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ASH-FALL-DERIVED VITROCLASTIC TUFFACEOUS SEDIMENTS IN THE PERMIAN OF THE PARANÁ BASIN AND THEIR PROVENANCE

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ABSTRACT

Examination of a large number of thin sections taken from drill cores in southern Brazil has disclosed the occurrence of at least one widespread ash fall during the Late Permian, between 235 and 260 m.y. ago, recorded in sediments of the Paraná Basin

Thin sections show sparce or concentrated shards within silty and/or carbonate (calcrete?) sediments of Permian formations (Rio Bonito Formation and Tatui Formation, mainly) in five southern Brazilian states.

As expected in buried material, the glass shards are now completely replaced by zeolites (commonly analcite) and, rarely, calcite. Chalcedony is suspected in a few cases. "Bogen" structure in sediments with concentrated shards is still well preserved.

A rhyolitic or dacitic volcanogenic provenance was sought along the margins of the Paraná Basin, in the volcanic Andean Pre-Cordillera and in South Africa. One suitable source area is located in the Provincia de La Pampa, Central Argentina, where a swarm of Upper Permian rhyolitic centers have been described. Ash apparently formed there by violent explosions related to acid volcanism, which travelled NE at least 2.500 km before finally settling in deltaic and shallow marine environments. The same type of Permian tuffaceous sediments should be expected in parts of Africa that would have been reached by the cloud. If found, such sediments should provide an excellent stratigraphic marker.

INTRODUCTION

During the well drilling campaign (1981-83) in the Paraná Basin by the Paulipetro Consortium in search for oil and gas, the Petrology Group of the IPT made and studied under the microscope hundreds of thin sections from core samples. The purpose was to characterize the different lithofacies in the sediment pile and reveal features of diagenesis and porosity which could help in the foregoing search.

Almost as an accident the attention of the senior author was called to the presence of microscopic "glass" shards in mudstone and limestone samples from Upper Permian formations. The unique shapes were incontrovertible but the glassy composition of the isotropic, low refringent shards was disputable. X-ray examination revealed the matter of most shards was actually analcite. In this study, to simplify understanding, wherever possible they will continue to be named glass shards. The host sediment, likewise, is here defined as a vitroclastic tuffaceous sediment.

After the closing of Paulipetro in 1983, the petrographic data were filed and the subject of glass shards left aside and almost forgotten for years. Nevertheless, it became clear to the authors that one or more voluminous rhyolitic ash falls occurred during the Late Permian in part, or all over Gondwanaland, a fact that may help stratigraphers, tectonicists and sedimentologists to make correlations, deduce tectonic environment and introduce new ideas about the genesis of certain lithotypes.

This Symposium is perhaps a good opportunity to divulge the results, however scant and provisional they may seem.

DISTRIBUTION OF OCCURRENCES

Figure 1 shows the location of fourteen holes drilled by Paulipetro and CPRM. Most are positioned in the Paraná Basin border zone but two (2-RA-1-MS and 2-CB-1-SP) are deep holes bored along the Basin's axial zone.

Twenty seven other holes in the Brazilian Paraná Basin were sampled and microscopically examined. No vitroclastic remains were there found. In most of such cases the sampling was made either above or below a "critical zone" which extends vertically from the top of the Teresina Formation (about 750 m above the base of the Irati Formation) to the base of the Rio Bonito Formation (about 250 m below the base of the Irati Formation). All these formations belong to the Upper Permian. Another unfavorable condition for shard findings is a widely spaced sampling - say more than 30 m - wich was the common case in sampling even for the critical zone. Likewise, it is believed that certain rock types, such as porous sandstone, are not propitious hosts for glass shards. As Table 1 shows, all the shard - carrying sediments are either limestone or fine grained unsorted sandstone.

Figure 2 exhibits the distribution of shard findings along the stratigraphic columns in the fourteen wells described. Except for the Irati Formation all other neighboring formations may carry shards or strong signs of vitroclastic deposition.

Until now there have been no sure records of tuffaceous or shard-carrying sediments in surface outcrops. Glass shards were described in a thin section from a mudstone, said to come from the base of the Estrada Nova Formation in a quarry at Limeira, State of São Paulo; the thin section is probably mislabelled and belongs to another locality. On the other hand, the greenish calcareous mudstones commonly found in outcrops of the Tatui

Formation in São Paulo (Almeida e Barbosa, 1953) still wait for a complete microscopic revision. It is believed that they may actually be true tuffaceous or shard-carrying sediments.

The geographical and stratigraphical distribution of shard-carrying sediments indicates that a widespread ash fall took place in the Late Permian over a large area of Gondwanaland, the remains being preserved under special geologic conditions.

PETROGRAPHICAL AND MINERALOGICAL FEATURES

Description

As the petrographic observations summarized in Table 1 point out, most of the shard-carrying samples may be described as calcareous mudstones. They usually show angular to subrounded particles of quartz, subordinate feldspar and micas, immersed in a clayey matrix containing irregularly distributed micritic calcite. The clasts range in granularity up to fine sand grade. Some samples in which sand predominates show also the presence of glauconite. Sparry calcite may form local concretions (calcrete?) as well as chalcedony (silica dolls, chert). Analcite is present as glass-shard pseudomorphs, but in shard concentrations can make up part of the cement or even appear as reworked(?) irregularly shaped clasts.

A smaller portion of the samples constitute micritic limestone, some of them enclosing intraclasts and/or carbonatic or phosphatic fossils.

Perhaps the most familiar type of shard seen in the thin sections examined is the flat or slightly curved plate, resulting from the glass walls separating large flattened vesicles. They average a lenght of 150 mμ (100-200 mμ) and a width of 15 mμ (10-20 mμ). On the other hand, very telling forms are the cuspate or lunate-shaped fragments of broken bubble walls that are commonly Y shaped (in cross section), representing remnants of three bubble junctions or double concave plates (X shaped in cross section) that formed the wall between adjoining bubbles in a pumice (Fisher and Schmincke, 1984). The three types mentioned above are fairly well represented in the photomicrographs of Figures 4, 5, 6 and 7.

In some samples the shards are broken to smaller pieces (probably reworked) or show serrated edges (incipient dissolution).

The mineral substance in the shards is no longer obsidian glass, as would be expected in recent ash. Some are now silicic (or zeolitic?) and some calcitic, but most are analcitic as proved by the 3.43, 5.61, 2.93, 1.74 d-spacings observed in X-ray powder diagrams.

Genetic Considerations

Origin of glass shards

Many glass shards are made of the walls of tiny broken bubbles developed by the vesiculation of silicic magma (Heiken, 1974, Fischer and Schmincke, 1984). It is true in a general way that the most frequent and largest masses of vitric ash deposits are found in those derived from rhyolitic and dacitic magmas (Carozzi, 1960) and less frequently from those of trachytic or andesitic composition. The vitric ash forms by the disruption of liquid lava by expanding gas. When much of the froth is desintegrated, all that remains are the septa that separated the bubbles, chilled to glass and carried away by the column of gas rushing out from a volcanic crater. The shapes of the ash fragments (shards) clearly reveal their origin. When it is ejected, most ash consists of a mixture of crystals and glass fragments. The crystals are denser than glass,and both crystals and bits of glass with crystals tend to fall faster than the crystal-free glass fragments. Thus crystals are more abundant in the ash deposited close to the vent and become less and less numerous at increasing distances (Macdonald, 1972).

In the acid (rhyolitic) magmas that cause most violently explosive eruptions, the portions of ash that fall at greater distances (of the order of thousands of km) are progressively richer in very small siliceous glass shards and poorer in larger or denser vitric or crystalline fragments showing higher settling velocities.

The shards examined in the present study contained no traces of phenocrysts embedded in a former glass and also did not exceed 0,150 mm in its longest dimension. Volcanic quartz or feldspar were not recognized among the clastic components of the sediments.

It is therefore reasonable to conclude that the Paraná Basin shards originated from ashes of a silicic (rhyolitic), very light and highly vesiculated magma, having travelled long downwind distances before settling.

Diagenetic generation of analcite and chert from silicic glass

The commonest type of mineral substance found as diagenetic replacement of rhyolitic glass shards, in the Paraná Basin, is analcite. This fact poses a problem because it has been generally aknowledged (Fisher and Schmincke, 1984) that, for the generation of analcite, a basaltic magma (and zeolite intermediates) should be assumed.

Muller (1967) however draws attention to the occurrence of unusually huge deposits of analcite in the Central Congo Basin (Africa), found within Jurassic-Cretaceous sub-aqueous non-marine strata, with no traces of volcanic material and suggests that special physico-chemical conditions may have prevailed, viz. concentration of soda, alumina and silica in alkaline lakes. The present authors observe that, as in other parts of Central-East Africa, an alkalic volcanism should be involved in the generation of soda-rich lakes. Still more, Muller (1967) remarks that in Late Cenozoic lake sediments in western U.S., analcite among other zeolites is a product of low-temperature reaction between the sediments (usually containing glass shards) and the lake waters of restricted basins.

Such reactions are well explained in a recent work on the burial diagenesis of thick volcanic piles in Japan. Iijima (in Sand and Mumpton, 1978) distinguished a downward sucession of four zones, each dominated by specific mineral assemblages of the reaction series (silicic glass-alkali zeolites-albite), representing dehydration with depth. With increasing temperature and burial depth, part of the silicic glass is seen to alter initially to montomorillonite and opal (zone I). In zone II, reaction of the remaining silica glass with intersticial water has led to the formation of alkalic clinoptilolite and mordenite plus opal and montmorillonite. These alkalic zeolites are then transformed into analcite in zone III, which changes to albite in the deepest zone IV, already at the threshold of metamorphism.

Relics of precursor zeolites (and montmorillonite, opal or chalcedony also) persist in the succeding zones, a fact that also seems to occur in the Paranã Basin.

The observation in the Japanese holes established that the boundary between zones II/III (reaction clinoptilolite → analcite) occurred at depths of 1700-3500 m, at 89-91°C. Independently of other variables (time, kinetics, Na^+ concentration), the foregoing depth and temperature may be an indication of the generation conditions of analcite from glass shards in the Paranã Basin sediments.

An important by-product freed in the formation of analcite is the excess silica, further deposited as opal or chalcedony or chert.

The Permian sediments in the Paranã Basin usually contain much fine silica dissemination or chert beds and concretions ("dolls"). This type of silicification has been variously assigned to: 1 - metasomatic replacement by silica-rich solutions from basaltic magma (Leinz, 1938); 2 - biogenic contribution of silicic skeletons; 3 - silica released in the reaction yielding kaolinite from montmorillonite (Amaral, 1971).

Taking into account the close stratigraphical and chemical relationships between ash and chert, the authors put forward the alternative model of chert generation by dissolution of siliceous volcanic ash and precipitation of silica as chert, possibly accompanied by formation of analcite.

PROVENANCE

Sorting, size and the originally glassy nature of the shards found in the sediments of the Paraná Basin show that violent explosive eruptions from Late Permian volcanoes have thrown fine ash high into the atmosphere, where it may have drifted downwind for long distances until settling. The deposits then became preserved under special circunstances. The observed shapes of shards are also telling. Izett (1981) presents evidence to show that pumice shards tend to develop from relatively high viscosity rhyolitic magmas with temperatures below 850°C, whereas bubble wall and bubble junction shards (the only ones described in this paper) tend to develop from lower viscosity rhyolitic magmas at temperatures above 850°C.

It is only natural to look for rhyolitic volcanic centers of Upper Permian age around the Gondwanian Basins in the Southern hemisphere. Already Amaral (1987) had pointed out that the end of the Permian Period in South America witnessed intensive acid (to intermediate) volcanism, stretching from the Argentinian Sierras Pampeanas northward along the Chilean-Argentine frontier. He also noticed that volcanic material has been identified in the Irati Formation (?) and in the Lower Tatui Formation, in which geochronological determinations have indicated a synchronism of eruption and deposition events. There are thus good grounds for locating the source rhyolitic volcanism along the Argentinian Cordillera Frontal (arc magmatism with the Upper Permian Choiyoi Volcanics, Ramos et al. 1986, or the "Formación Varíscica de Choiyoi", Caminos, 1979) and, farther southeast, in the ignimbritic plateau of western La Pampa province (Lambias and Leveratto, 1975), both reproduced in Figure 3.

Other possible sources could be envisaged in Tierra del Fuego, where Permian terrains (with volcanism?) have been dated (M.A. Basei, personal communication) and, farther south, in the Graham Land of the Antarctic peninsula, where Smellie(1988) has detected Early Jurassic silicic volcanism. No record of Permian rhyolitic volcanism anywhere in the adjoining Gondwanian continents is known to the present authors that could be responsible for such powerfull explosive eruptions. The possible source magmatism and its subsequent northeastward ash aereal motion are depicted in Figure 3.

SPAN OF VOLCANISM

The borehole samples in which glass shards were detected are stratigraphically located in a column including the Estrada Nova Formation (Teresina and Serra Alta), at the top, and the Rio Bonito Formation, at the bottom.

According to Daemon and Quadros (1970) and the Petrobras specialists (Zalán et al., 1987), who adopted the Geologic Time

Scale published by Cambridge University Press in 1982, the base of the Rio Bonito Formation is of Kungurian age (Upper Eopermian) 260 m.y. ago, and the top of the Teresina is Tatarian, 250 m.y. ago. This leaves a span of 10 m.y. for the assumed rhyolitic volcanism.

In the well known Elsevier's Time Table, those ages are respectively 255 m.y. and 235 m.y., increasing the spread to 20 m.y.

In any event, 10 or 20 m.y. seem to be an adequate enough estimate for the duration of the silicic volcanic explosions that took place in many vents in Central and Northwest Argentina.

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Table 1. Sample descriptions and Locations

Well and Sample number	Well location	Sampling depth and Formation	Petrographic description
2-RA-1-MS RA-15	Cassilândia (Rio Aporé)	900-1000 m Estrada Nova	Gray mudstone with calcitic and phosphatic fragments (fossils ?). Scattered analcite shards.
2-CB-1-SP CB-68	Cuiabá Paulista 22°18'11,9"S 52°02'21,6"W	3200 m Serra Alta	Cuttings. Mudstone with analcitized or silicified corroded shards, from this depth downwards.
1-PA-1-SP PA-247	Piratininga 22°28'02"S 49°09'08"W	680 m Tatui	Light gray limestone. Fine sand micrite fragments and analcitized or calcitized broken shards in a micritic matrix.
PCE-1-SP ID 2218 Dipetro 4272	Cerquilho 7.434.200 m 209.700 m	139,7 m Rio Bonito	Sandy limestone with creamy and greenish convoluted bands. Fine sand in micritic matrix. Silicified or zeolitized shards are highly concentrated in bands.
2-PN-1-SP PN-36	Paranapanema 23°26'07"S 48°46'27"W	2408 m Tatui	Sandy limestone. Fine sand and much analcitized shards in a micritic, clayey or analcitic matrix. Analcitic rocks up to 1 m. above this level.
2-CS-1-PR CS-118	Chapeu de Sol 24°57'50"S 51°58'02"W	1782 m Teresina	Cuttings. Calcitic and analcitic mudstone and fine sandstone are abundant from 1488 down to 1980 m (entire Teresina). Many with suspected analcitized shards, made certain at 1782 m.
1-IV-04-PR Dipetro 4125	Imbituva 7.210.000 m 537.000 m	123 m Rio Bonito	Mudstone and wacke. Suspected analcitized shards at this level 20 m above and 10 m below.
1-IV-06-PR ID-2153 Dipetro 4136	Irati 7.180.000 541.000	58,6 m Palermo	Glauconitic green fine sandstone with brownish gray carbonatic spots. Analcitized shards sparse or concentrated (in lenses of carbonatic limestone). Same features (less carbonate) at 68,7 m.
1-IV-07-PR Dipetro 4164	Imbituva 7.190.000 544.000	ca. 20 m Rio Bonito	Slightly calcareous mudstone with sparry calcitic spots. Analcitized shards concentrated in some noncalcareous fine sand lenses.

Table 1. (cont.)

Well and Sample number	Well location	Sampling depth and Formation	Petrographic description
NF-02-PR Dipetro 4283	Congoinhas 7.376.600 m	43 m Teresina	Greenish gray shale interbedded with broken contorted white silt. Shard fragments concentrated in the silty portions with much analcitic cement.
ID-2303 Dipetro 4311		256 m Rio Bonito	Laminated white analcitic rock. Abundant analcitized shards and some fine sand in analcitic matrix.
NF-05-PR ID-2369 Dipetro 4372	Sapopema 7.360.500 542.700	320,7 m Palermo	Gray limestone. Micritic and sparritic beds convolute around sandy lenses with clasts of quartz, feldspar, calcite, fossil fragments and calcitized and analcitized shards.
ID-2375 Dipetro 4378		378,3 m Rio Bonito	Grayish green mudstone, brownish carbonatic spots and white aureoles. Sparse analcitized shards in the mudstone and spots and highly concentrated in analcitic aureoles.
1-PP-07-SC ID-2680 Dipetro 4478	Monte Castelo 7.065.700 585.000	103,8 m Rio Bonito	Gray mudstone. Analcitized shards dispersed in the quartzose silty fraction.
ID-2691 Dipetro 4489		173,5 m Rio Bonito	Gray mudstone with a high proportion of quartzose fine sand. Clay beds desintegrated. Well preserved analcitized shards dispersed among clasts with some glauconite and calcite.
2-AO-1-RS AO-21	Nova Bassano (Atanasio) 28°42'06"S 51°39'52"W	1959 m ? Palermo	Mudstone. Suggestive forms of analcitized shards scattered among quartz-feldspathic clasts.

N. A number of thin sections were examined with uncertain or incomplete informations as to nature of shards location, sampling depth or labelling. They include:

1. Outcrop in Limeira? SP? (quarry). FM. Serra Alta? Shards in mudstone.
2. NF-09-PR. Sapopema. Fm. Rio Bonito. Shards? in cherty micrite.
3. 1-PP-11-SC. Canoinhas. Fm. Rio Bonito. 115 m. Shards? in mudstone and micrite.
4. 1-PN-23-SC. Location? Dipetro 4729. Shards in calcitic mudstone.
5. 5-CA-25-RS. Location? Fm. Palermo or Rio Bonito. Dipetro 4958. Suspected shards in mudstone.
6. 5-AT-19-RS. Location? Fm. Rio Bonito? Dipetro 4958. Analcite shards in mudstone.
7. 1-PB-25-SC? Location? Fm. Rio Bonito? Suspected shards in mudstone.

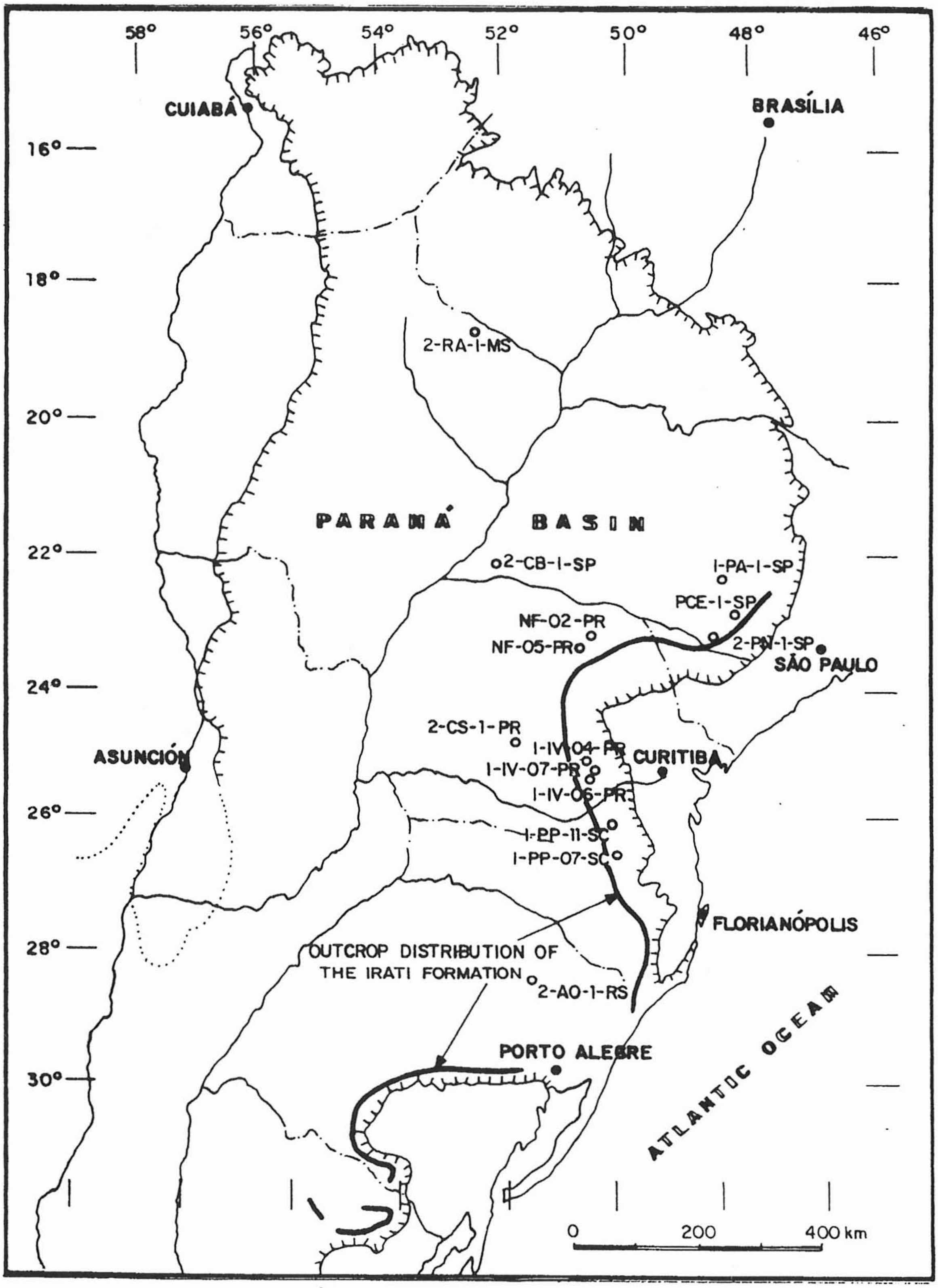


Figure 1 - Location of 14 wells in Southern Brazil that produced evidence of rhyolitic ash fall in Permian core samples.

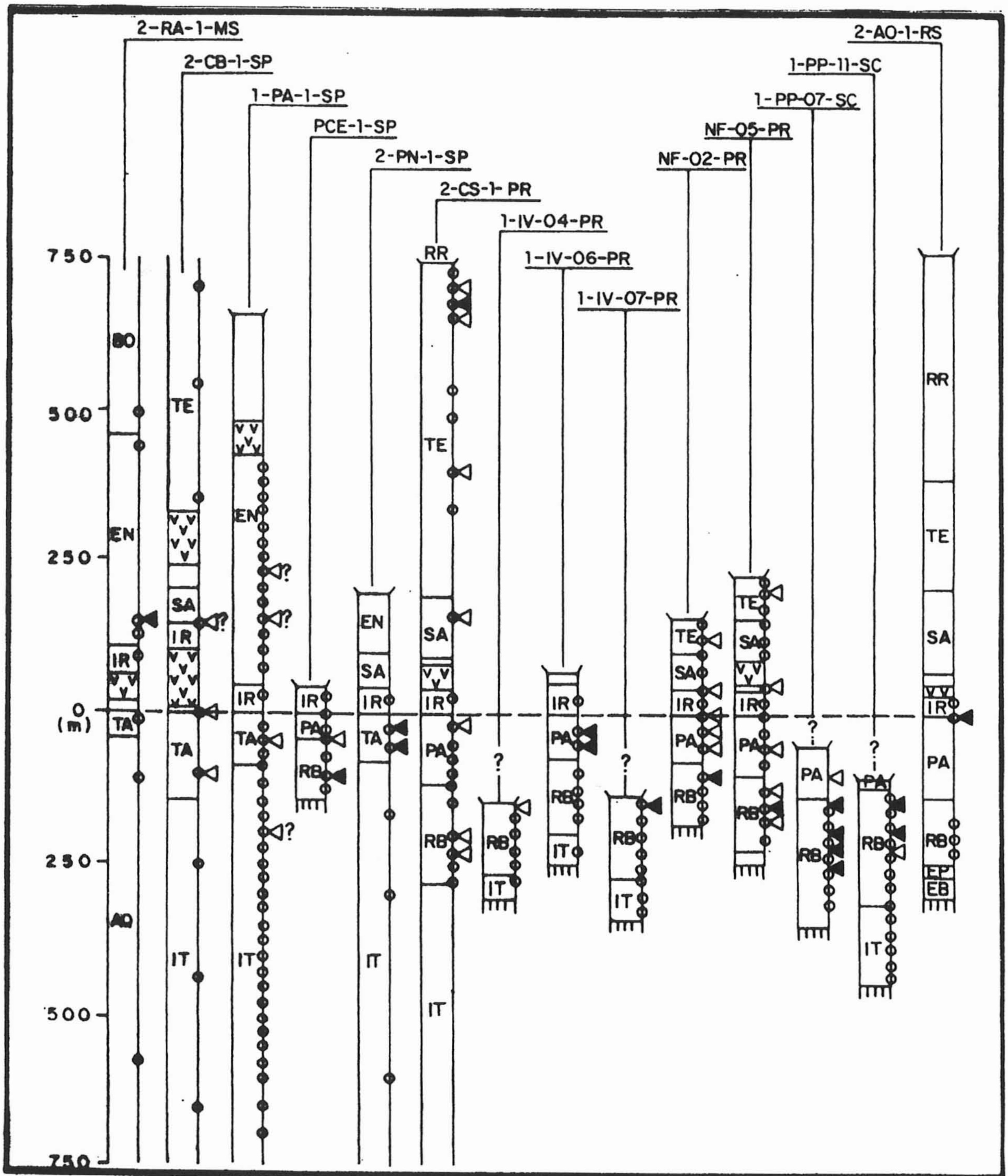


Figure 2 - Simplified profiles of the 14 wells in Figure 1. For deep wells only the critical zone is represented. The base of the Irati Formation is levelled as a marker, for all wells. Symbols: Open circle: Depth point in a 50 m interval where at least two thin sections were taken. Open triangle: Sample with signs of ash. Full triangle: Sample carrying "glass" shards. Formations: AQ-Aquidauana. BO-Botucatu. EB-Basement rocks. EN--Estrada Nova. EP-Eopaleozoic. IR-Irati. IT-Itararé.PA-Palermo. RB-Rio Bonito. RR-Rio do Rasto. SA-Serra Alta. TA-Tatui. TE-Teresina.

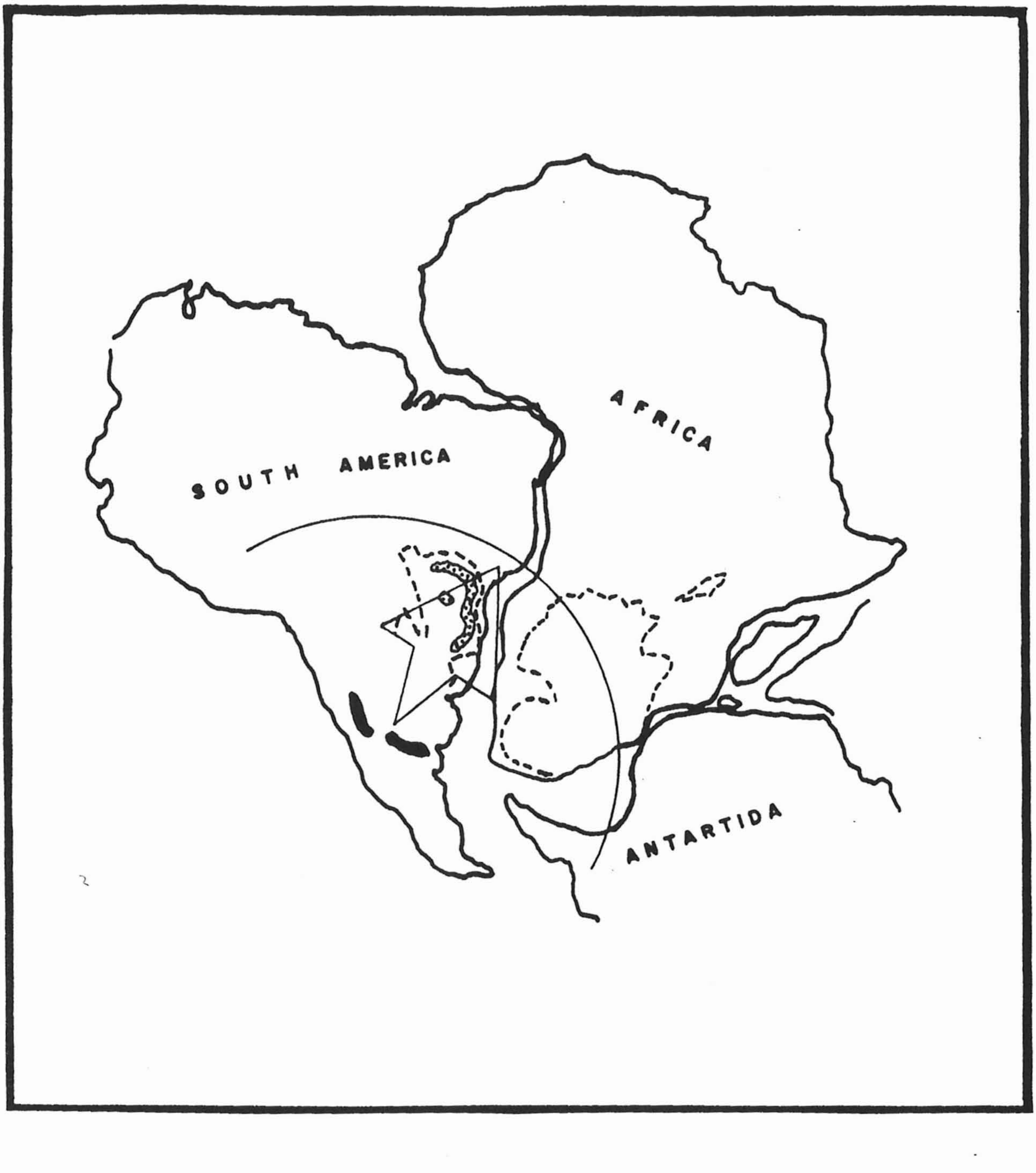


Figure 3 - Fit of neighbouring continents in a Permian pre-drift position. Dots: Zone of boreholes detecting ash in the Paranã Basin. Dashes:Outline of the Gondwanian basins: Paraná in South America, Karroo in Africa. Black areas: Upper Permian rhyolitic volcanic centers in Argentina.

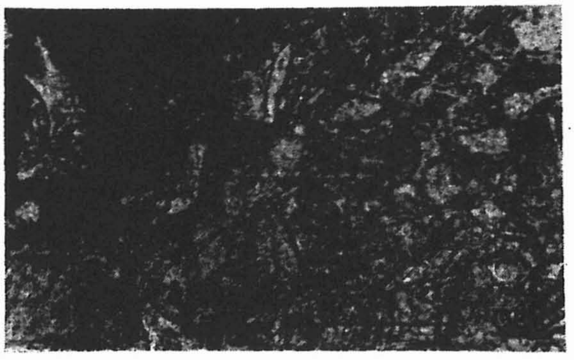


Figure 4 - Photomicrograph (uncrossed polarizers) of a Tatui Formation mudstone (2-PN-1-SP). Analcitized shards are plentiful in the main rock but scarce in the micritized area (top left).

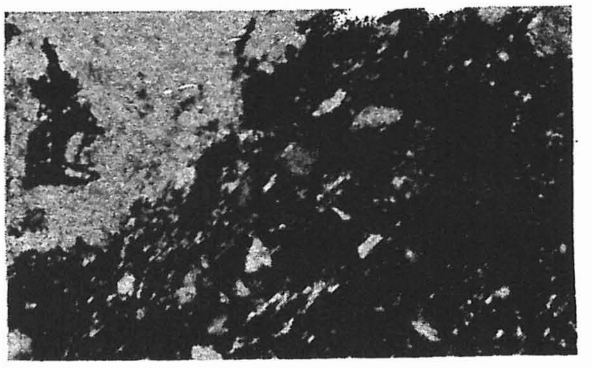
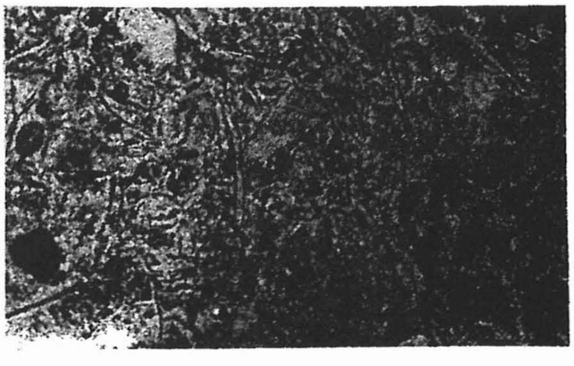


Figure 5 - Same as Figure 4 (crossed polarizers). Analcites in all shards are extinct. A double concave shard (formed from adjoining bubbles) is enhanced in the lighted calcite micrite area, upper left.



.gure 6 - Photomicrograph (uncrossed polarizers) of a Rio Bonito Formation mudstone (PCE-1-SP). Zeolitized (or silicified?) shards in a micritic and cherty base.

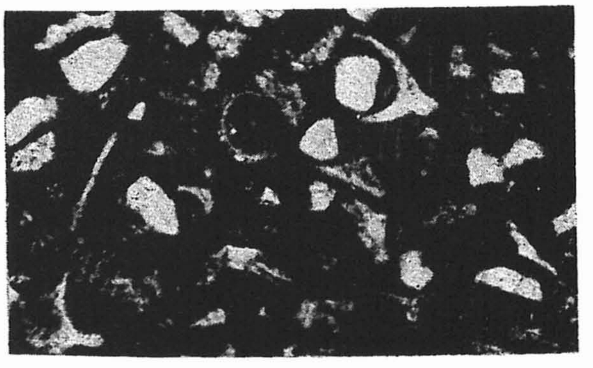


Figure 7 - Photomicrograph (uncrossed polarizers) of a micritic spot in a Rio Bonito Formation mudstone)NF-09-PR). Analcitic, calcitic and silicic shards, together with silt in a micritic matrix.