedimentation regimes most likely associated with, and more simply explained by, glacigenic processes. At any rate, the possibility that these coals are of interglacial or interstadial settings is intriguing and would represent one of the few ancient analogs of the Pleistocene peats of North America (example of Hudson Bay Lowland) and of Europe (example of Holland and northern Germany). The European peats are found in fluvial sequences which locally do not contain any direct sedimentological evidence of glaciation, but their interglacial origin is demonstrated by their age and lateral association with tills.

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REFERENCES CITED

Bernardes de Oliveira, M.E.C., 1977, Tafoflora Eogondvânica da Camada Irapuá, Formação Rio Bonito (Grupo Tubarão), SC [Doctor's Thesis]: São Paulo, Instituto de Geociências, Universidade de São Paulo, v. 1, 301 p.

Bernardes de Oliveira, M.E.C., 1978, Tafoflora Eogondvânica da Formação Rio Bonito ("Camada Irapuá"), Bacia do Paraná, Brasil: Actas del Segundo Congreso Argentino de Paleontologia y Bioestratigrafia y Primer Congreso Latinoamericano de Paleontologia, Asociación Paleontologica Argentina, p. 69-87.

Bortoluzzi, C.A., Mendes-Piccoli, A.E., Bossi, G.E., Guerra Sommer, M., Marques Toigo, M., Pons, M.E.H., Wolf, M., and Correa da Silva,Z. C., 1978, Pesquisa geológica na bacia carbonífera de Santa Catarina. Instituto de Geociências, Universidade Federal do Rio Grande do Sul. Pesquisa, v. 11, p. 33-192.

Cabral Jr., M., Ciantelli Jr., C.A., and Nakano, S., 1983, Prospecção regional de carvão na região de Taquarituba-Itaporanga (SP). Sociedade Brasileira de Geologia, Núcleo de São Paulo. 4º Simpósio Regional de Geologia. Atas, p. 341-352.

Cabral Jr., M., Campanha, V.A., Motta J.F.M., and Saad, A.R., 1988, Contribuição à estratigrafia e paleogeografia para carvão no Estado de São Paulo: Sociedade Brasileira de Geologia, Anais do XXXV Congresso Brasileiro de Geologia, v.2, p. 879-893.

Cabral Jr., M., and Motta, J.F.M., 1985, Geologia da Formação Itararé e sua potencialidade para carvão na região de Buri-Itapeva (SP). Sociedade Brasileira de Geologia, Núcleo de São Paulo, 5º Simpósio Regional de Geologia. Atas, v. 2, p. 459-472.

Canuto, J.R., 1985, Origem dos diamictitos e rochas associadas do Subgrupo Itararé no sul do Estado do Paraná e norte do Estado de Santa Catarina. [M.S. Dissertation]: São Paulo, Instituto de Geociências, Universidade de São Paulo, 187 p.

Canuto, J.C. de, 1980, Facies, ambientes e seqüências deposicionais das formações Rio do Sul e Rio Bonito, leste de Santa Catarina. Sociedade Brasileira de Geologia, Anais do XXXI Congresso Brasileiro de Geologia, v. 1, p. 283-299.

Castro, J.C. de, 1980, Facies, ambientes e seqüências deposicionais das formações Rio do Sul e Rio Bonito, leste de Santa Catarina. Sociedade Brasileira de Geologia, Anais do XXXI Congresso Brasileiro de Geologia, v. 1, p. 283-299.

Castro, J.C. de, 1988, Sedimentology, stratigraphy and paleontology of the Gondwana sequence of the Paraná Basin. Seventh Gondwana Symposium, Guidebook, Excursion A2, Petróleo Brasileiro S.A., 29 p.

Ciantelli Jr., C.A., Cabral Jr., M., and Nakano, S., 1983, Avaliação preliminar das ocorrências de carvão mineral na região de Buri-Itapeva. Sociedade Brasileira de Geologia, Núcleo de São Paulo, Atas, p. 353-365.

Correa da Silva, Z.C., 1978, Observações sobre o Grupo Tubarão no Rio Grande do Sul com especial destaque à estratigrafia da Formação Itararé. Instituto de Geociências, Universidade Federal do Rio Grande do Sul, Pesquisas, v. 9, p. 9-61.

Correa da Silva, Z.C., 1980, The Permian coal deposits of South Brazil. Acta Geologica Leopoldensia, v. 4, p. 19-43.

Daemon, R.F., and Quadros, L.P., 1970, Bioestratigrafia do Neopaleozóico da Bacia do Paraná. Sociedade Brasileira de Geologia, Anais do XXIV Congresso Brasileiro de Geologia, p. 359-412.

Drewry, D., 1986. Glacial Geologic Processes. E. Arnold, London, 276 p.

Eyles, C.H., and Eyles, N., 1983, Sedimentation in a large lake. A reinterpretation of the late Pleistocene stratigraphy at Scarborough Bluffs, Ontario, Canada, Geology, v. 11, p. 146-152.

Frakes, L., and Crowell, J.C., 1969, Late Paleozoic glaciation: I South America. Geological Society of America Bulletin, v. 80, p. 1007-1042.

Fulfaro, V.J., Stevaux, J.C., Souza Filho, E.E. de, and Barcelos, J.H., 1984, A Formação Tatui (P) no Estado de São Paulo. Sociedade Brasileira de Geologia, Anais do XXXIII Congresso Brasileiro de Geologia, v. 2, p. 711-724.

Fulton, R.J., (ed.), 1984, Quaternary stratigraphy of Canada. Geological Survey of Canada Paper 84-10, 210 p.

Gamermann, N., and Coulon, F.K., 1975, Estudo do diamictito "pedra-areia" e sua influência na gênese do carvão na mina do Leão (RS). Instituto de Geociências, Universidade Federal do Rio Grande do Sul, Pesquisas, p. 167-180.

Gravenor, C.P., and Rocha-Campos, A.C., 1983, Patterns of late Paleozoic glacial sedimentation on the southeast side of the Paraná Basin, Brazil. Palaeogeography, Palaeoclimatology, Palaeoecology, v.432, p. 1-39.

Landim, P.M.B., and Barros, M.B.R., 1972, Distinção de tilitos dentre os mistitos do Subgrupo Itararé. Revista da Sociedade Brasileira de Geologia, v. 2, p. 270-274.

Landim, P.M.B., and Frakes, L.A., 1986, Distinction between tills and other diamictons based on textural characteristics. Journal of Sedimentary Petrology, v. 38, p. 1213-1223.

Lopes,C.R. da, Lavina, E.L., and Signorelli, N., 1986, Facies sedimentares e evolução paleoambiental do Supergrupo Tubarão na borda leste da bacia do Paraná. Uma seção regional nos estados do Rio Grande do Sul e Santa Catarina. Sociedade Brasileira de Geologia, Anais do XXXIV Congresso Brasileiro de Geologia, v. 1, p. 206-218.

Machado, L.C.R., 1989, Facies e arcabouço estratigráfico do Grupo Itararé em Alfredo Wagner (SC) - Sedimentação periglacial [M.S.Dissertation], Ouro Preto, Escola de Minas, Universidade Federal de Ouro Preto, 161 p.

Martin, H., 1961, The hypothesis of continental drift in the light of recent advances of geological knowledge in Brazil and in South West Africa. Geological Society of South Africa, Alex L. du Toit Memorial Lectures nº 7, 55 p.

Martini, I.P., and Bowlby,J.R., (in press), Geology of the Lake Ontario Basin: review and outlook. Canadian Journal of Fisheries and Aquatic Sciences.

Martini, I. P., and Glooschenko, W.A., 1985, Cold climate peat formation in Canada, and its relevance to Lower Permian coal measures of Australia. Earth Science Review, v. 22, p. 107-140.

McDonald, B.C., 1969, Glacial and interglacial stratigraphy, Hudson Bay Lowland. Geological Survey of Canada Paper 68-53, p. 78-99.

Mendes-Piccoli, A.E., Holz, M., Degrazia Sarturi, J.A., Munaro, P., and Granitoff, W., 1985, Estratigrafia da bacia carbonífera de Charqueadas-Santa Rita, RS, Brazil. Instituto de Geociências, Universidade Federal do Rio Grande do Sul, Pesquisas, v. 17, p. 269-310.

Mendes-Piccoli, A.E., Lopez da Cunha, R., and Camozzato, E., 1986, Análise paleoambiental das jazidas de carvão do Estado do Rio Grande do Sul. Acta Geologica Leopoldensia, v. 10, p. 35-54.

Millan, J.H., 1975, Tafoflórula de Monte Mor do Estado de São Paulo: seus elementos e seu significado no Gondwana Inferior do Brasil. Revista Brasileira de Geociências, v.5, p. 1-14.

Millan, J.H., 1987, Os pisos florísticos do carvão do Subgrupo Itararé do Estado de São Paulo e suas implicações. Sociedade Brasileira de Paleontologia, Anais do X Congresso Brasileiro de Paleontologia, v. 2, p. 831-867.

Mussa, D., 1982, Lignitafofloras permianas da Bacia do Paraná, Brasil (Estados de São Paulo e Santa Catarina) [Doctor's thesis]. São Paulo, Instituto de Geociências, Universidade de São Paulo, v. 1, 463 p.

Nagalli, J.T., and Consoni, J.O.C., 1984, Comportamento faciológico do intervalo que encerra as camadas de carvão, na região de Cerquilho, Sociedade Brasileira de Geologia, Anais do XXXIII Congresso Brasileiro de Geologia, v. 2, p. 974-982.

Retallak, G., 1980, Late Carboniferous to Middle Triassic megafossil floras from the Sydney Basin, in Herbert, C., and Helby, R., eds., A Guide to the Sydney Basin. Geological Survey of New South Wales Bulletin, v. 26, p. 384-430.

Rocha-Campos, A.C., 1967, The Tubarão Group in the Brazilian portion of the Paraná Basin, in Bigarella, J.J., Becker, R.D., and Pinto I.D., eds., International Symposium on Gondwana Stratigraphy and Paleontology: Curitiba, Brazil, p. 27-102.

Rocha-Campos, A.C., Farjallat, J.E.S. and Yoshida, R., 1968, New glacial features of the Upper Paleozoic Itararé Subgroup in the State of São Paulo, Brazil. Boletim da Sociedade Brasileira de Geologia, v. 17, p. 47-57.

Rocha-Campos, A.C., Farjallat, J.E.S., and Yoshida, R., 1969, Crescentic marks on a Late Paleozoic glacial pavement in Southeastern Brazil. Geological Society of America Bulletin, v. 80, p. 1123-1126.

Rocha-Campos, A.C., and Santos, P.R. dos, 1981, The Itararé Subgroup, Aquidauana Group and San Gregorio Formation, Paraná Basin, southeast South America in Hambrey, M.J., and Harland, W.B., eds., Earth's pre-Pleistocene glacial record, Cambridge University Press, p.842-852.

Rocha-Campos, A.C., Santos, P.R. dos, and Canuto, J.R., 1986, Glaciotectonic structures in the upper Itarare Subgroup (Late Paleozoic) near Cerquilho, State of São Paulo, Brasil. Sociedade Brasileira de Geologia, XXXIV Congresso Brasileiro de Geologia, Boletim nº 1, Resumos e Breves Comunicações, p. 57-58.

Rocha-Campos, A.C., Machado, L.C.R., Santos, P.R. dos, Canuto, J.R., and Castro, J.C. de, 1989, Pavimento estriado da glaciação neopaleozóica, em Alfredo Wagner, Santa Catarina, Brasil. Instituto de Geociências, Universidade de São Paulo, Bol. IG-USP, v. 19, p. 39-46.

Rösler, O., 1978, The Brazilian eogondwanic floral succession. Instituto de Geociências, Universidade de São Paulo, Boletim IG-USP, v. 9, p. 85-89.

Rösler, O., 1979, Plantas fósseis de São João do Triunfo (PR), Formação Rio Bonito, e suas implicações geológicas. Sociedade Brasileira de Geologia, Núcleo de São Paulo, 2º Simpósio Regional de Geologia, v. 1, p. 181-194.

Santos, P.R. dos, 1987, Facies e evolução paleogeográfica do Subgrupo Itararé/Grupo Aquidauana (Neopaleozóico) na Bacia do Paraná, Brasil [Doctor's thesis]. São Paulo, Instituto de Geociências, Universidade de São Paulo, 128 p.

Schneider, R.L., Muhlmann, H., Tommasi, E., Medeiros, R.A., Daemon, R.F., and Nogueira, A.A., 1974, Revisão estratigráfica da Bacia do Paraná. Sociedade Brasileira de Geologia, Anais do XXVII Congresso Brasileiro de Geologia, v. 1, p. 41-65.

Shilts, W.W., 1982, Quaternary evolution of the Hudson/James Bay Region. Naturaliste Canadien, v. 108, p. 309-332.

Soares, P.C., 1972, O limite glacial/pos-glacial do Grupo Tubarão no Estado de São Paulo. Anais da Academia Brasileira de Ciências, v. 44, Supl., p. 333-342.

Soares, P.C., and Cava, L.T., 1982, Faciologia e potencial carbonífero da Formação Rio Bonito no norte do Estado do Paraná. Sociedade Brasileira de Geologia, Anais do XXXII Congresso Brasileiro de Geologia, v. 3, p. 1120-1134.

Stevaux, J.C., Souza Filho, E. E. de, Perinotto, J.A. de J., and Tai, W.F., 1985, Análise paleogeográfica da ocorrência de carvão no Bairro Aliança, Cerquilho (SP). Sociedade Brasileira de Geologia, 5º Simpósio Regional de Geologia, Atas 1, p. 221-233.

Ter Wee, M.W., 1983, The Saalian Glaciation in the Northern Netherlands, in Ehlers, J., ed., Glacial deposits in North-West Europe: Balkema, Rotterdam, p. 405-412.

Tomazelli, L.J., and Soliani, E. Jr., 1982, Evidências de atividade glacial no Paleozóico Superior do Rio Grande do Sul, Brazil. Sociedade Brasileira de Geologia, Anais do XXXI Congresso Brasileiro de Geologia, v. 4, p. 1378-1391.

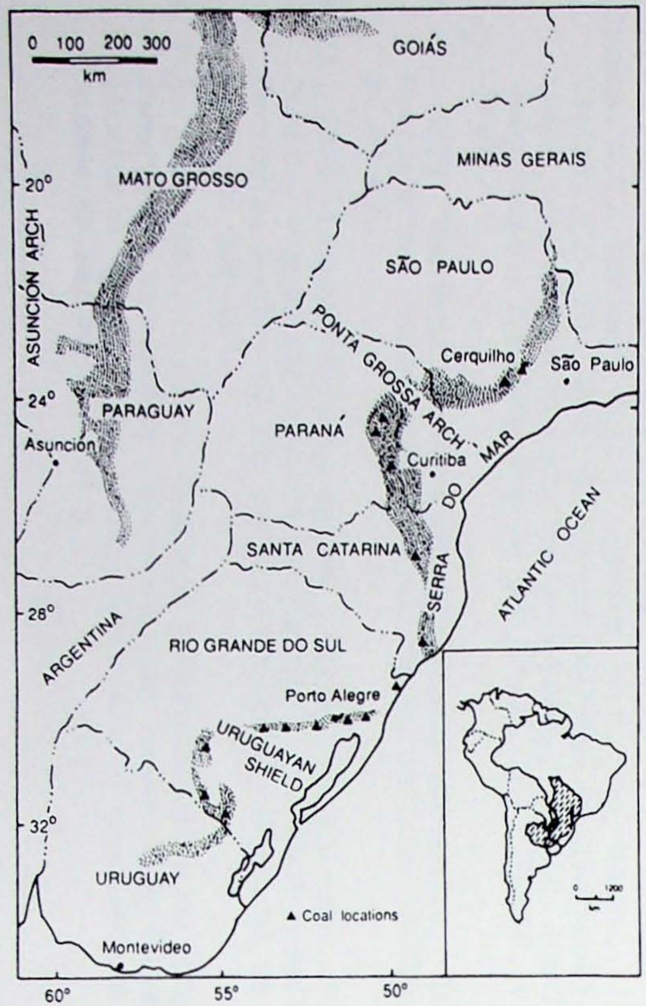

Figure 1. Location Map of the Parana' Basin.

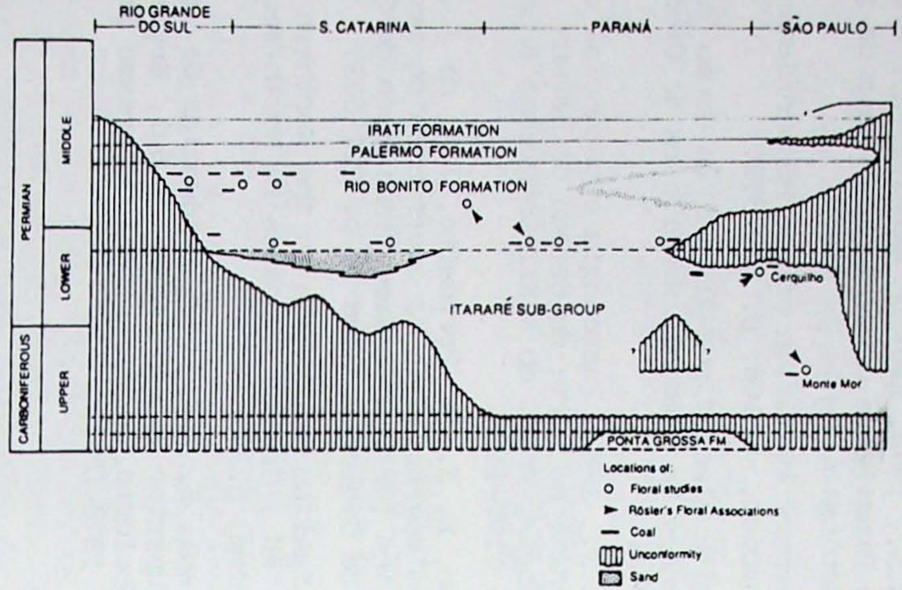

Figure 2. Stratigraphy of the Parana' Basin. *(after Rosler, 1979)*

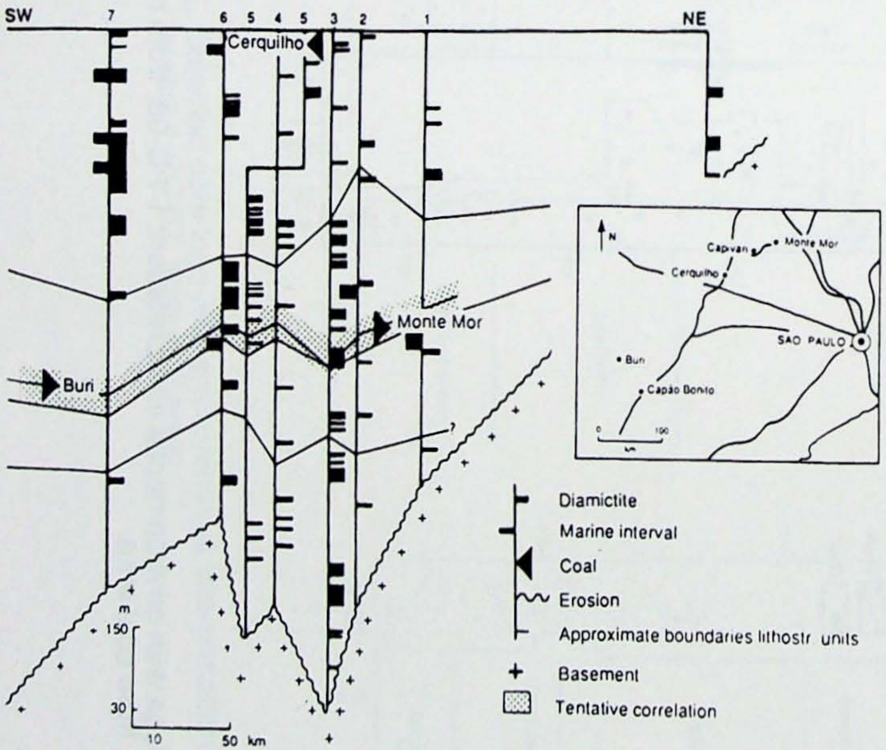

Figure 3. Stratigraphic cross-section in Sao Paulo State from northeast of Monte Mor to Capao Bonito with location of three coal zones. *(after Gravenor and Rocha-Campos, 1983)*

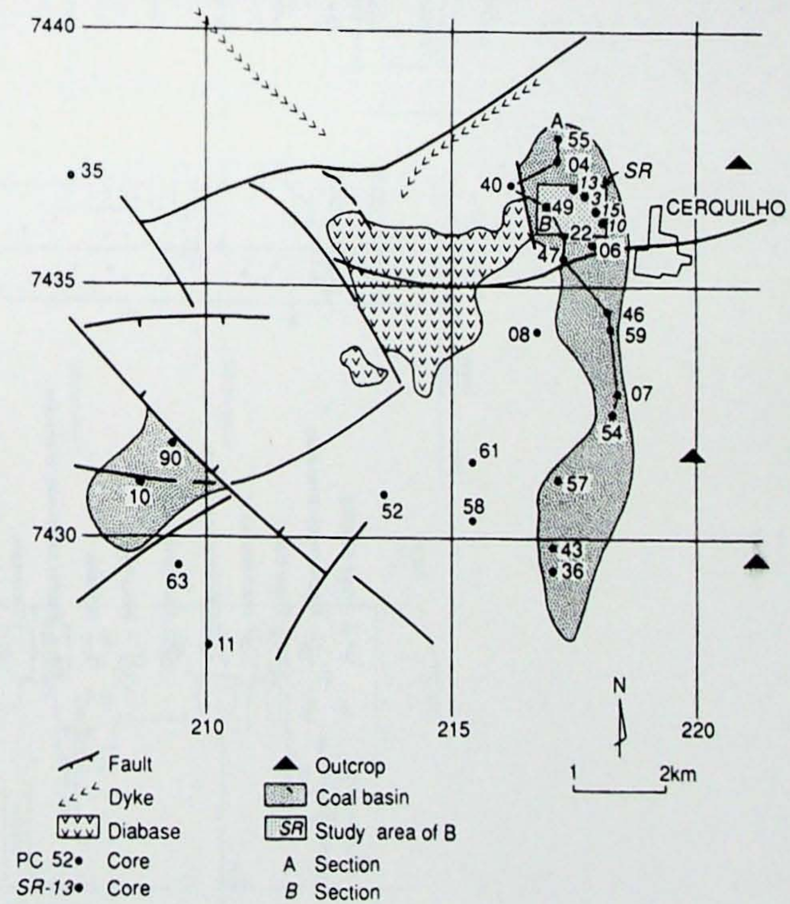

Figure 4. Coal areas near Cerquilho and location of a few cores and outcrops.

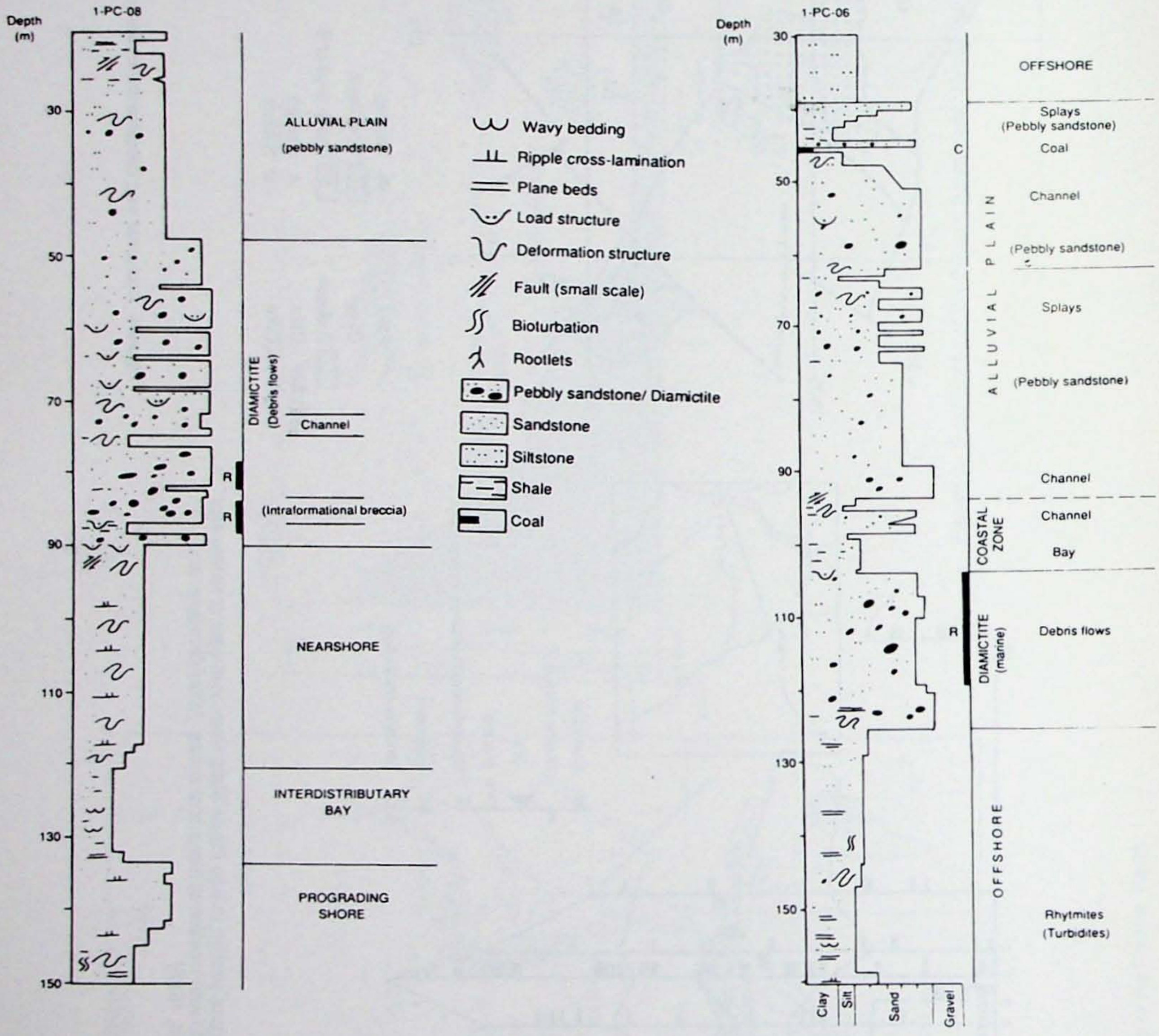

Figure 5. Selected core logs with environmental interpretation: 1-PC-08, from near coal area; 1-PC-06, from coal area.

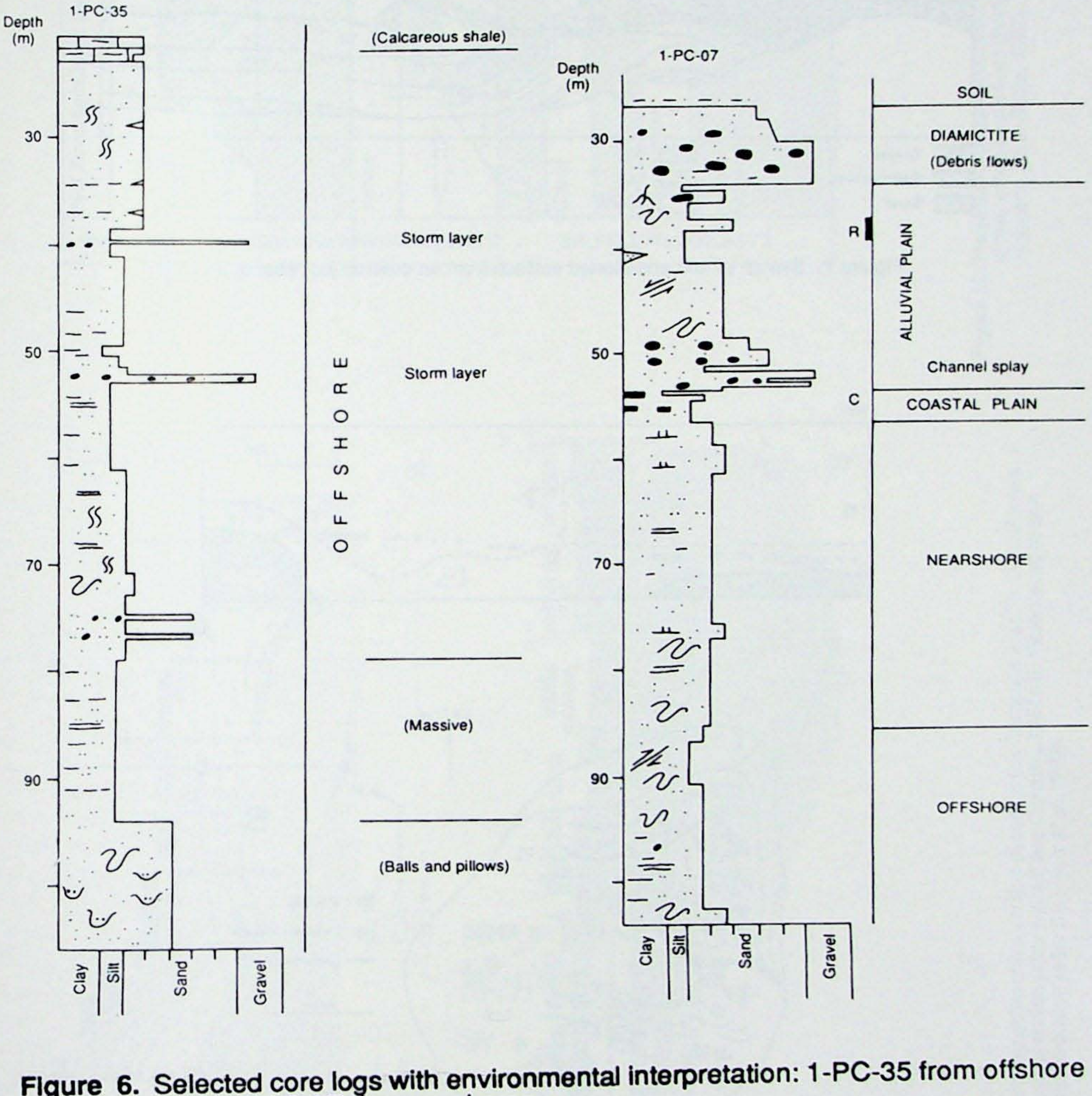

Figure 6. Selected core logs with environmental interpretation: 1-PC-35 from offshore areas; 1-PC-07, from coal area.

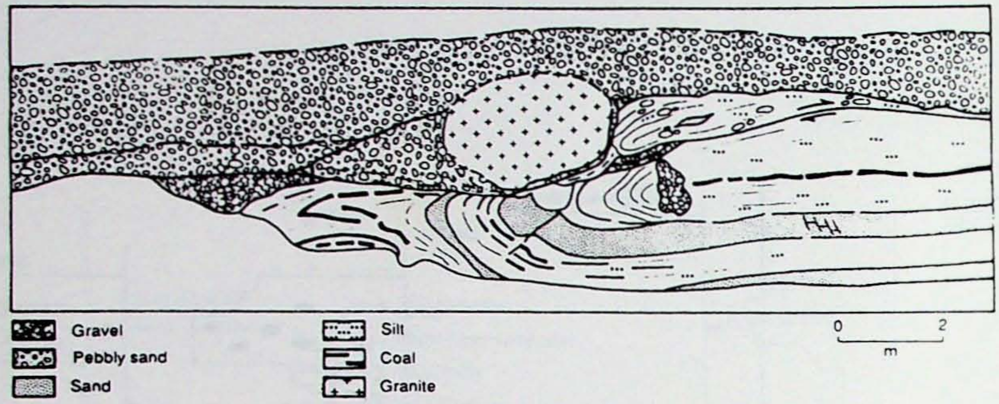

Figure 7. Sketch of fold and planed surface from an outcrop just east of Cerquilho.

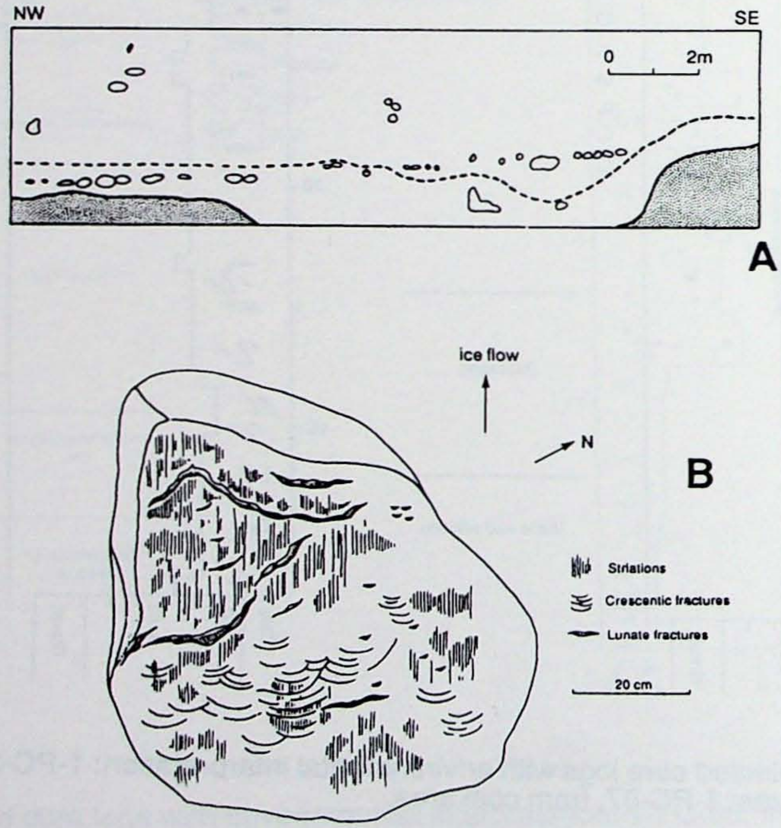

Figure 8. Jumirim outcrop: A. Boulder pavement *(after Rocha-Campos et al. 1968)*; B. Striated boulder *(after Rocha-Campos et al 1969)*.

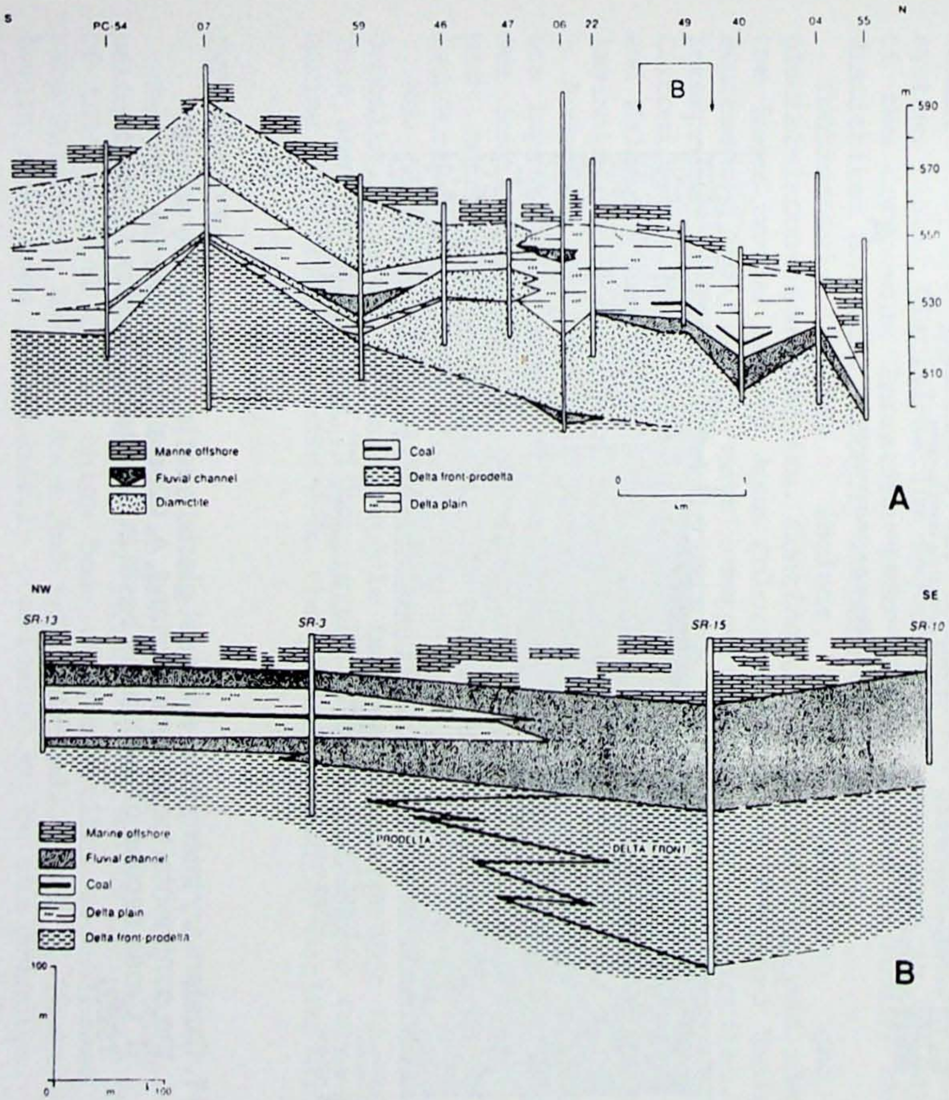

Figure 9. Stratigraphic cross-section of core in the Cerquilho area: A. Glacial lobes interpretation *(after Nagalli and Consoni, 1984)*; B. Post-glacial deltaic interpretation *(after Steavaux at al. 1985)*.

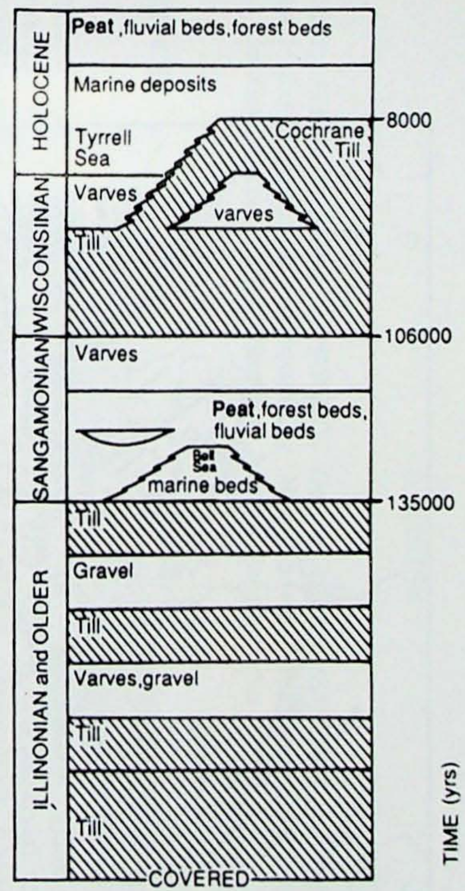

Figure 10. Pleistocene stratigraphic section showing two similar offlap sequences during Sangamon and Holocene *(after Shilts, 1982)*.

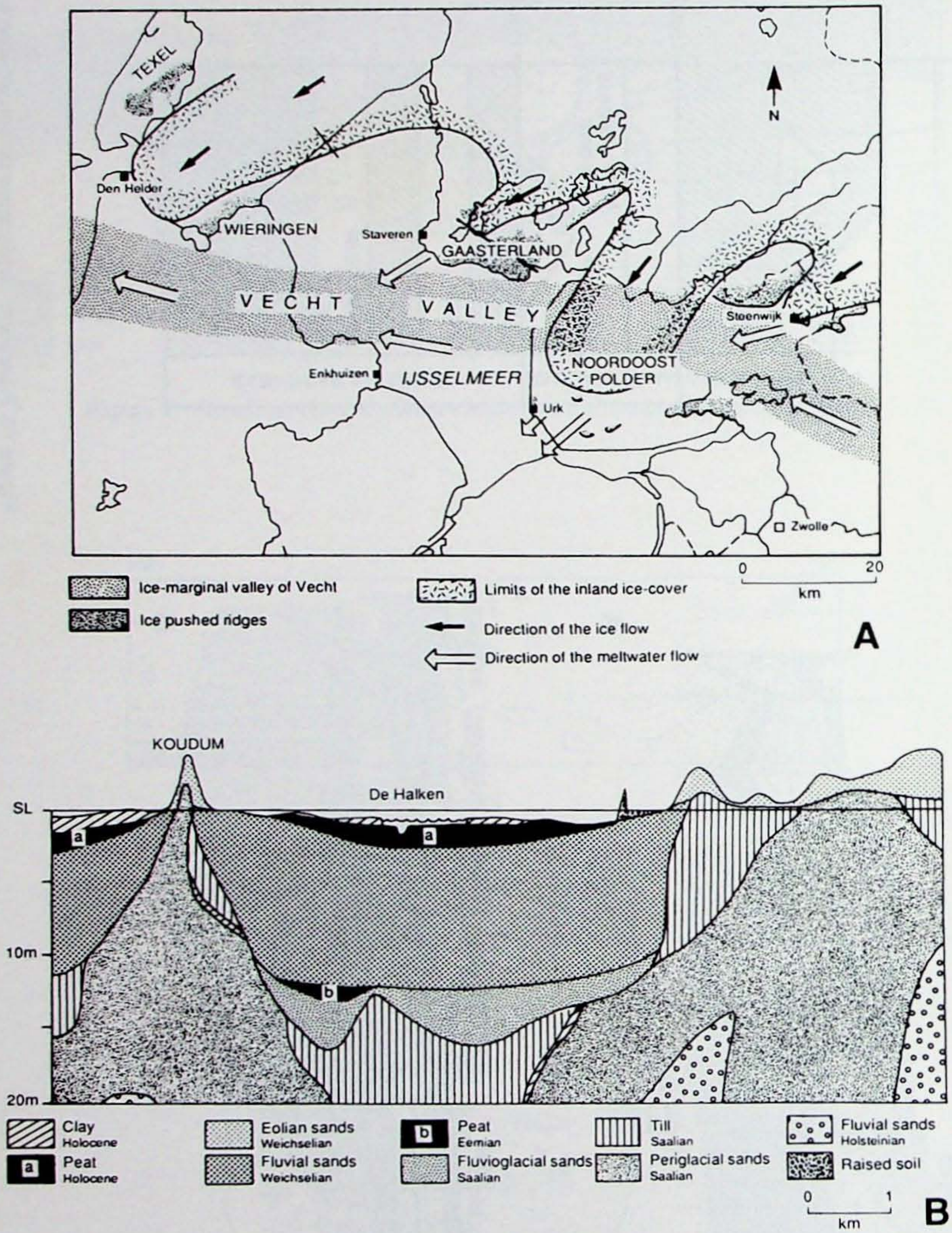

Figure 11. Quaternary interglacial and post-glacial peat layers near the edge of the continental ice sheet in Holland. A. Glacial map of late Saalian; B. Cross section of the tongue basin in Gaasterland *(after Ter Wee, 1983)*