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Stratigraphy, depositional environment, and reservoir analysis of the Itarare Group (Permo-Carboniferous), Parana Basin - Brazil

Franca, Almerio Barros, Ph.D.

University of Cincinnati, 1987

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Stratigraphy, Depositional Environment, and

Reservoir Analysis of the

Itarare Group (Permo-Carboniferous),

Parana Basin - Brazil

A dissertation submitted to the

Division of Graduate Studies and Research
of the University of Cincinnati

in partial fulfillment of the
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in the Department of Geology
of the College of Arts and Sciences

1987

by

Almerio B. Franca

B.S., Universidade de Brasilia, 1974

UNIVERSITY OF CINCINNATI

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I hereby recommend that the thesis prepared under my supervision by Almerio B. Franca

entitled Stratigraphy, Depositional Environment, and Reservoir Analysis of the Itarare Group (Permo-Carboniferous), Parana Basin - Brazil

be accepted as fulfilling this part of the requirements for the degree of Doctor of Philosophy

Approved by:

Paul Edwin Potter

Wayne A. Pryor

David L. Meyer

ABSTRACT

The present work is a stratigraphic, reservoir, and environmental analysis of the Itarare Group (Permo-Carboniferous) using the well data of the Parana Basin which covers about 1,000,000 Km^2 in Brazil alone. More than three thousand kilometers of cross sections were analysed, over 100 wells were studied, nearly 400 meters of cores were described, and 95 thin sections were analysed.

A stratigraphic subdivision of the subsurface is proposed for the Itarare Group and three new formations and four new members are proposed. The lowermost formation is called the Lagoa Azul, which is subdivided into the Cuiaba Paulista Member, composed mostly of sandstones; and the Tarabai Member, composed predominantly of siltstones and pebbly mudstones. The new middle unit is the Campo Mourao Formation, composed mostly of sandstones and pebbly mudstones, and the new uppermost unit is the Taciba Formation. The Taciba is subdivided into the Rio Ivai Member, composed of sandstones; the Chapeu do Sol Member composed of pebbly mudstones; and the Rio do Sul Member composed mostly of shales.

This new stratigraphic subdivision is necessary because only in the central part of the basin is the sedimentation most continuous and unconformities are less likely. Furthermore, the new stratigraphic nomenclature facilitates subsurface exploration and surface mapping as well.

Well logs show that the Itarare Group has three major depositional cycles termed lower, middle, and upper, which correspond broadly to the three new formations. Each cycle is composed of a sandy basal section and an upper 'shaly' section. It is likely that the cycles

are responses to climatic and sea level changes. Pebbly mudstones present in the 'shaly' sections of the cycles were probably deposited by glaciers, whereas fossiliferous shales containing dropstones were deposited in a cold sea during a major transgression.

Three major ice lobes seem to have entered the Parana Basin during the Permo-Carboniferous. One lobe came from the east, apparently an extension of the Kaokoveld Lobe from Africa. Two lobes came from west - the Santa Catarina Lobe and the Mato Grosso Lobe, apparently linked to glaciation in the Assuncion Arch.

The sandy section of the depositional cycles were probably deposited by braided rivers on outwash plains or as alluvial fans, deltas, and turbidites. These sandstones comprise the reservoir rocks in the Itarare Group.

There are two sandstone types in the Itarare Group, one is clay-rich with no porosity, and the other has little or no clay. The latter has secondary porosity mostly due to dissolution of early siderite cement. Dissolution is probably contemporaneous with or later than the Gondwana break-up (Jurassic-Cretaceous), when the Parana Basin had its hottest period associated with great igneous activity. This event may have accelerated thermomaturation of organic matter, releasing organic acids and carbon dioxide which were responsible for most of the corrosive solutions that percolated through sandstones, leaching carbonate minerals and other unstable constituents to form the secondary porosity.

TABLE OF CONTENTS

Table of Contents (cont.)

Table of contents (cont.)

APPENDICES

ACKNOWLEDGEMENTS

The present work and the degree achieved by the author was possible thanks to a scolarship sponsored by the **Conselho Nacional de Desenvolvimento Cientifico e Tecnologico - CNPq** to which I am greatly indebted.

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Finally, special thanks to my mother, my wife Rosangela, to Binomino da Costa Lima (Meco), and to my family in Brazil who helped me with this important achievement in my professional life.

ILLUSTRATIONS

FIGURES

Page

ILUSTRATIONS (cont.)

ILLUSTRATIONS (cont.)

PLATES

TABLES

APPENDICES

"There are those who try to generalize, synthesize and build models, and those who believe nothing and constantly call for more data. The tension between these two groups is a healthy one; science develops mainly because of the model builders, yet they need the second group to keep them honest"

(Miall, 1984, p. 363)

INTRODUCTION

The Parana Basin is a large, oval-shaped basin covering 1,600,000 km^2 in southeastern South America in parts of Brazil,Argentina, Paraguay and Uruguay. The Brazilian portion, which is the subject of this research, covers about 1,000,000 km^2 (Fig. 1).

The Parana Basin comprises the largest South American record of the Gondwana succession (Fig. 2). Glacial deposits associated with the **Glossopteris** flora (Permo-Carboniferous) are correlated to similar succesions in Africa, India, Australia and Antarctica. The **Mesosaurus**, a small reptile that lived in brackish coastal shallows in Permian time, is found only in the Irati Formation of the Parana Basin and in the White Band of the Karroo Basin (South Africa). Both the glacial deposits and the **Mesosaurus** have been broadly used as arguments for continental drift since the early days of the Continental Drift Theory.

Brazil imports about 30 percent of the petroleum it uses. Much of this petroleum is consumed near the Parana Basin in the industrial states of Sao Paulo, Minas Gerais, and Rio de Janeiro. However, the hydrocarbon potential of the huge Parana Basin is not well known. This is mostly because much of the basin is covered by a thick (greater than 1km) sequence of Jurassic lava flows. The lava flows, and associated dikes and sills, make seismic mapping of structures in the underlying sedimentary rocks, very difficult, consequently the Parana Basin is less attractive than other Brazilian sedimentary basins.

Technological advances in seismic data acquisition and processing have facilitated mapping of structures beneath the thinner lava areas. The use of new prospecting methods, such as magnetotelluric

Fig. 1 Geologic map of Parana Basin.

The Brazilian portion of the Parana Basin covers an extension of approximatelly 1,000,000 km^2. Most of this area is covered by basalts of the Serra Geral Formation (Jurassic - Cretaceous). In the northeast area the basalts are partially covered by continental sandstones of the Bauru Formation (Cretaceous).

The Itarare Group, which is the subject of this work occurs mostly covered by the lava flows; however, a minor section outcrops in the southern margin of the Parana Basin (strippled pattern). In the northwest outcrop belt the Itarare Group is represented by the red beds of the Aquidauana Formation.

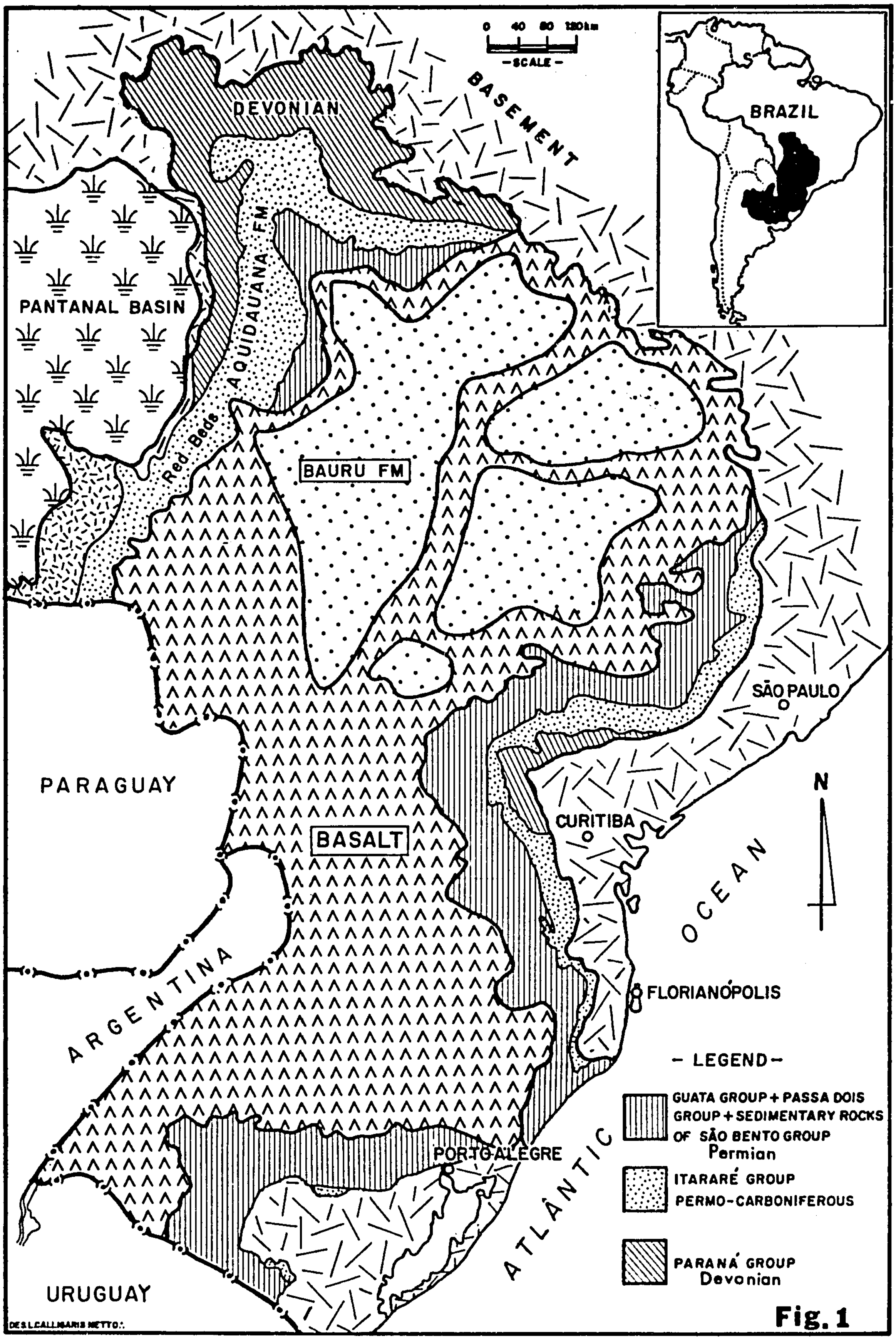
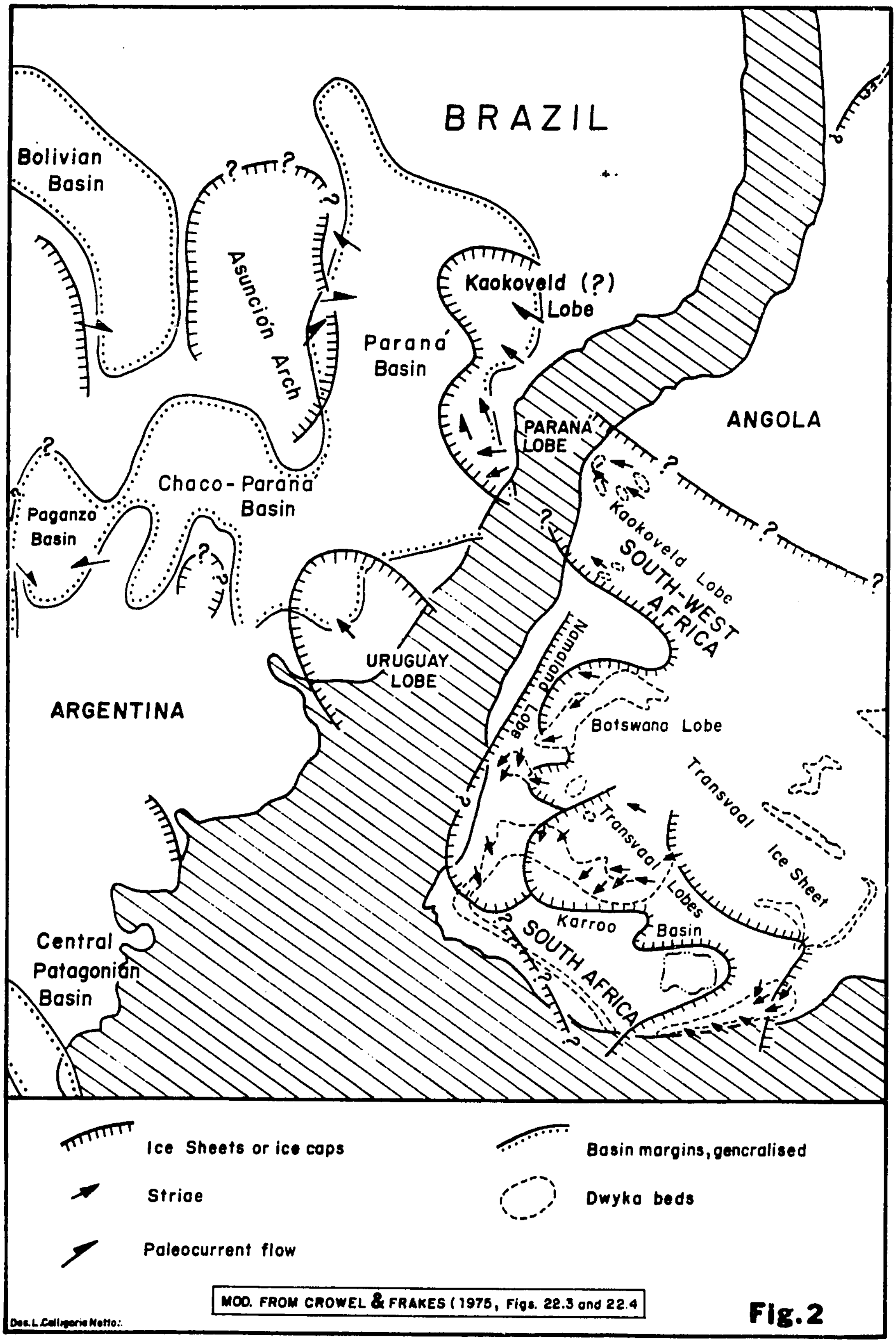

0 40 80 120km
-SCALE-
BASEMENT
DEVONIAN
BRAZIL
PANTANAL BASIN
AQUIDAUANA FM
Red Beds
BAURU FM
SÃO PAULO
PARAGUAY
CURITIBA
N
BASALT
OCEAN
ARGENTINA
FLORIANÓPOLIS
- LEGEND -
GUATA GROUP + PASSA DOIS GROUP + SEDIMENTARY ROCKS OF SÃO BENTO GROUP
Permian
PORTO ALEGRE
ATLÂNTIC
ITARARÉ GROUP
PERMO-CARBONIFEROUS
PARANÁ GROUP
Devonian
URUGUAY

Fig. 1

Fig. 2 Late Paleozoic Glaciation in South America and Africa. Modified from Crowell and Frakes (1975, pgs. 321 and 323).

The Kaokoveld (?) Lobe in the eastern side of the basin was proposed by Crowell and Frakes (1975) based on outcrop information; they also mention the possibility of lobes coming from glaciation in the Assuncion Arch.



BRAZIL
Bolivian Basin
Asunción Arch
Kaokoveld (?) Lobe
Paraná Basin
PARANÁ LOBE
ANGOLA
Chaco-Paraná Basin
Paganzo Basin
Kaokoveld Lobe
SOUTH-WEST AFRICA
Namaland Lobe
URUGUAY LOBE
ARGENTINA
Botswana Lobe
Transvaal Ice Sheet
Transvaal Lobes
Karroo Basin
SOUTH AFRICA
Central Patagonian Basin
Ice Sheets or ice caps
Basin margins, generalised
Striae
Dwyka beds
Paleocurrent flow
MOD. FROM CROWEL & FRAKES (1975, Figs. 22.3 and 22.4
Des. L. Calligaris Netto.

Fig.2

surveys, has enabled explorationists to see through the "seismic shield" and confidently map: (1) large scale features such as the base of the basalt, (2) the top of the basement, (3) some stratigraphic contacts, and (4) bodies of sills and dikes (Silva and Vianna, 1982; Stanley et al, 1985). Mapping of sills and dikes may become a very important key in the exploration of the Parana Basin, because so far, the best gas shows come from sandstones in the Itarare Group, which are probably capped by diabases.

Approximately 100 wells have been drilled in the Brazilian part of the Parana Basin (Fig. 3). Most of these wells were stratigraphic tests. The majority of these wildcat wells had oil and gas shows. Some drill stem tests (DST's) had gas recovery as high as 3 MM cfd. However none was drilled on a structural closure.

In addition to the non-commercial discoveries, numerous oil seep and tar deposits occur in the eastern outcrop belt of the Parana Basin. Therefore, Parana Basin is a huge, and relatively unexplored basin, which has good potential for discovery of hydrocarbon accumulations in structural and stratigraphic traps beneath the basalt.

Basin Setting. The Parana Basin is a polyhistory intracratonic basin. Based on the basin classification system of Kingston et al (1983), the Parana Basin is classified as a continental interior fracture (IF) in its early stages of deposition from Devonian and Upper Carboniferous to Lower Permian. From the Lower Permian (Sakmarian) to its final stage of deposition in the Cretaceous, the Parana Basin is classified as an Interior Sag Basin (IS).

The sedimentary fill of the Parana Basin is approximately 5,000m thick and is composed mainly of Paleozoic and secondarily of

Fig. 3 Location of wells in Parana Basin.

About 100 wells have been drilled in the Parana Basin, and most of them are concentrated in the southern part of the basin near the outcrop belt, where the basalt is thinner.

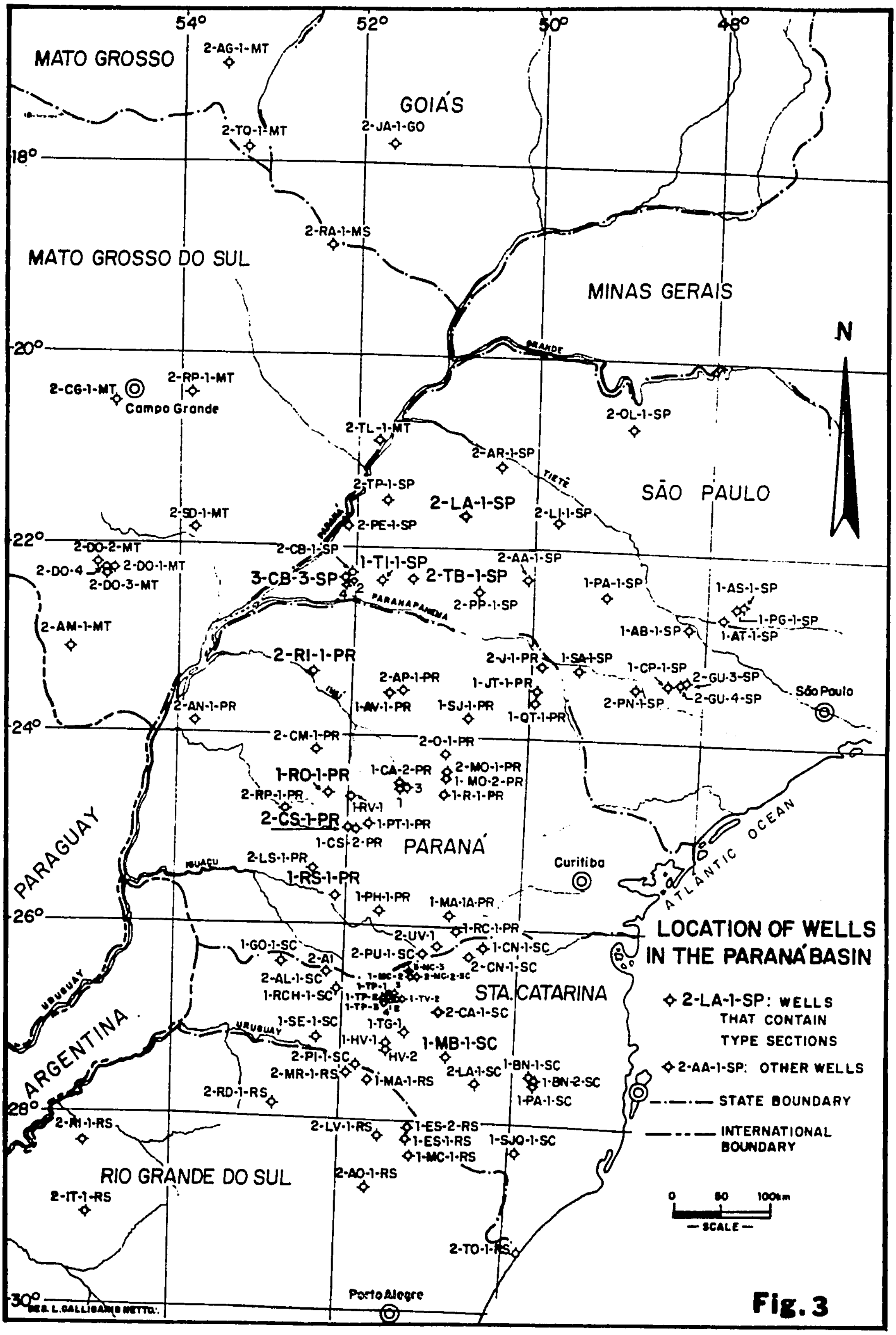
Wells nomenclature is as follow:

The first figure indicates the well status, i.e. 1: wildcat well; 2: stratigraphic well; 3: extension well.

The first two letters stands for the well name, for instance TB: Taciba (named after the Taciba town).

The second figure is the well number.

The last two letters are the state abreviation: RS- Rio Grande do Sul State; SC- Santa Catarina State; PR- Parana State; SP- Sao Paulo State; MS- Mato Grosso do Sul State; MT- Mato Grosso State; and, GO- Goias State.



LOCATION OF WELLS IN THE PARANÁ BASIN
2-LA-1-SP: WELLS THAT CONTAIN TYPE SECTIONS
2-AA-1-SP: OTHER WELLS
STATE BOUNDARY
INTERNATIONAL BOUNDARY
0 50 100km
SCALE
N
54°
52°
50°
48°
18°
20°
22°
24°
26°
28°
30°
MATO GROSSO
GOIÁS
MATO GROSSO DO SUL
MINAS GERAIS
SÃO PAULO
PARANÁ
STA.CATARINA
RIO GRANDE DO SUL
PARAGUAY
ARGENTINA
ATLANTIC OCEAN
Campo Grande
São Paulo
Curitiba
Porto Alegre
GRANDE
TIETÊ
PARANAPANEMA
IGUAÇU
URUGUAY
2-AG-1-MT
2-TQ-1-MT
2-JA-1-GO
2-RA-1-MS
2-CG-1-MT
2-RP-1-MT
2-OL-1-SP
2-TL-1-MT
2-AR-1-SP
2-TP-1-SP
2-LA-1-SP
2-LI-1-SP
2-SD-1-MT
2-PE-1-SP
2-DO-2-MT
2-DO-1-MT
2-DO-4
2-DO-3-MT
2-CB-1-SP
3-CB-3-SP
1-TI-1-SP
2-TB-1-SP
2-AA-1-SP
1-PA-1-SP
1-AS-1-SP
1-PG-1-SP
1-AT-1-SP
1-AB-1-SP
2-PP-1-SP
2-AM-1-MT
2-RI-1-PR
2-J-1-PR
1-SA-1-SP
1-CP-1-SP
2-GU-3-SP
2-GU-4-SP
2-PN-1-SP
2-AP-1-PR
1-JT-1-PR
1-AV-1-PR
1-SJ-1-PR
1-QT-1-PR
2-AN-1-PR
2-CM-1-PR
2-O-1-PR
1-RO-1-PR
1-CA-2-PR
2-MO-1-PR
1-MO-2-PR
1-R-1-PR
2-RP-1-PR
1-RV-1
2-CS-1-PR
1-PT-1-PR
1-CS-2-PR
2-LS-1-PR
1-RS-1-PR
1-PH-1-PR
1-MA-1A-PR
1-RC-1-PR
2-UV-1
1-GO-1-SC
2-AI
2-PU-1-SC
1-CN-1-SC
2-CN-1-SC
2-AL-1-SC
1-RCH-1-SC
2-CA-1-SC
1-SE-1-SC
1-TG-1
1-HV-1
HV-2
1-MB-1-SC
2-PI-1-SC
2-MR-1-RS
1-MA-1-RS
2-LA-1-SC
1-BN-1-SC
1-BN-2-SC
1-PA-1-SC
2-RD-1-RS
2-RI-1-RS
2-LV-1-RS
1-ES-2-RS
1-ES-1-RS
1-SJQ-1-SC
1-MC-1-RS
2-AO-1-RS
2-IT-1-RS
2-TO-1-RS
DES. L. GALLIGANI NETTO.

Fig. 3

Mesozoic rocks. The Paleozoic rocks comprise two major depositional cycles separated by an erosional unconformity. The first-cycle sediments are Siluro-Devonian deposits of the Parana Group. The second cycle of deposition is Permo-Carboniferous in age and includes the Itarare Group, Guata Group and Passa Dois Group (Fig. 4). Sedimentary Mesozoic rocks are represented by the Sao Bento Group, which lies unconformably over the Passa Dois Group in the marginal areas of the basin, but is in conformable contact in the central part of the basin (Fig. 4).

The sedimentary sequence is covered by the Serra Geral Formation, which is the most voluminous flood basalt complex in the world, and may be more than 1700m thick. Associated with the basalt are sills and dikes some of which may be as thick as 250m. In some wells, igneous rocks may form 40 percent of the total section drilled; for example, in the state of Parana 2-AN-1-PR well (Fig. 3) has a total depth 5554m, but 2138m is basalt + diabases, about 38 percent.

In addition to the major sequences cited above, the Parana Basin has some minor units, such as the Vila Maria Formation of Silurian age. The Vila Maria Formation was first described by Faria and Reis (1978) and restudied later by Faria (1982), and Gray et al (1985). Recent wells drilled in the central part of the basin have found new lithotypes, commonly preserved in grabens. Most of these sequences are not yet classified, and are poorly understood. Some of them deserve attention due to their great thicknesses. As much as 800m have been drilled in 1-SE-1-SC well (Fig.3), in the State of Santa Catarina.

About 5 percent of the Parana Basin sedimentary rocks are exposed, the remainder are covered by lava flows. In addition, the exposed sedimentary rocks probably represent sediments deposited near

Fig. 4 Stratigraphic column of Parana Basin.

Symbols:

BAUR - Bauru Formation
SGRL - Serra Geral Formation
BTCT - Botucatu Formation
RSUL - Rosario do Sul Formation
PIRB - Piramboia Formation
RRST - Rio do Rasto Formation
TRZN - Terezina Formation
SRLT - Serra Alta Formation
CBTI - Corumbatai Formation
IRTI - Irati Formation
PLRM - Palermo Formation
TTUI - Tatui Formation
DPL - Delta da Formacao Palermo
RBNT - Rio Bonito Formation
TCBA - Taciba Formation
CSL - Chapeu do Sol Member
RDS - Rio do Sul Member
LNT - Lontras Member
CMPM - Campo Mourao Formation
AQDN - Aquidauna Formation
LZUL - Lagoa Azul Formation
TRB - Tarabai Member
CBP - Cuiaba Paulista Member
RCR - Roncador Shale Member
PTGR - Ponta Grossa Formation
FRNS - Furnas Formation
VLMA - Vila Maria Formation

Basalt

Sandstone

Siltstone

Shale

Limestone

Coal Beds

Pebbly Mudstone

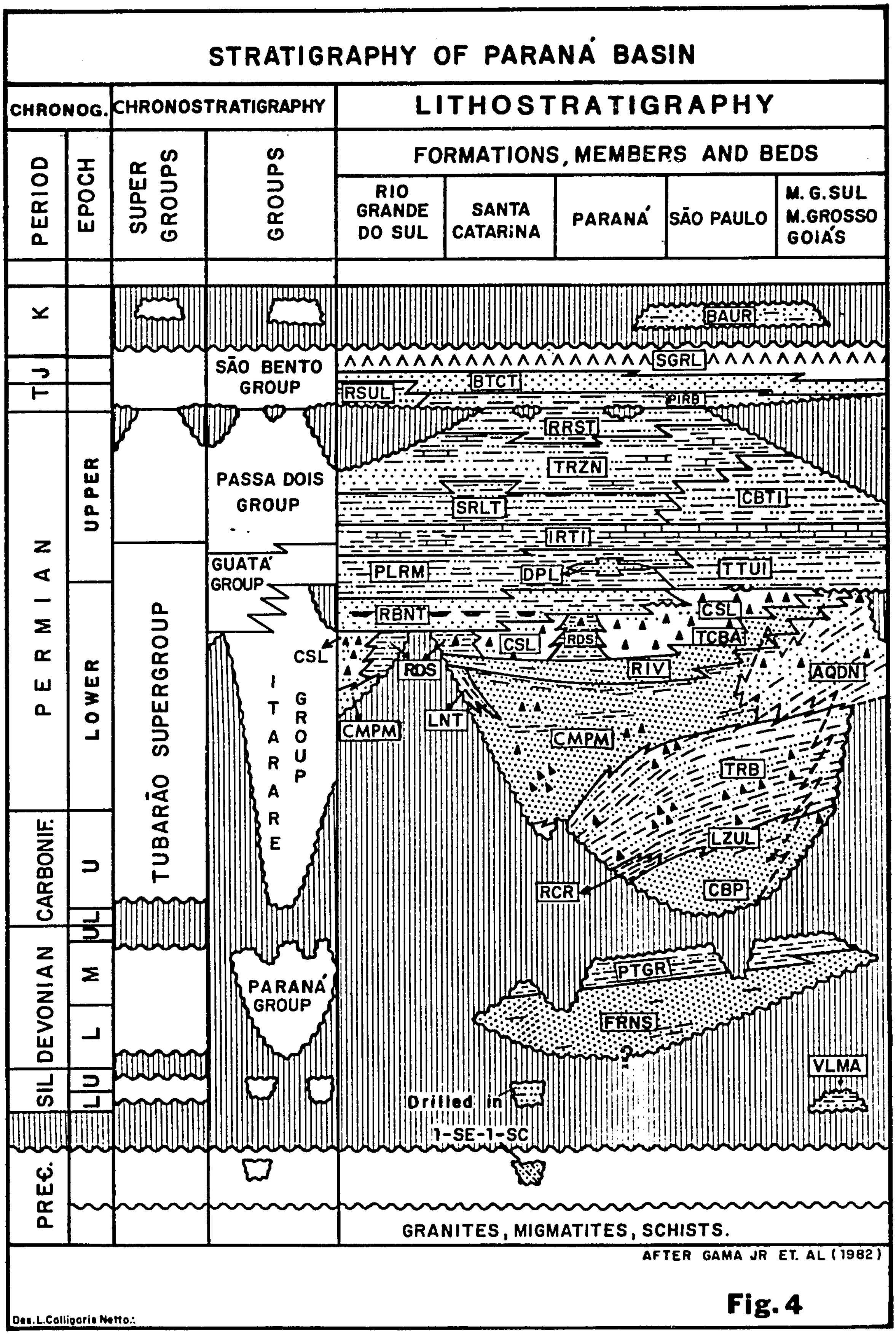

STRATIGRAPHY OF PARANÁ BASIN
CHRONOG.
CHRONOSTRATIGRAPHY
LITHOSTRATIGRAPHY
PERIOD
EPOCH
SUPER GROUPS
GROUPS
FORMATIONS, MEMBERS AND BEDS
RIO GRANDE DO SUL
SANTA CATARINA
PARANÁ
SÃO PAULO
M. G. SUL M. GROSSO GOIÁS
K
J
T
PERMIAN
UPPER
LOWER
CARBONIF.
U
L
DEVONIAN
M
L
SIL
U
L
PRE€.
SÃO BENTO GROUP
PASSA DOIS GROUP
GUATÁ GROUP
TUBARÃO SUPERGROUP
ITARARÉ GROUP
PARANÁ GROUP
CSL
BAUR
SGRL
BTCT
RSUL
PIRB
RRST
TRZN
SRLT
CBTI
IRTI
PLRM
DPL
TTUI
RBNT
CSL
RDS
TCBA
RIV
AQDN
CMPM
LNT
TRB
LZUL
RCR
CBP
PTGR
FRNS
VLMA
Drilled in 1-SE-1-SC
GRANITES, MIGMATITES, SCHISTS.
AFTER GAMA JR ET. AL (1982)
Des. L. Colligaris Netto.

Fig. 4

the original depositional margin of the basin, and these outcrops exhibits facies that do not exist in the central part of the basin. Moreover, the outcrops are affected to different degrees by tropical weathering. It is under these difficult constraints that most previous studies have been done in the Parana Basin. Viewed in this light, the information available from the past studies is a great complement to the geologists who worked in the outcrop belt.

Tectonically, the Parana Basin was once thought to be very stable with almost no deformation. Later research has shown that this is not true. Recent results obtained from well, seismic, and aeromagnetic studies, show that the basin is significantly deformed. Several structural lineaments associated with faulting and diabase intrusions have been mapped, mainly in the southern part of the basin (Fig.5). These dominantly northwest trending lineaments, can be identified either by aeromagnetics (Ferreira, 1982, p. 145) or by remote sensing from satellites and radar images (Soares, 1982, p. 6).

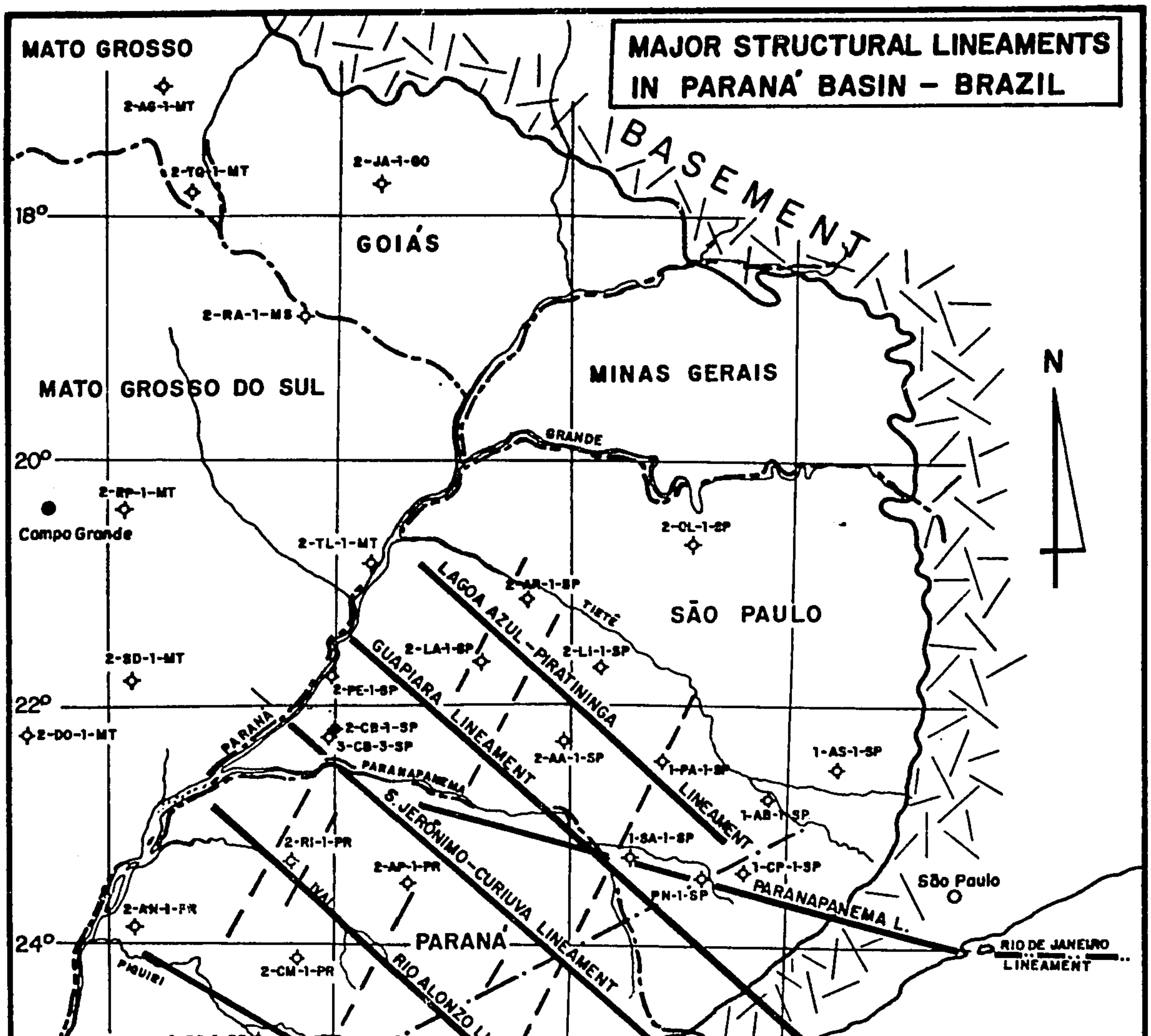
The NW-SE lineaments are 20 to 100 km wide and may extend for 600 km. They are easily traced from the recent coast line through Precambrian terrains, far into the Parana Basin and ending near the Parana River (Fig. 5).

The Paranapanema and Uruguay lineaments are the continental extensions of two offshore fracture zones; (1) the Rio de Janeiro Lineament and (2) the Florianopolis Lineament (Asmus and Guazelli, 1981, Fig. 3). These two lineaments are respectively the northern and southern bounding features of the Ponta Grossa Arch which is the most conspicuous structural feature in the Parana Basin (Fig. 5). According to Asmus (1981, p. 264) and Fulfaro et al (1982, p. 97), these lineaments were probably established in the basement during Upper

Fig. 5 Major structural lineaments in Parana Basin.

The structural lineaments are identified by aeromagnetics or by remote sensing from satellites and radar images. Most of the lineaments are associated with faulting and diabase intrusions and can be traced for more than 600 km. Two of these lineaments are continental extension of two offshore fracture zones (The Rio de Janeiro Lineament and the Florianopolis Lineament).

Faulting associated to some of these structural lineaments were active during the deposition of the Itarare Group, controlling its sedimentation as will be seen later.



Des. L. Calligaris Netto.

Precambrian/Eopaleozoic time. Fulfaro et al (1982, p. 590) related these lineaments to aulacogens that might have developed in the Cambro-Ordovician.

Subsurface Research. Subsurface study in the Parana Basin started in 1892 (Yoshida et al 1982, p. 2) and has three stages. The first stage, from 1892 to 1953, involved private companies and the government in an attempt to find oil. This first attempt was mostly concentrated in the outcrop area of Sao Paulo State. The second stage from 1953 to 1974, was carried out by Petrobras, the national oil company. This exploration effort was actually the first modern exploration phase in the basin. At this time Petrobras used new prospecting methods, including seismic mapping. In this phase, 71 wells were drilled, some of which are located in the outcrop belt, but some were also drilled in the deeper parts of the basin covered by basalt. The third stage from 1980 to 1983 was carried out by Paulipetro which drilled 31 wells, 8 located in the central part of the basin.

Exploration carried out by Petrobras found oil in the Rio Bonito and Ponta Grossa formations, probably in stratigraphic traps. Exploration from 1980 to 1983 found gas and condensate in the Itarare Group, beneath diabases. However, none of these occurrences resulted in commercial fields.

One important result of the three stages of exploration is that the Itarare Group was recognized as the best target for hydrocarbon exploration in the Parana Basin, because; (1) it is in direct contact with underlying source rocks; (2) it contains massive bodies of sandstone with good reservoir qualities even at depths as great as

4600m; (3) it contains potentially good cap rocks represented by pebbly mudstones, siltstones and even diabase bodies; and (4) chiefly because it has had the best hydrocarbon shows to date.

The Itarare Group is the thickest unit in the Parana Basin (1310m in well 2-LA-1-SP in Sao Paulo State, Fig. 6), and was deposited in only 36 million years (Fig. 7). Because macrofossils are rare in the Itarare Group except for the Gondwana flora, its Upper Carboniferous-Lower Permian age was assigned based on palynologic data (Daemon and Quadros, 1970).

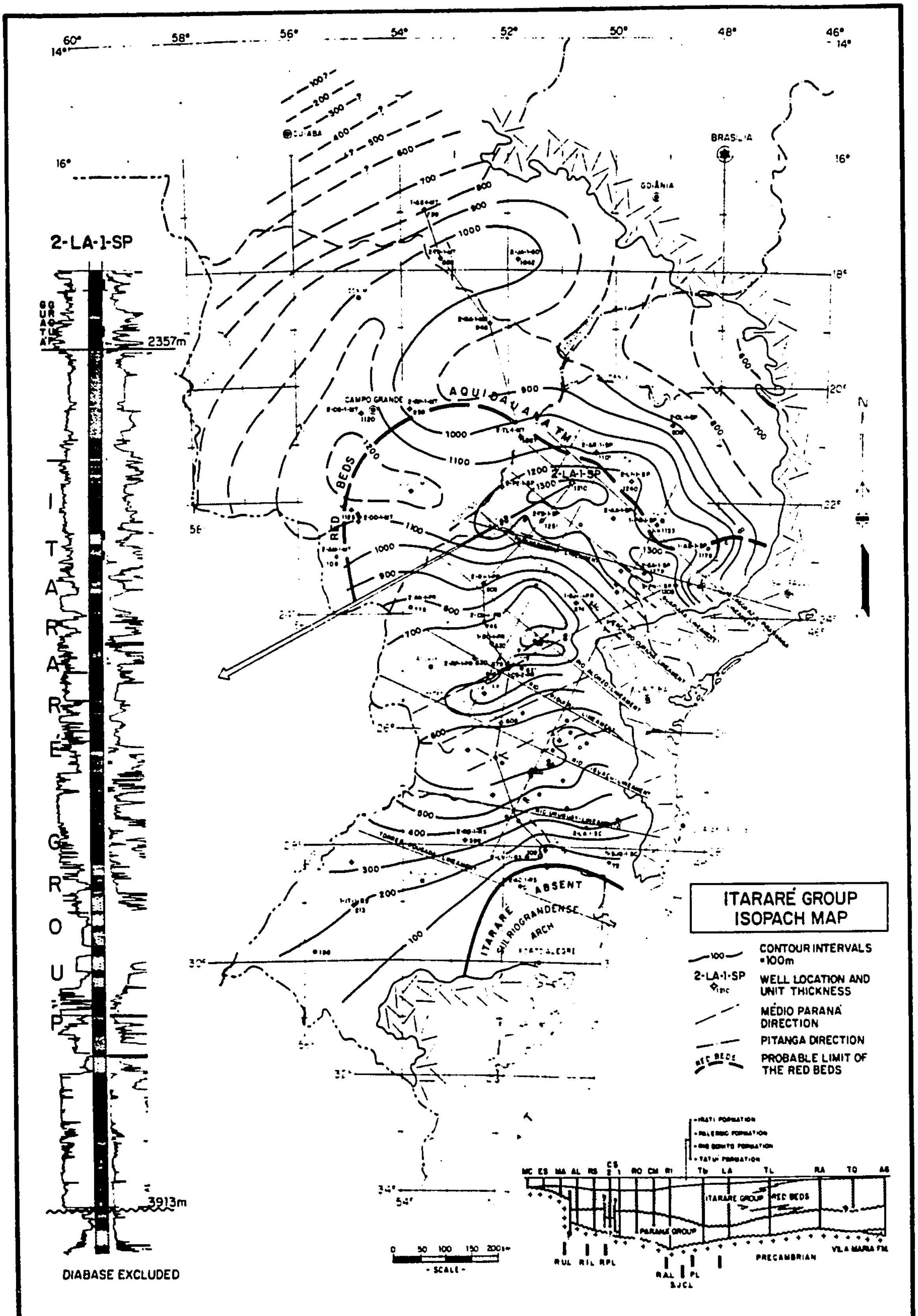
The Itarare Group is well studied in the outcrop area and several stratigraphic classifications have been proposed, most of which are valid only locally. The first attempt to subdivide the Itarare Group, using mainly subsurface data, was made by Baumman (1981), who subdivided the whole Paleozoic sequence above the Devonian into six units.

The main goals of the present work are: 1) to subdivide the Itarare Group using well logs; 2) to correlate the subsurface and outcrop belt; 3) to develop an appropriate nomenclature and, 4) to make a reservoir analysis of its sandstones. Figures 4 and 7 display stratigraphic columns in the states of Rio Grande do Sul; Santa Catarina; Parana; Sao Paulo; Mato Grosso do Sul/Mato Grosso/Goias. Each unit was studied to determine depositional environments using well logs, cores, and facies on map patterns. Sandstone types, porosity and cement stratigraphy as well as diagenetic sequence were developed for the major reservoirs. The ultimate goal of this work is to improve the understanding of the Parana Basin in relation to hydrocarbon exploration, as a consequence of studying the best target in the basin - The Itarare Group.

Fig. 6 Isopach map of the Itarare Group.

The thickest section of the Itarare Group (1310m) was drilled in the 2-LA-1-SP well in Sao Paulo State. The composite log with gamma ray and resistivity of the 2-LA-1-SP well is shown in the left hand side of the figure. In the bottom of the figure is a generalized north-south cross section.

The isopach open towards the Atlantic Ocean suggesting previous continuity of the Itarare Group eastwards.

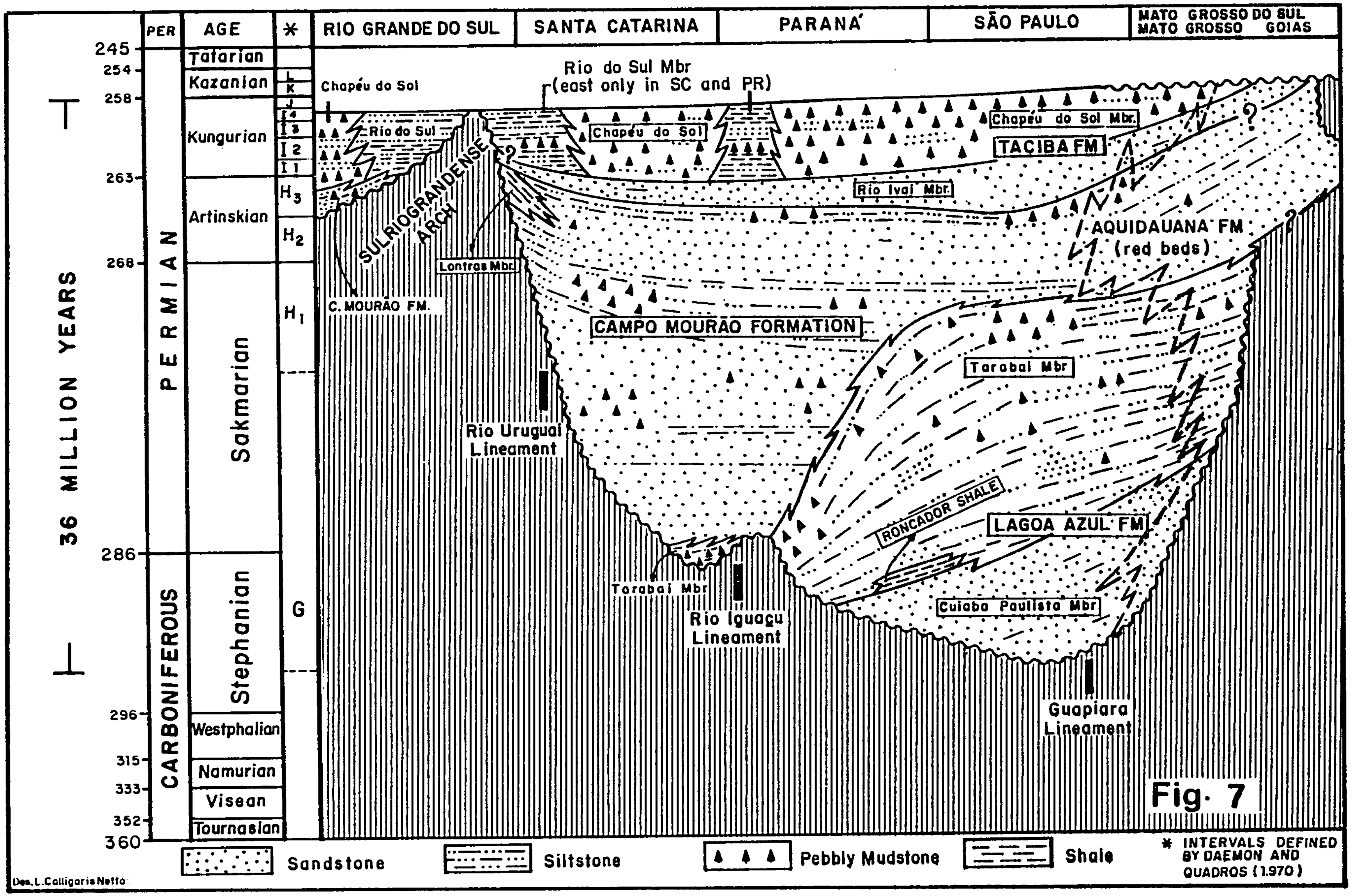


2-LA-1-SP
2357m
ITARARÉ GROUP
3913m
DIABASE EXCLUDED
BRASILIA
GOIÂNIA
CAMPO GRANDE
AQUIDAUANA FM.
RED BEDS
ITARARÉ ABSENT
SUL RIOGRANDENSE ARCH
ITARARÉ GROUP
ISOPACH MAP
CONTOUR INTERVALS =100m
WELL LOCATION AND UNIT THICKNESS
MÉDIO PARANÁ DIRECTION
PITANGA DIRECTION
PROBABLE LIMIT OF THE RED BEDS
ITARARÉ GROUP
RED BEDS
PARANÁ GROUP
PRECAMBRIAN
VILA MARIA FM.
SCALE

Fig. 6

Fig. 7 Proposed Stratigraphic column for the Itarare Group.

This new stratigraphic subdivision is proposed after careful basin-wide analysis of more than three thousand kilometers of cross sections. This stratigraphic column was prepared based in well data from the central part of the Parana Basin, where sedimentation was most continuous and unconformities are less likely. The relationships between these new stratigraphic units proposed for the subsurface and the outcrop area is relatively easy and clear in southern parts of the basin. However, in the northern areas it is necessary additional studies such as correlation of shallow drilling and paleontology to improve the correlation between subsurface and outcrop.


PER
AGE
*
RIO GRANDE DO SUL
SANTA CATARINA
PARANÁ
SÃO PAULO
MATO GROSSO DO SUL
MATO GROSSO GOIAS
245
254
258
263
268
286
296
315
333
352
360
36 MILLION YEARS
PERMIAN
CARBONIFEROUS
Tatarian
Kazanian
Kungurian
Artinskian
Sakmarian
Stephanian
Westphalian
Namurian
Visean
Tournasian
H3
H2
H1
G
Chapéu do Sol
Rio do Sul
Rio do Sul Mbr
(east only in SC and PR)
Chapéu do Sol
Chapéu do Sol Mbr.
TACIBA FM
Rio Ival Mbr.
SULRIOGRANDENSE ARCH
Lontras Mbr.
C. MOURÃO FM.
AQUIDAUANA FM
(red beds)
CAMPO MOURÃO FORMATION
Tarabai Mbr
Rio Uruguai Lineament
RONCADOR SHALE
LAGOA AZUL FM
Tarabai Mbr
Rio Iguaçu Lineament
Cuiaba Paulista Mbr
Guapiara Lineament
Fig. 7
Sandstone
Siltstone
Pebbly Mudstone
Shale
* INTERVALS DEFINED BY DAEMON AND QUADROS (1970)
Des. L. Calligaris Netto

STRATIGRAPHY

The lava flows that cover most of the sedimentary rocks in the Parana Basin are a major problem not only for the geophysicists, but also for the stratigraphers who have long been trying to establish the stratigraphic sequence of the Parana Basin. The thick basalt of the Serra Geral Formation confines the surface geologist to the outcrop in the marginal areas of the basin where the stratigraphic sequence is incomplete. Certainly, the problems of establishing the stratigrapic sequence of a basin from its marginal outcrops have long been recognized. See for example Krumbein and Sloss (1963, p. 20): "Pratically all of the concepts which modern stratigraphers have inherited from their predecessors are derived from studies of rocks in outcrop. It is obvious, however, that by far the greatest volume of the sedimentary rocks is buried and unavailable for surface study. No stratigraphic concept which ignores this great bulk of unexposed strata can be considered complete". Kingston et al (1983, p. 2176),states essentially the same idea "The sedimentary stages should be described from the center of the depositional cycle in enclosed basins...". Or consider Miall (1984, p. 3), "Stratigraphic units ideally should be stablished on the basis of a basin-wide perspective, but they rarely are. Local terminology continues to be proposed by geologists studying limited areas while paying little or no attention to the regional framework".

These quotations are cited here to emphasize that careful subsurface studies of the central part of the Parana Basin are essential and important in order to understand the regional stratigraphy. These subsurface stratigraphic studies are the foundation for all exploration and for an improved understanding of the origin of the basin.

Fortunately, there are now more than 20 deep holes in the basin, most of which have an exceptionally good suites of wireline logs and many with carefully collected cores. These new data provide the basis for the new stratigraphic units proposed here. These units were proposed only after careful basin-wide study of more than threethousand kilometers of cross sections (Fig. 8, and appendices 1 and 2) and the preparation of basin-wide maps. All these units were chosen for their practical application to subsurface stratigraphy.

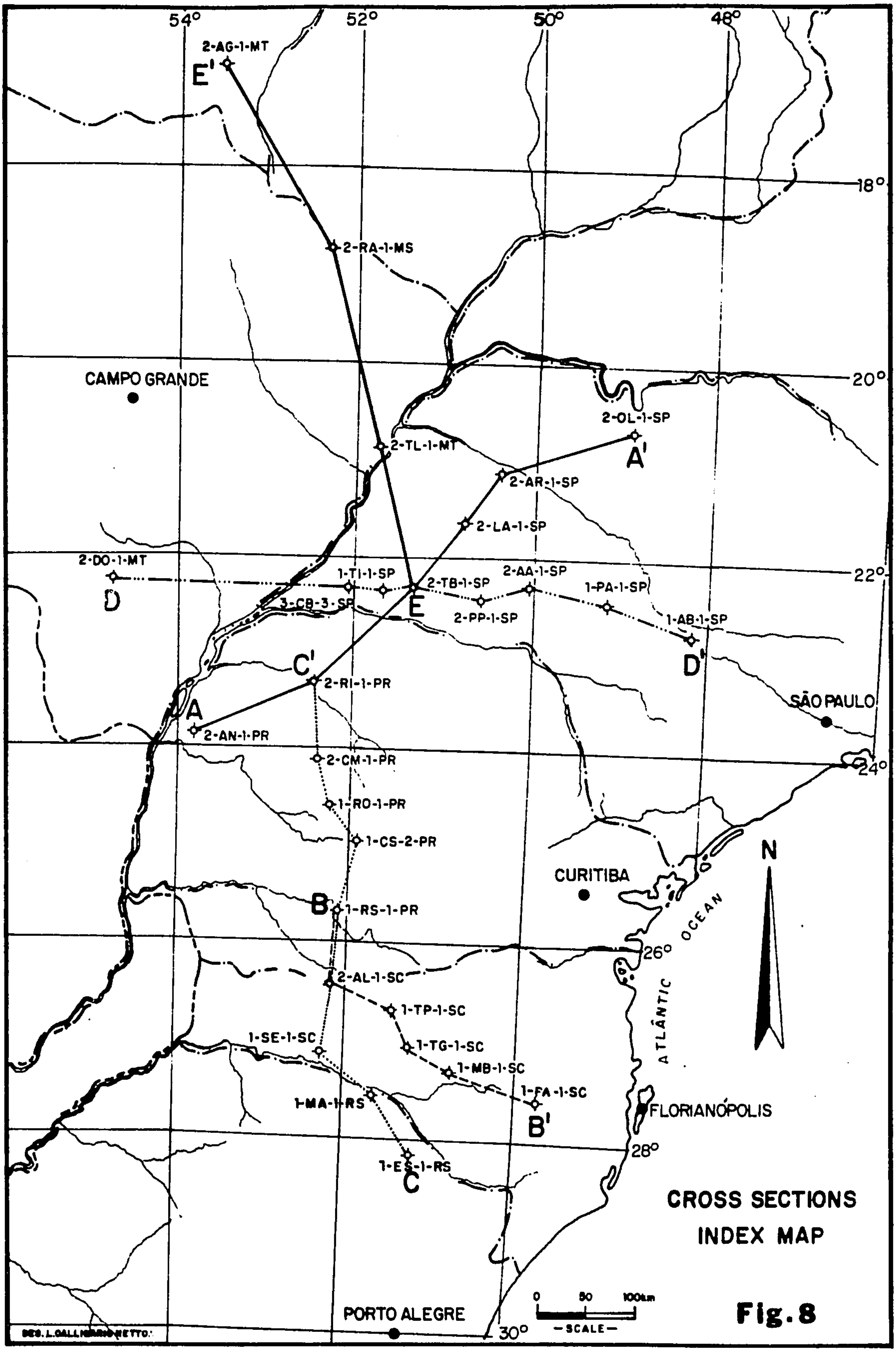
One of the objectives of this work is to improve the knowledge of a major segment of the long history of the basin; this segment is the Itarare Group, which belongs to the Tubarao Supergroup.

Tubarao Supergroup. The Tubarao Series name was assigned by White (1908 p. 48). White used Tubarao Series for all the sediments below the Permian Irati Formation in Santa Catarina State. Later, the Tubarao Series was extended to the rest of the basin and modified to Tubarao Group and Tubarao Supergroup (Table 1). The Tubarao Supergroup comprises the Itarare Group and Guata Group, as defined by Schneider et al (1974, p. 45). This nomenclature is adopted here with a minor change that is, the inclusion of the Tatui Formation in the Guata Group (Table 1).

Itarare Group. The term Itarare was first used by Oliveira (1927, p. 41) who designated the Itarare Series as all sediments with glacial

Fig. 8 Cross sections index map.

Ten cross sections were prepared to study the Itarare Group. Five of them were select to show the subsurface correlation of the Itarare Group. Cross section BB' correlates subsurface with outcrop area in Santa Catarina State.



54°
52°
50°
48°
18°
20°
22°
24°
26°
28°
30°
2-AG-1-MT
E'
2-RA-1-MS
CAMPO GRANDE
2-OL-1-SP
A'
2-TL-1-MT
2-AR-1-SP
2-LA-1-SP
2-DO-1-MT
D
1-TI-1-SP
2-TB-1-SP
2-AA-1-SP
1-PA-1-SP
3-CB-3-SP
E
2-PP-1-SP
1-AB-1-SP
D'
C'
2-RI-1-PR
A
2-AN-1-PR
SÃO PAULO
2-CM-1-PR
1-RO-1-PR
1-CS-2-PR
N
CURITIBA
B
1-RS-1-PR
ATLÂNTIC OCEAN
2-AL-1-SC
1-TP-1-SC
1-SE-1-SC
1-TG-1-SC
1-MB-1-SC
1-FA-1-SC
1-MA-1-RS
B'
FLORIANÓPOLIS
1-ES-1-RS
C
CROSS SECTIONS
INDEX MAP
0
50
100km
SCALE
PORTO ALEGRE
Fig. 8

Table 1 Stratigraphic Classification of the Tubarao Supergroup since 1969.

Former classifications has been proposed based on outcrop information. Gama Jr. et al (1982) presented the first stratigraphic column using well data; However, the Itarare Group was not subdivided and still had the status of formation. In this new proposition the Itarare has the status of group and is subdivided into four formations.

Similarly to the column presented by Schneider et al (1974) the Itarare Group is considered here a unit of the Tubarao Supergroup.

STRATIGRAPHIC CLASSIFICATION EVOLUTION OF TUBARÃO SUPERGROUP SINCE 1969.

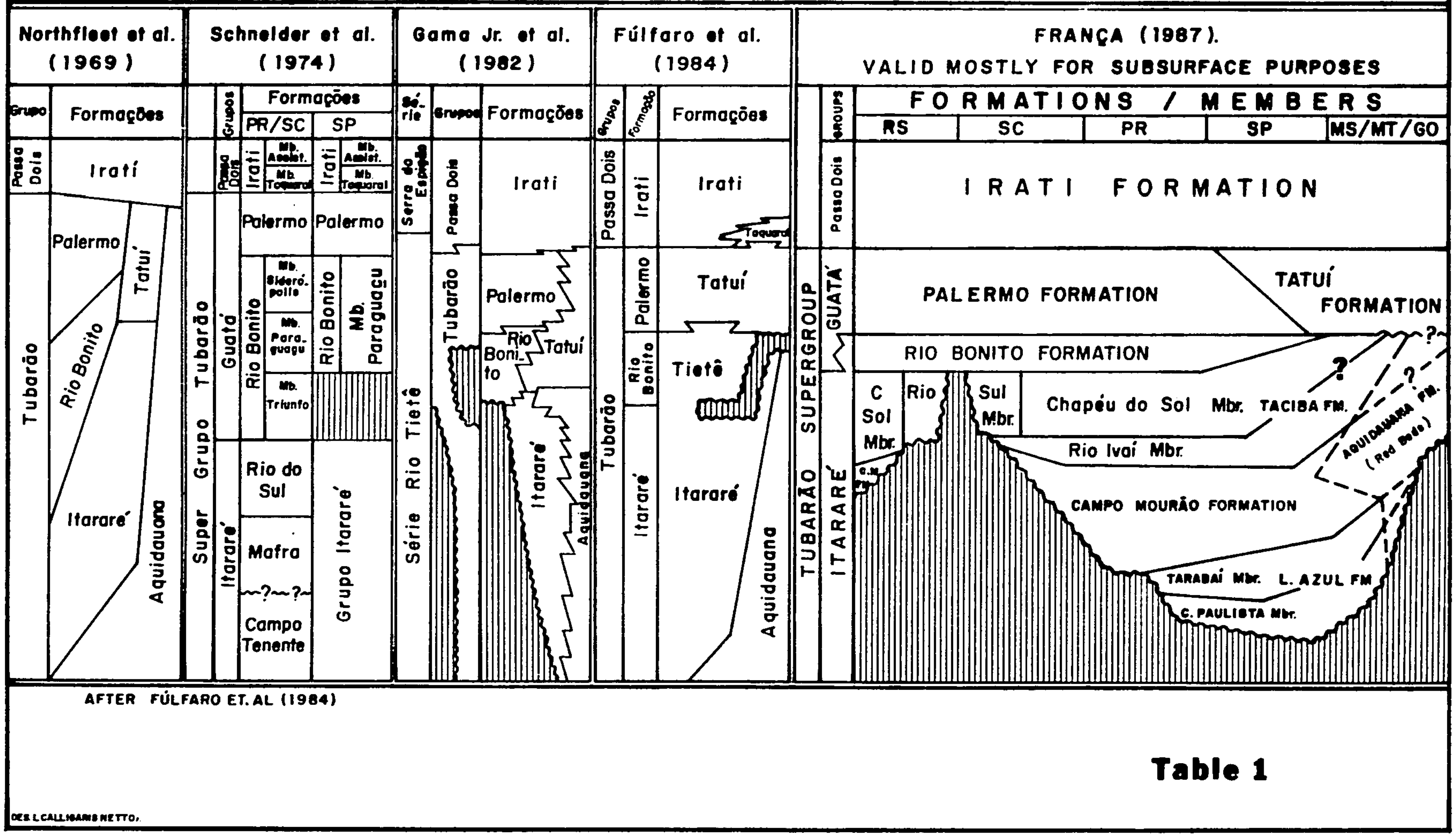


Table 1

influences in the basin of the Itarare River in Sao Paulo State. According to Schneider et al (1974, p. 45), the Itarare Series was changed into Itarare Group by Gordon (1947, p. 4). Some authors, however, such as Northfleet et al (1969), Gama et al (1982), and Fulfaro et al (1984) use Itarare Formation rather than Itarare Group.

Group is definitely the best status for this unit which is more than 1300 meters thick and can be subdivided into conspicuous and mappable lithostratigraphic units. This has been shown by Schneider et al (1974, Fig. 2) in the outcrop belt in southern part of the basin, and by my present subsurface studies.

In the subsurface, it is herein proposed that the Itarare Group is divided into four formations: Lagoa Azul Formation, Campo Mourao Formation, Taciba Formation, and Aquidauana Formation (Fig. 7). The Lagoa Azul Formation occurs in the central part of the basin, mainly in Parana and Sao Paulo states. It is subdivided into the Cuiaba Paulista Member and Tarabai Member. The Lagoa Azul Formation in central Parana State has a distinct radioactive shaly unit which occurs in the Tarabai Member, called the Roncador Shale Lens. The Campo Mourao Formation occurs throughout the entire basin, but is absent in some areas of the state of Rio Grande do Sul. It contains the Lontras Member which occurs in southeastern Santa Catarina. The Taciba Formation is present throughout the entire basin, except in the Sul Riograndense Arch, where the Itarare Group is absent. The Taciba Formation is subdivided into Rio Ivai Member, Chapeu do Sol Member, and Rio do Sul Member. The Aquidauana Formation is the major unit in the northern part of the basin extending as far south as the central part of Sao Paulo State.

Lagoa Azul Formation.: It is proposed to designate the basal section of the Itarare Group in Sao Paulo, Parana, and Southern Mato Grosso do Sul, as the Lagoa Azul Formation (Fig.7). The Lagoa Azul Formation is composed of grayish sandstone, siltstone and pebbly mudstone. The proposed type section occurs between 3144m and 3913m in the 2-LA-1-SP well (Lagoa Azul No 1, Fig.3), excluding the diabases (Fig. 9).

The correlation of the Lagoa Azul Formation is shown in cross sections (Figs. 10, 12, 13, and 14). The total area and thickness of the Lagoa Azul Formation is shown on the isopach map (Fig. 15). This formation is present over 480,000 km^2.

The major characteristic of the Lagoa Azul Formation in well logs, is the cylindrical gamma ray log pattern of the sandy unit (Cuiaba Paulista Member). The sandy unit commonly has a sharp contact with the argillaceous unit above, the Tarabai Member.

The Lagoa Azul Formation commonly overlies the Parana Group (Devonian) from which it is always separated by an erosional unconformity. When the Parana Group is not present, the Lagoa Azul Formation is underlain by crystalline basement as shown in cross sections AA' and DD' (Figs. 10 and 13).

No macrofossils have been observed in the Lagoa Azul Formation; however, palynologically it has been dated as Upper Carboniferous (Stephanian to Sakmarian), and corresponds to the interval G and G + H_1 (Fig. 7), as defined by Daemon and Quadros (1970, p. 363). According to these authors (p. 363), the spores present in the interval G and H_1 belong to the **Potonieisporites** microflora, and are equivalent to stages Talchir and Kharhabari in India. All spores found in the

Fig. 9 Proposed type section for the Lagoa Azul Formation with some typical lithological examples.

1 Sandstone with inclined bedding from core No. 7 (box 13), 3-CB-3-SP in Sao Paulo State (4475m).

2 Siltstone with deformed sedimentary structure from core No. 10 (box 8), 3-CB-3-SP in Sao Paulo State (4546m)

3 Sandstone with sub-horizontal bedding and micro- faults from core No. 7 (box 6), 3-CB-3-SP in Sao Paulo State (4469m)

4 Massive sandstone with dish structures from core No.13 (box 9) 2-LA-1-SP in Sao Paulo State (3880m).

5 Massive sandstone from core No. 13 (box 8), 2-LA-1- SP in Sao Paulo State (3879m).

6 Argillaceous sandstone with inclined bedding from core No. 10 (box 3), 2-AA-1-SP in Sao Paulo State (2760m).

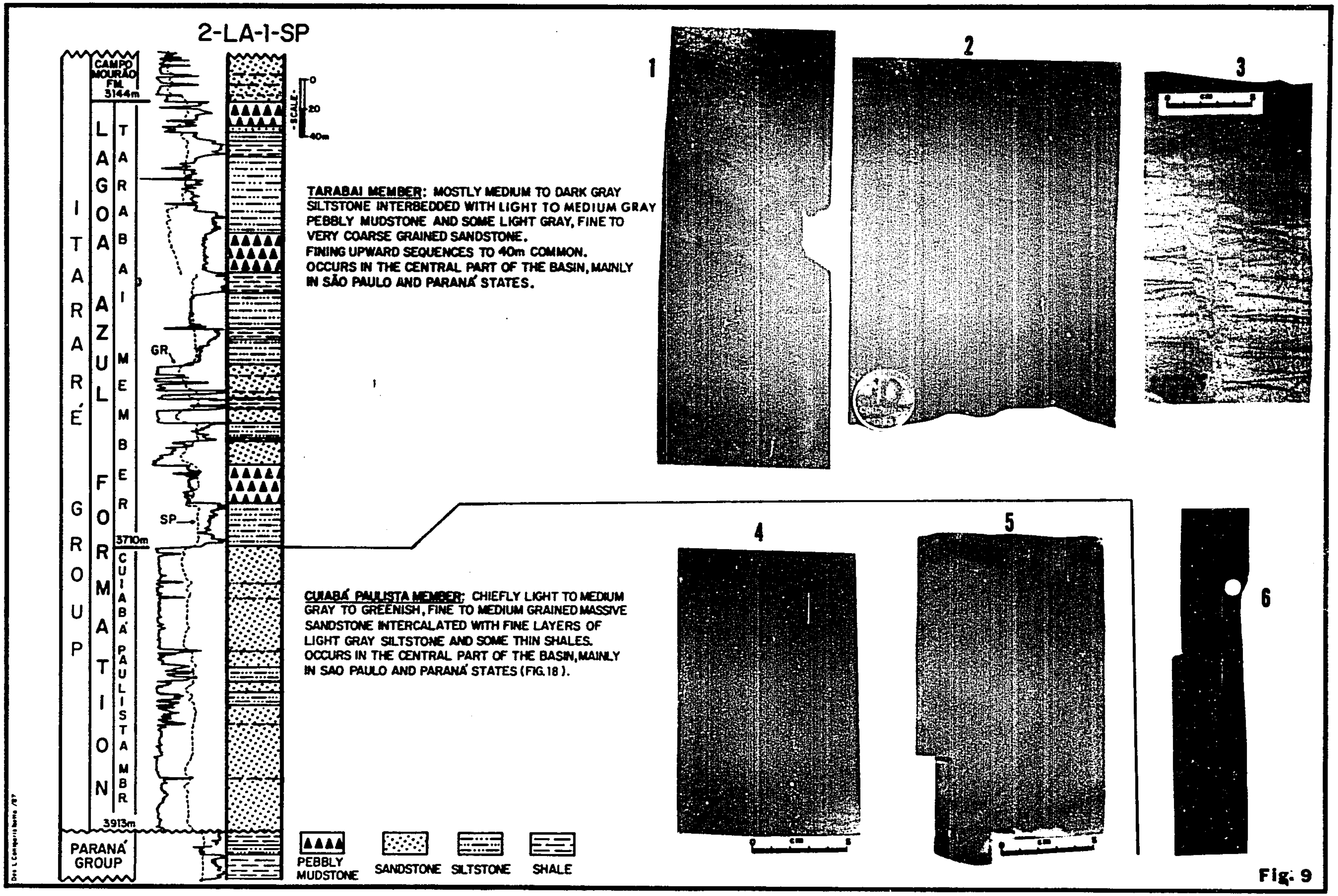

2-LA-1-SP
CAMPO MOURÃO FM.
3144m
ITARARÉ GROUP
LAGOA AZUL FORMATION
TARABAI MEMBER
3710m
CUIABÁ PAULISTA MBR
3913m
PARANÁ GROUP
GR
SP
SCALE
0
20
40m
TARABAI MEMBER: MOSTLY MEDIUM TO DARK GRAY SILTSTONE INTERBEDDED WITH LIGHT TO MEDIUM GRAY PEBBLY MUDSTONE AND SOME LIGHT GRAY, FINE TO VERY COARSE GRAINED SANDSTONE.
FINING UPWARD SEQUENCES TO 40m COMMON.
OCCURS IN THE CENTRAL PART OF THE BASIN, MAINLY IN SÃO PAULO AND PARANÁ STATES.
CUIABÁ PAULISTA MEMBER: CHIEFLY LIGHT TO MEDIUM GRAY TO GREENISH, FINE TO MEDIUM GRAINED MASSIVE SANDSTONE INTERCALATED WITH FINE LAYERS OF LIGHT GRAY SILTSTONE AND SOME THIN SHALES.
OCCURS IN THE CENTRAL PART OF THE BASIN, MAINLY IN SAO PAULO AND PARANÁ STATES (FIG.18).
PEBBLY MUDSTONE
SANDSTONE
SILTSTONE
SHALE
1
2
3
4
5
6
Fig. 9

Fig. 15 Isopach map of the Lagoa Azul Formation.

The Lagoa Azul Formation covers an area of about 480,000 km^2. Its depocenter is aproximatelly east-west, parallel to the Paranapanema Lineament. Minor depocenters in southern parts of the basin are apparently controled by the Rio Alonzo, Rio Piquiri, and Rio Iguacu lineaments.

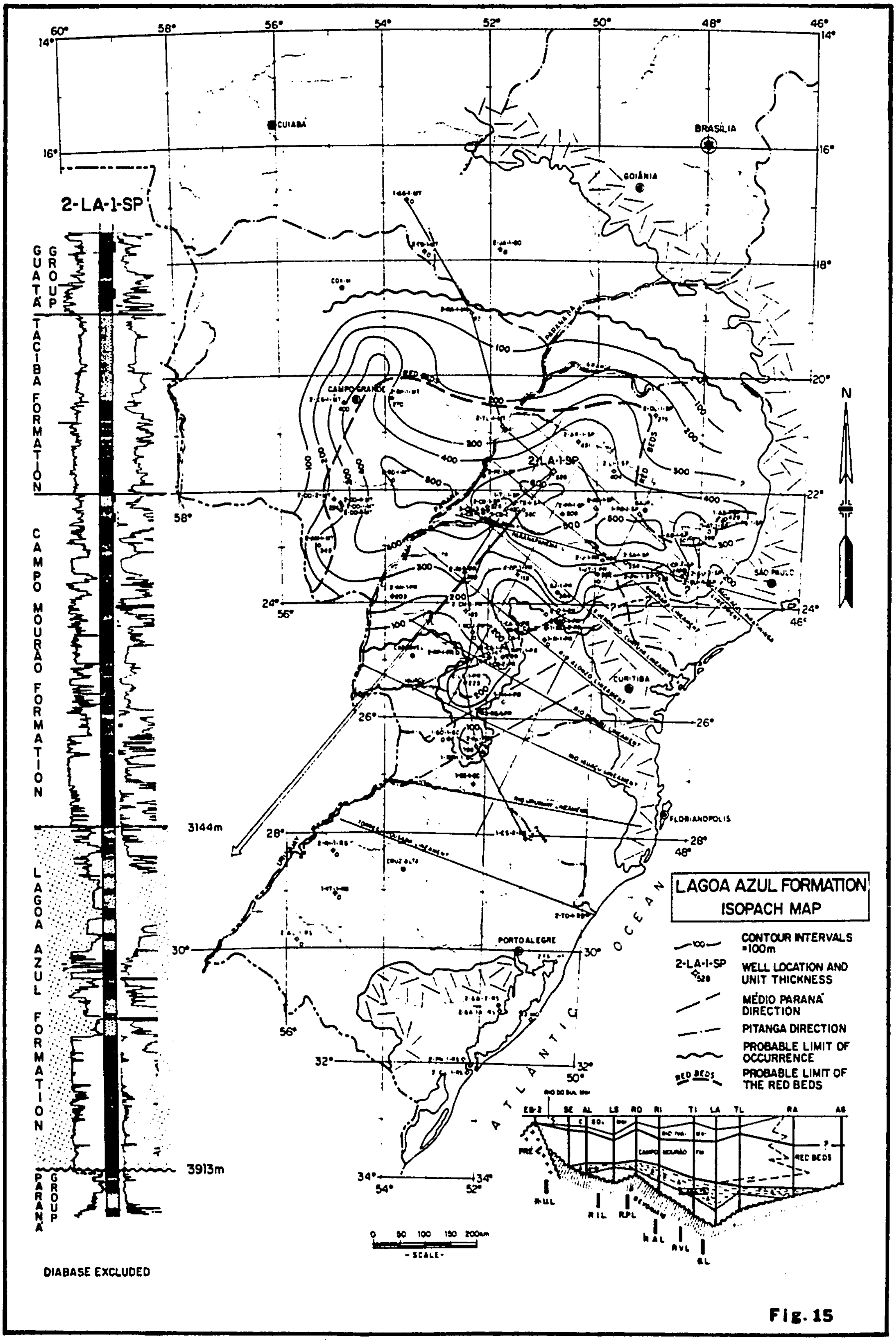

LAGOA AZUL FORMATION
ISOPACH MAP
CONTOUR INTERVALS =100m
2-LA-1-SP
WELL LOCATION AND UNIT THICKNESS
MÉDIO PARANÁ DIRECTION
PITANGA DIRECTION
PROBABLE LIMIT OF OCCURRENCE
RED BEDS
PROBABLE LIMIT OF THE RED BEDS
2-LA-1-SP
GUATÁ GROUP
TACIBA FORMATION
CAMPO MOURÃO FORMATION
LAGOA AZUL FORMATION
PARANÁ GROUP
3144m
3913m
DIABASE EXCLUDED
CUIABÁ
BRASÍLIA
GOIÂNIA
CAMPO GRANDE
SÃO PAULO
CURITIBA
FLORIANÓPOLIS
PORTO ALEGRE
ATLANTIC OCEAN
N
SCALE
0 50 100 150 200Km

Fig. 15

interval G and H_1 are continental in origin and are probably Gymnosperms, mainly conifers (Daemon and Quadros 1970, p.363).

Recent research (Daemon et al 1982, p. 7) has shown that the basal section of the Itarare Group in the central part of the basin, which corresponds to the proposed Lagoa Azul Formation, has reworked fossils from the Ponta Grossa Formation (Devonian); therefore good evidence exists that erosion of the Devonian supplied sediments for the Lagoa Azul Formation.

The maximum known thickness for the Lagoa Azul Formation is 560 meters in Sao Paulo State in 2-TB-1-SP (Fig. 15). Typical thicknesses are 200 to 400m. The formation is commonly present at depths greater than 2000m. The deepest known depth to the top is 4649m in Parana State in 2-AN-1-PR (Fig. 3). It becomes shallower towards the eastern border of the basin, where it is only 1070m deep in 1-JT-1-PR in Parana State (Fig. 3). Even closer to the outcrop area of the Itarare Group, the Lagoa Azul Formation is still deep as shown by the 1-AB-1-SP well in Sao Paulo State where it is at a depth of 1349m (Cross section DD', Fig. 13).

It is not known if the Lagoa Azul Formation crops out; however, if it does it should be thinner than in most of the area where it is in the supsurface as suggested by the isopach map (Fig. 15). If present in outcrop, it may also be easily confused with the overlying unit, the Campo Mourao Formation, which has similar lithology.

The isopach map of the Lagoa Azul Formation (Fig. 15) suggests that a sub-basin was established in the central and northern part of the Parana Basin at the outset of Itarare Group deposition. This sub-basin has a depositional axis about east-west, sub parallel to the Paranapanema Lineament. The isopach pattern suggests that the deposition of the Lagoa Azul Formation was tectonically controlled by structural lineaments striking northwest and northeast. The intersection of these lineaments defines somewhat rectangular areas that seem to have subsided differentially. These are informally called "rectangular grabens." These grabens are easily seen in the isopach map of the Lagoa Azul Formation; however, they tend to be less defined in upper sections of the Itarare Group, perhaps suggesting less tectonic control on the sedimentation as the basin filled.

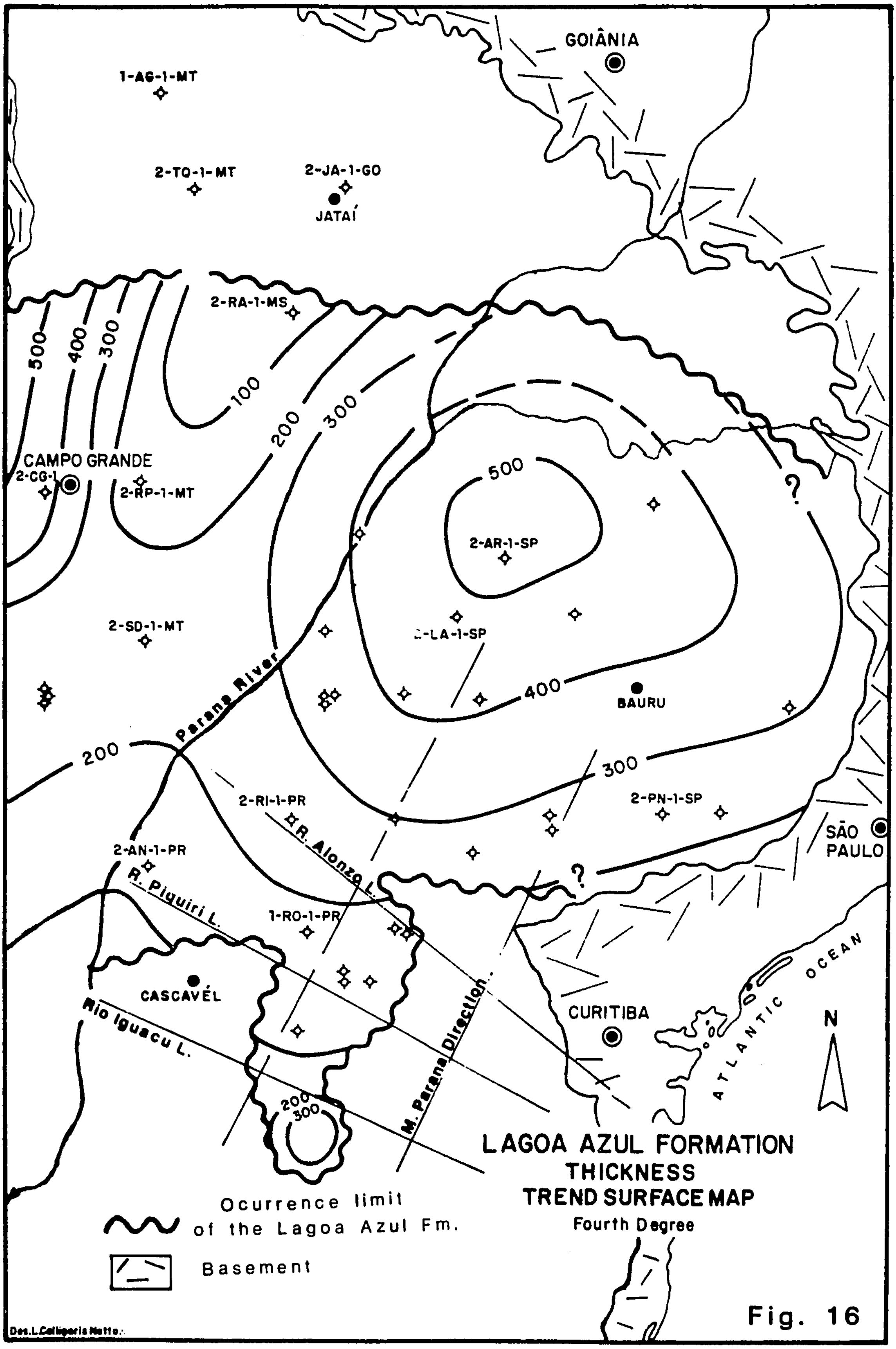
Polynomial trend surface maps of first, second, third, and fourth degree (Krumbein and Graybill, 1965, p. 320); Davis, 1973, p. 322) were computed for the thicknesses data of the Lagoa Azul and Taciba formations, lowermost and uppermost units in the Itarare Group. They were computed to see if the residuals from the fourth order trend surfaces reflect differential subsidence across the basin. For example, do the residuals correlate with the grabens between the lineaments (Fig. 15) ? The residuals from the fourth degree surface seems to be the best for this purpose (Figs. 16 and 17).

The trend surface map (Fig. 16) shows a major depocenter in Sao Paulo State separated by a northeast-southwest saddle from another possible depocenter in Mato Grosso do Sul Sate. Note that the saddle is parallel to the Medio Parana Direction Lineament. The residual map (Fig. 17) was deliberately contoured to show the maximum association between thickness (positive residuals) and rectangular grabens; and conversely to show an association between source areas (negative residuals) and possible horsts.

It is interesting that Daemon et al (1983, p. 7) have shown that the basal section of the Itarare Group in Sao Paulo and Mato Grosso

Fig. 16 Fourth-degree trend surface map of the Lagoa Azul Formation (thickness).

The fourth-degree trend surface map of the Lagoa Azul Formation shows a major depocenter in Sao Paulo State and a positive area aligned northeast-southwest. The figure suggest a second depocenter westwards that may extend into Paraguay.



GOIÂNIA
1-AG-1-MT
2-TQ-1-MT
2-JA-1-GO
JATAÍ
2-RA-1-MS
500
400
300
100
200
300
CAMPO GRANDE
2-CG-1
2-RP-1-MT
500
2-AR-1-SP
2-SD-1-MT
2-LA-1-SP
400
BAURU
Parana River
200
300
2-RI-1-PR
2-PN-1-SP
SÃO PAULO
2-AN-1-PR
R. Alonzo L.
R. Piquiri L.
1-RO-1-PR
CASCAVÉL
Rio Iguacu L.
M. Parana Direction
CURITIBA
ATLANTIC OCEAN
N
200
300
LAGOA AZUL FORMATION
THICKNESS
TREND SURFACE MAP
Fourth Degree
Ocurrence limit
of the Lagoa Azul Fm.
Basement
Des. L. Calligaris Netto

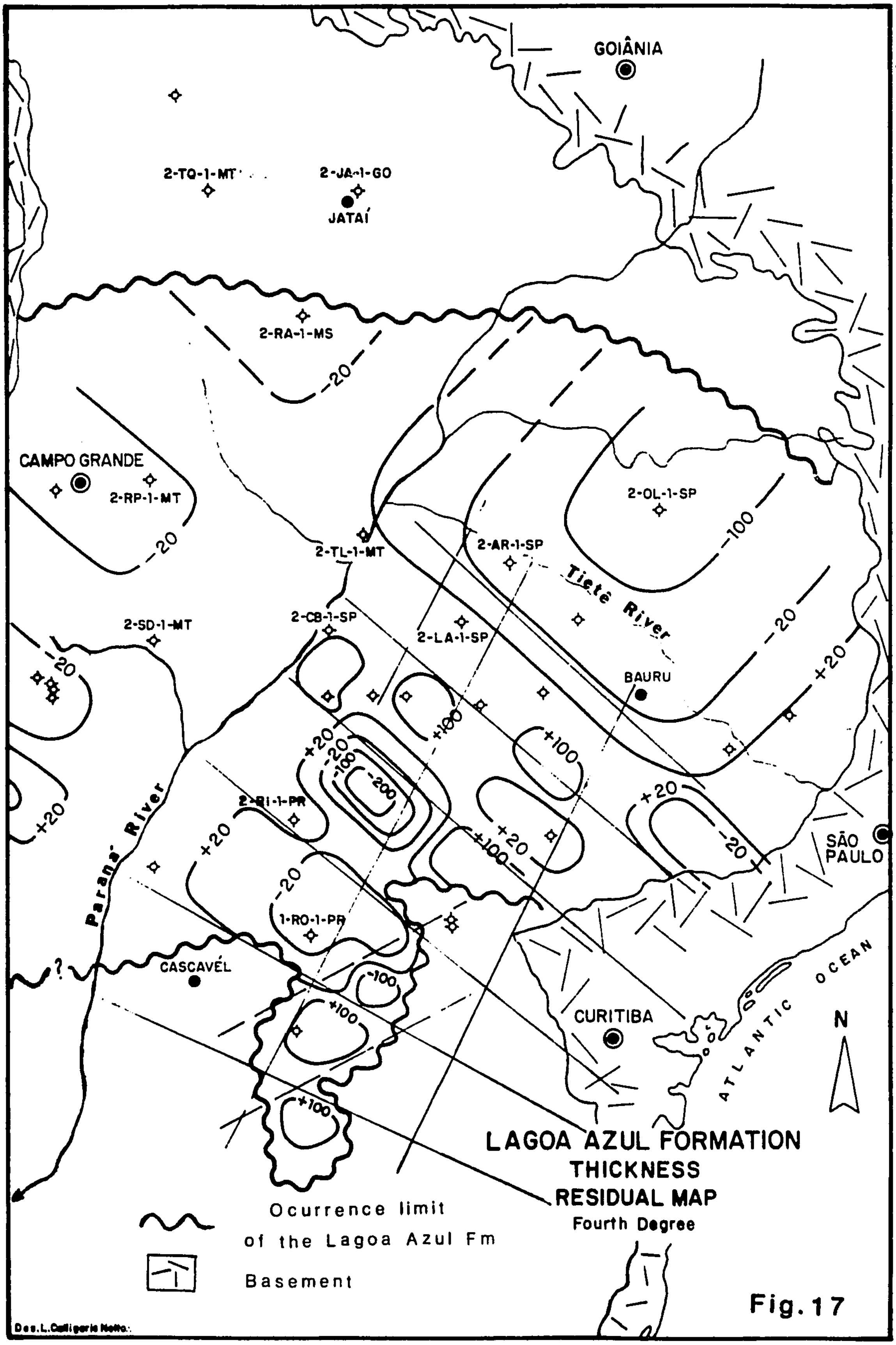
Fig. 16

Fig. 17 Fourth-degree residual map of the Lagoa Azul Formation (thickness).

This map was deliberately contoured to enhance the influence of the structural lineaments in the deposition of the Lagoa Azul Formation. The positive values represent depocenters (rectangular grabens), whereas negative values represent probable source areas (rectangular horsts).

Note that the Parana River and its tributaries flow parallel to the structural lineaments in the Parana Basin, suggesting that their courses are controlled by the trends of the structural lineaments.

For names of the structural lineaments, please see Figure 5.


GOIÂNIA
2-TQ-1-MT
2-JA-1-GO
JATAÍ
2-RA-1-MS
CAMPO GRANDE
2-RP-1-MT
2-OL-1-SP
2-TL-1-MT
2-AR-1-SP
Tietê River
2-SD-1-MT
2-CB-1-SP
2-LA-1-SP
BAURU
Paraná River
1-RO-1-PR
CASCAVEL
SÃO PAULO
ATLANTIC OCEAN
CURITIBA
N
LAGOA AZUL FORMATION
THICKNESS
RESIDUAL MAP
Fourth Degree
Ocurrence limit
of the Lagoa Azul Fm
Basement
Fig. 17

do Sul states have reworked fossils from the Ponta Grossa Formation (Devonian). Therefore, it is possible that vertical movements along the structural lineaments have exposed blocks of the Ponta Grossa Formation, which then could have been source rock for the rectangular grabens. This supports the contours of the residuals of Figure 17, which implies greater thickness between the lineaments.

Although the tendentiously contoured residual map has worked well with the thickness data from the Lagoa Azul Formation, it must always be seen as an option among others, of contouring the same map with the same data.

The Lagoa Azul Formation is composed of a basal sandy unit, the Cuiaba Paulista Member and by a 'shaly' unit, the Tarabai Member.

Cuiaba Paulista Member: Cuiaba Paulista is the name proposed for the basal Member of the Lagoa Azul Formation. The Cuiaba Paulista Member is present in the states of Parana, Sao Paulo and Mato Grosso do Sul and is present over an area of about 300,000 km^2 (Fig. 18). It is composed primarily of sandstone and locally siltstone. Locally it may contain some pebbly mudstone.

The proposed type section is the interval from 4557 to 4822m in 3-CB-3-SP (Cuiaba Paulista No.3, Figs. 3 and 13). On gamma ray logs, the major characteristic of the Cuiaba Paulista Member is its cylindrical pattern (Fig. 9).

The Cuiaba Paulista Member unconformably overlies the Parana Group in the states of Parana, Mato Grosso do Sul, and in most of Sao Paulo State and unconformably overlies Precambrian basement in eastern Sao Paulo (Figs. 10 and 13).

The age of the interval corresponding to the Cuiaba Paulista

Fig. 18 Isopach map of the Cuiaba Paulista Member.

The Cuiaba Paulista Members is essentially a sandy unit and covers an area of about 300,000 km^2. There are two major depocenters separated by one positive thin area parallel to the Medio Parana Direction Lineament. The two minor depocenters in southern realm were controlled by the Rio Alonzo, Rio Piquiri, and Rio Iguacu Lineament.

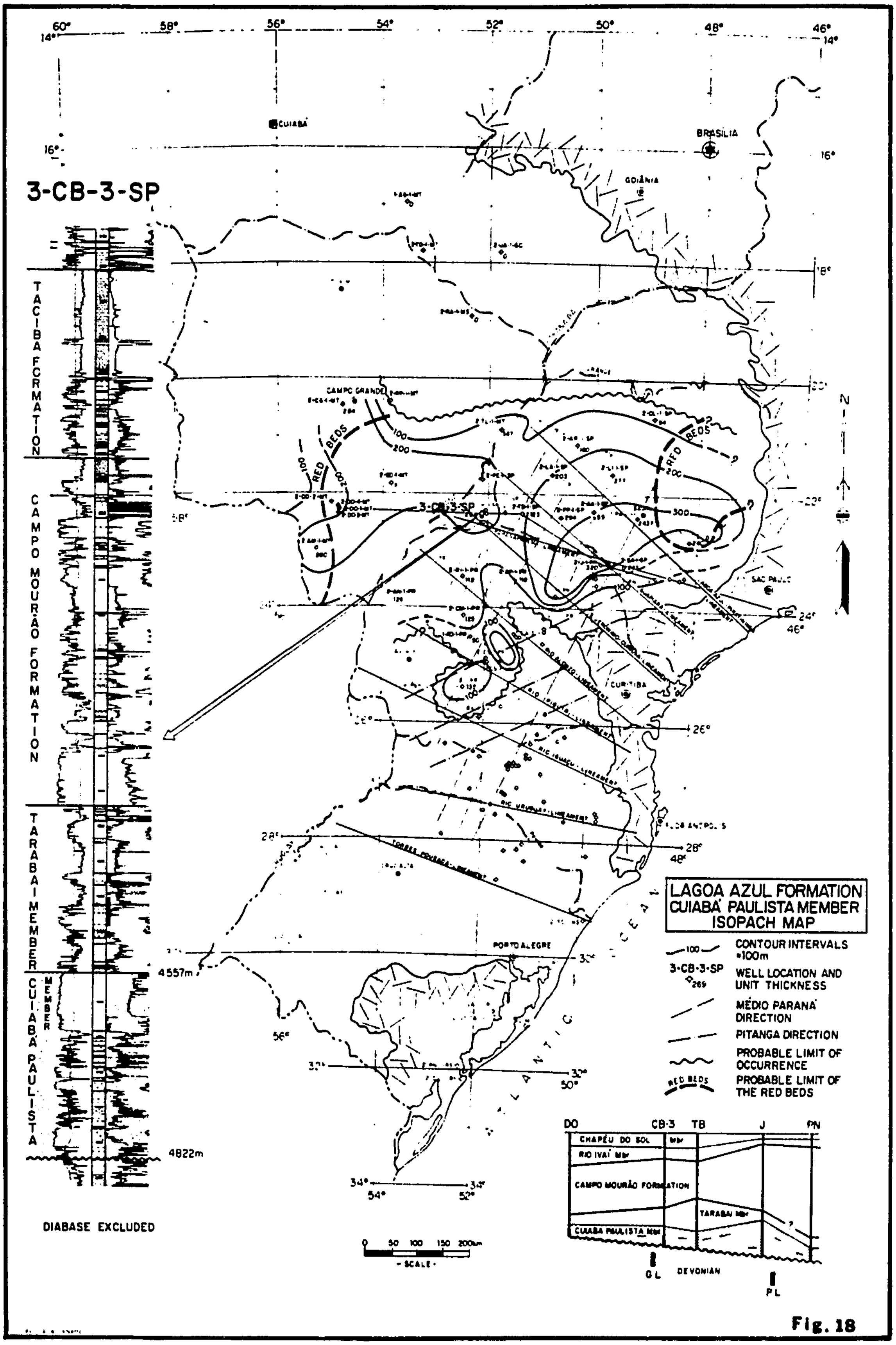

3-CB-3-SP
TACIBA FORMATION
CAMPO MOURÃO FORMATION
TARABAI MEMBER
CUIABÁ PAULISTA MEMBER
4557m
4822m
DIABASE EXCLUDED
LAGOA AZUL FORMATION
CUIABÁ PAULISTA MEMBER
ISOPACH MAP
CONTOUR INTERVALS =100m
WELL LOCATION AND UNIT THICKNESS
MÉDIO PARANÁ DIRECTION
PITANGA DIRECTION
PROBABLE LIMIT OF OCCURRENCE
PROBABLE LIMIT OF THE RED BEDS
RED BEDS
CUIABÁ
BRASÍLIA
GOIÂNIA
CAMPO GRANDE
SÃO PAULO
CURITIBA
PORTO ALEGRE
ATLANTIC OCEAN
N
SCALE
0 50 100 150 200km
DO CB-3 TB J PN
CHAPÉU DO SOL Mbr
RIO IVAÍ Mbr
CAMPO MOURÃO FORMATION
TARABAI Mbr
CUIABÁ PAULISTA Mbr
DEVONIAN
GL
PL

Fig. 18

Member is Upper Carboniferous-Lower Permian (Stephanian to Sakmarian), intervals G and G+H_1, according to paleontological informations in composite logs and to studies of Daemon and Quadros (1970, Fig. 4).

The maximum known thickness of the Cuiaba Paulista Member is 368m in 2-J-1-PR, eastern Parana State (Fig. 18) and typical thicknesses are 100 to 200m.

The Cuiaba Paulista Member was cored in several wells by Petrobras and Paulipetro (Fig. 19). The lithologic descriptions of all units discussed in this study are based on core descriptions and/or description of cuttings from the composite logs. Detailed petrographic descriptions will be presented later in the reservoir analysis.

Sandstones in the Cuiaba Paulista Member are light to medium gray (N6 - N7), greenish (5GY 6/1), fine to medium grained, moderately to well sorted, and composed essentially of quartz with minor feldspar and lithic fragments. Pyrite and heavy minerals are also present in some cores. Commonly, the sandstone is massive, which is in agreement with the cylindrical gamma ray pattern observed in well logs. The major sedimentary structures are dish structures, especially in core No.13 of 2-LA-1-SP (Fig. 9), shaly partings, cross laminations and climbing ripples.

Although the sandstone appears to be clay-free as suggestedby the gamma ray log, drill-stem tests run in the Cuiaba Paulista Member have shown that commonly the sandstone has very low permeability, in some cases with no fluid production at all. Possible reasons for the low permeability will be discussed later in the section on reservoir analysis.

The isopach map of the Cuiaba Paulista Member (Fig. 18) shows two major depositional centers located in Sao Paulo and Mato Groso do Sul. These depositional centers are separated by one positive feature aligned NE-SW parallel to the Medio Parana Direction lineaments (Soares et al, 1982, p. 9; Saad in prep.).

Two minor depositional centers are located in Parana State in the area of the 1-PT-1-PR and 2-LS-1-PR wells. These two minor depositional centers apparently had tectonic control as suggested by the isopach contour pattern. This control is visible where the Rio Iguacu, Rio Uruguai, and Rio Alonzo lineaments intersect lineaments of the Medio Parana Direction (Fig. 18), creating the rectangular depositional centers in Southern Parana. These centers persisted to the time of deposition of the Tarabai Member.

Tarabai Member: It is proposed to designate the 'shaly' unit in the upper part of the Lagoa Azul Formation as the Tarabai Member (Fig. 9). The correlation of the Tarabai Member is shown on cross sections AA' to EE' (Figs. 10 to 14). The area extent of the Tarabai Member is about 390,000 km^2 as shown in Figure 20.

The proposed type section is the interval from 4161 to 4396m in 2-TI-1-SP (Tarabai no.1 Figs. 3 and 13). The maximum known thickness is 437m in 2-TB-1-SP (Fig. 20). Typical thicknesses are 150 to 250m. The Tarabai Member is composed mainly of siltstone and pebbly mudstones. However, sandstone bodies up to 25m thick are common, some having fairly good reservoir qualities, such as in the 2-CB-1-SP in Sao Paulo State, which produced gas during DST's.

The coring program established by Paulipetro in the Tarabai Member (Fig. 19), was concentrated in sandstone bodies for reservoir purposes.

Fig. 20 Isopach map of the Tarabai Member.

The Tarabai Member is composed mostly of siltstones and pebbly mudstones, and covers an area of aproximatelly 390,000 km^2. Its major depocenter strikes east-west parallel to the Paranapanema Lineament. The Rio Iguacu and the Pitanga Direction lineaments apparently had controled the deposition of the Tarabai Member in the area of the 2-AL-1-SC well (southern part of the basin). See also cros section CC' (Fig. 12).

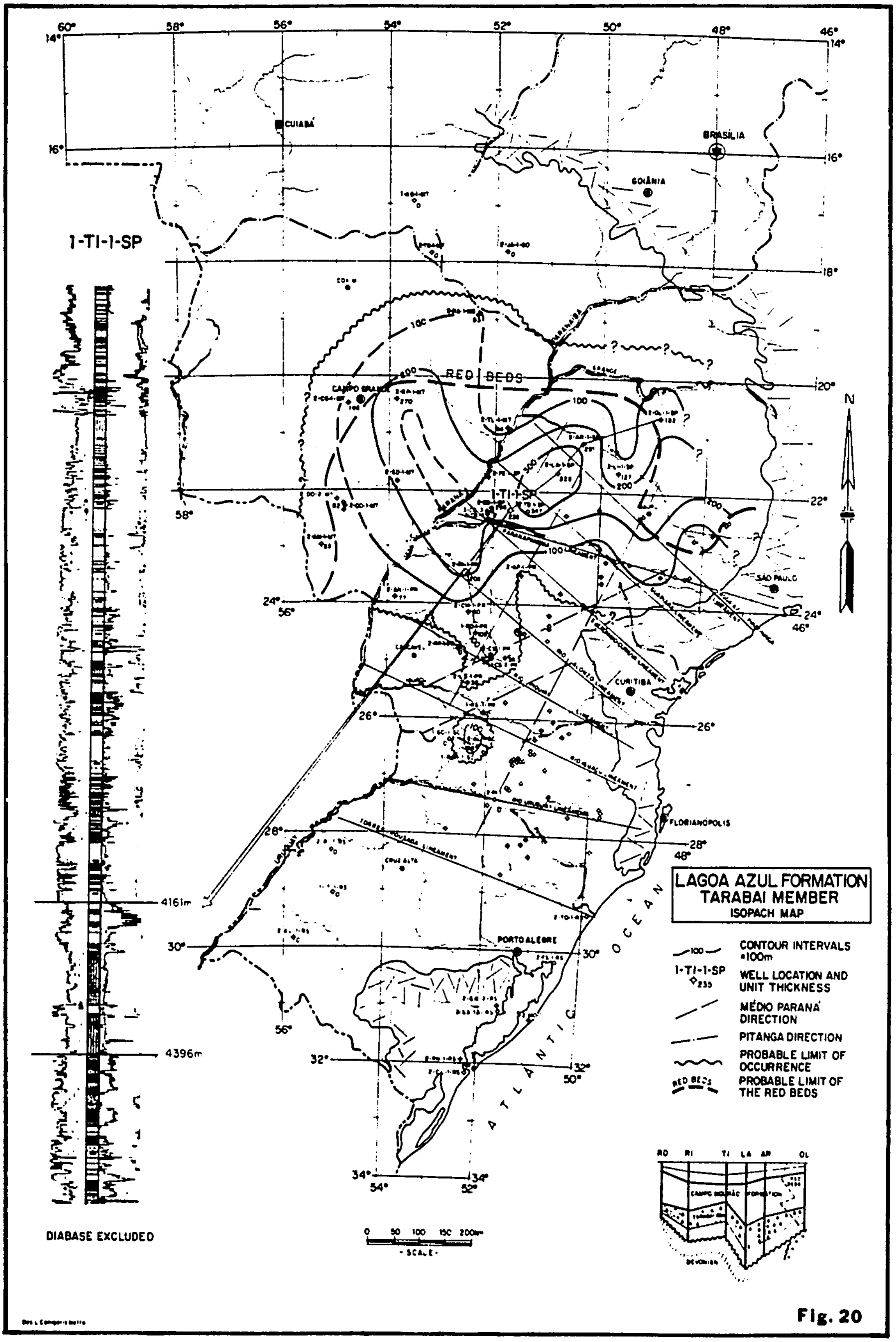

LAGOA AZUL FORMATION
TARABAI MEMBER
ISOPACH MAP
1-TI-1-SP
DIABASE EXCLUDED
4161m
4396m
CUIABÁ
BRASÍLIA
GOIÂNIA
CAMPO GRANDE
RED BEDS
SÃO PAULO
CURITIBA
FLORIANÓPOLIS
PORTO ALEGRE
ATLANTIC OCEAN
CONTOUR INTERVALS =100m
WELL LOCATION AND UNIT THICKNESS
MÉDIO PARANÁ DIRECTION
PITANGA DIRECTION
PROBABLE LIMIT OF OCCURRENCE
PROBABLE LIMIT OF THE RED BEDS
SCALE
N

Fig. 20

Siltstones are the major lithology in the Tarabai Member. Commonly they are medium to dark gray (N2/N3), micaceous and pyritic. In the 3-CB-2-SP in Sao Paulo State, core No.2 (4454-4460m) recovered a greenish-gray siltstone, probably caused by a high chlorite content. Chlorite is quite common as a cement in sandstones of the same core.

Dark-gray siltstone containing pebbles of granite up to 3cm was recovered in core No.9 from the 2-TB-1-SP in Sao Paulo State (Figs. 3 and 19).

Only one core of pebbly mudstone was recovered from the Tarabai Member. This is core No.12 from the 2-PN-1-SP, located in the State of Sao Paulo (Figs. 3 and 19). The entire 12m core consists of pebbly mudstone, light-gray in color with massive bedding containing relatively small pebbles (1 cm) predominantly composed of sedimentary rocks. Pebbly mudstone bodies in the Tarabai Member are relatively thick, such as 80 meters in 2-AN-1-PR and 110 meters in 2-AR-1-SP (Cross section AA, Fig. 10). The pebbly mudstone strata seem fairly continuous, and because there is good evidence that they are impermeable, (based on SP and density logs), they might be good cap rocks.

Sandstones of Tarabai Member are of particular interest because they had the best gas shows in the Parana Basin in 2-CB-1-SP (Fig. 3). There are cores from this well, but the best continuous cored sequence in the Tarabai member is in the 3-CB-3-SP well (Fig. 19).

Sandstones of Tarabai Member cored in 3-CB-3-SP well (52m) have fining-upward sequences commonly less than 1 meter thick, are light to medium gray in color (N6), fine to medium grained in size, and composed mainly of quartz and cemented by carbonate minerals. Commonly, they show cross bedding and cross lamination, and have irregular shaly partings, convolute laminations, shale clasts, and dish structures. Scattered reddish staining, probably hematite cement, is also common. Laminations are defined by carbonaceous material. There are abundant small tensional microfaults and subhorizontal stylolites, filled with greenish mineral, probably chlorite.

Three drill-stem tests were made on the interval cored in the 2-CB-1-SP and all indicated low to normal permeability.

The 2-CB-1-SP well, which was drilled about 3 km northeast of the 3-CB-3-SP, was cored supposedly in the same stratigraphic level as the 3-CB-3-SP well. Core No.8 (4676 to 4682m) was cut in a 35m massive sand body with a cylindrical gamma ray log pattern and has a gamma ray deflection of about 30 API units. This core is composed of greenish-gray sandstone, very coarse, and contains granules and pebbles of sedimentary and metamorphic rocks up to 1 cm. The core has low clay content. Core No.9 (4710 to 4715m) is located in an argillaceous sandstone unit immediately above a 20m fining-upward sequence idenfied in the composite log. The gammma ray response in this core is around 70 API units. The core is composed of greenish-gray sandstone, very fine to fine, massive with shaly partings and cross laminations. Microtensional faults are common. The top grades upward into a greenish siltstone.

A dril-stem test was logged in the interval 4649 to 4682m (core No.8) and indicates a zone of good permeability.

Shale with an anomalously high gamma ray deflection occurs in the Lagoa Azul Formation, within the Tarabai Member in two wells in Southern Parana State: 1-RO-1-PR and 2-CS-1-PR. The occurrence of this radioactive shale is confined to the "rectangular graben" generated by the intersection of Rio Alonzo, Rio Piquiri and Pitanga Direction lineaments (Fig. 20).

Because of its distinctive characteristics, this radioactive shale is considered as a separate unit within the Tarabai Member and it is called the Roncador Shale Lens.

Roncador Shale Lens: It is proposed to give the Roncador Shale Lens the status of lens (North American Stratigraphic Code, Article 25, Remark b). This anomalous radioactive shale occurs in the 1-RO-1-PR (Roncador No.1, Fig.3) and 2-CS-1-PR (Chapeu do Sol No.1, Fig. 3).

The proposed type section is the interval from 3025 to 3128m in 2-CS-1-PR. The correlation of the Roncador Lens is shown on Figure 21. It covers an area of about 5,000 km^2. The Roncador Lens was cored in both wells (core No.5 in 1-RO-1-PR well Fig. 19, and core No.29 in 2-CS-1-PR well, Fig. 19).

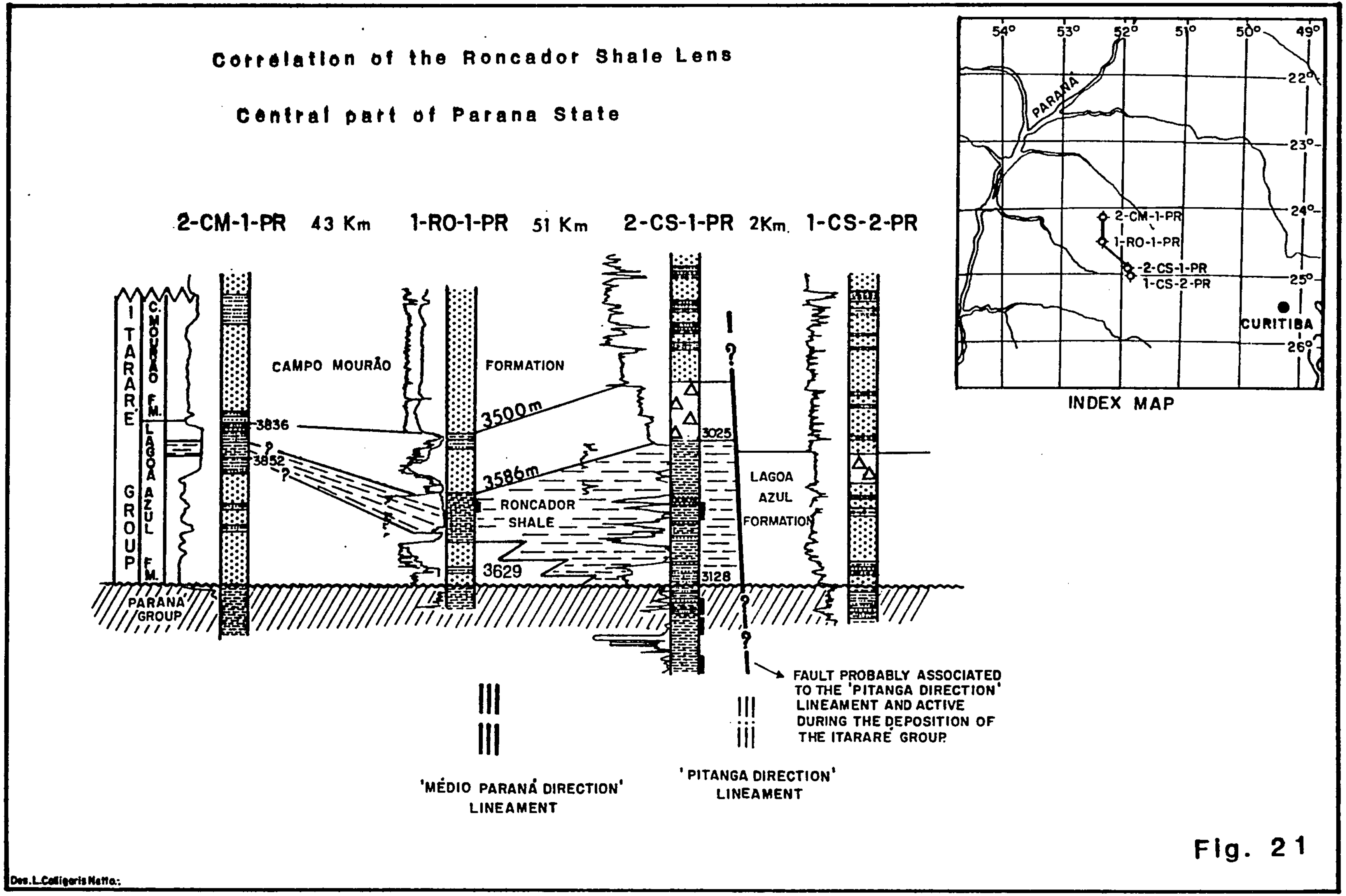
Core No.29 in the Chapeu do Sol well (3070 to 3083m) recovered 13 meters of black shale, well laminated, fissile and pytitic; this shale contains scattered pebbles of metamorphic rocks. Core No.5 in the Roncador well (3593 to 3602m) recovered well laminated, fissile, and pyritic black shale containing a few pebbles of metamorphic and sedimentary rocks, as well as some coarse quartz grains.

According to the biostratigraphic columns in the composite logs of the 2-CS-1-PR and 1-RO-1-PR wells, the radioactive shale was dated as Stephanian-Sakmarian, interval G + H_1.

The Roncador Shale Lens probably extends to the 2-CM-1-PR location (Fig. 21). The correponding sequence in 2-CM-1-PR was also cored and described as brownish shale. Neither the core nor the gamma ray log, which would provide a better correlation, are available.

Fig. 21 Correlation of the Roncador Shale Lens.

The anomalously radioactive shale of the Roncador Lens occurs in three wells and extends for about 95km in southern Parana State. Note that the radioactive shale is not present in 1-CS-2-PR, drilled only 2km south of the 2-CS-1-PR. It is suggested that faulting associated to the Pitanga Direction has controlled the sedimentation of the Roncador Shale Lens.


Correlation of the Roncador Shale Lens
Central part of Parana State
2-CM-1-PR 43 Km 1-RO-1-PR 51 Km 2-CS-1-PR 2Km. 1-CS-2-PR
ITARARÉ GROUP
C. MOURÃO FM.
LAGOA AZUL FM.
CAMPO MOURÃO FORMATION
3836
3852
3500m
3586m
RONCADOR SHALE
3629
3025
3128
LAGOA AZUL FORMATION
PARANÁ GROUP
FAULT PROBABLY ASSOCIATED TO THE 'PITANGA DIRECTION' LINEAMENT AND ACTIVE DURING THE DEPOSITION OF THE ITARARÉ GROUP
'MÉDIO PARANÁ DIRECTION' LINEAMENT
'PITANGA DIRECTION' LINEAMENT
54° 53° 52° 51° 50° 49°
22° 23° 24° 25° 26°
PARANÁ
2-CM-1-PR
1-RO-1-PR
2-CS-1-PR
1-CS-2-PR
CURITIBA
INDEX MAP
Des. L. Caligaris Netto.
Fig. 21

Campo Mourao Formation: It is proposed to call the middle section of the Itarare Group, the Campo Mourao Formation. It is predominantly a sandy unit, and also contains shales, siltstones and pebbly mudstones. The proposed type section is in the interval from 3230 to 3820m in the 2-CM-1-PR (Campo Mourao No.1), excluding the diabase intrusions (Fig. 22).

The Campo Mourao Formation occurs throughout almost the entire basin and covers an area of about 640,000 km^2 and is absent only in southern Rio Grande do Sul; towards the northern part of the basin it interfingers with red beds of the Aquidauana Formation (Fig. 7).

The maximum known thickness of the Campo Mourao Formation occurs in well 2-PN-1-SP in southeastern Sao Paulo (Fig. 23) and is 927m. Over much of the basin it is typically 400 to 500m thick.

The Campo Mourao Formation had important hydrocarbon shows in wells 1-CS-2-PR and 2-RP-1-PR, both in Central Parana State. These two wells produced gas and condensate from sandstones with low to normal permeability capped by diabase, shale, and thin layers of anhydrite. The 2-RP-1-PR is the only known well with anhydrite beds in the Itarare Group. However, anhydrite cement is common, as will be seen later in reservoir analysis.

The correlation of the Campo Mourao Formation is fairly good in the western part of Parana state (Fig. 12). In this area the Campo Mourao Formation has a basal sandy unit and an upper shaly unit (2-RI-1-PR, 2-CM-1-PR and 1-RO-1-PR). However, this subdivision is poorly defined in the rest of the Parana Basin, where the Campo Mourao Formation becomes essentially sandy towards the northern area (Fig. 13), and dominantly shaly towards the southern part of the basin (Fig. 11).

Fig. 22 Proposed type section for the Campo Mourao Formation with some typical lithological examples.

1 Pebbly mudstone from core No. 4 (box 3), 1-RO-1-PR in Parana State (3167M).

2 Pebbly mudstone from core No. 10 (box 5), 2-LA-1-SP in Sao Paulo State (2662m).

3 Laminate siltstone from core No. 9, 2-LA-1-SP in Sao Paulo State (2631m).

4 Finning-upward conglomerate from core No. 8 (box 11), 2-AA-1-SP in Sao Paulo State (2294m).

5 Massive sandstone containing shale fragments from core No. 8 (box 8), 2-AA-1-SP in Sao Paulo State (2291m).

6 Fining-upward sandstone from core No. 8 (box 11), 2-AA-1-SP in Sao Paulo State (2294m).

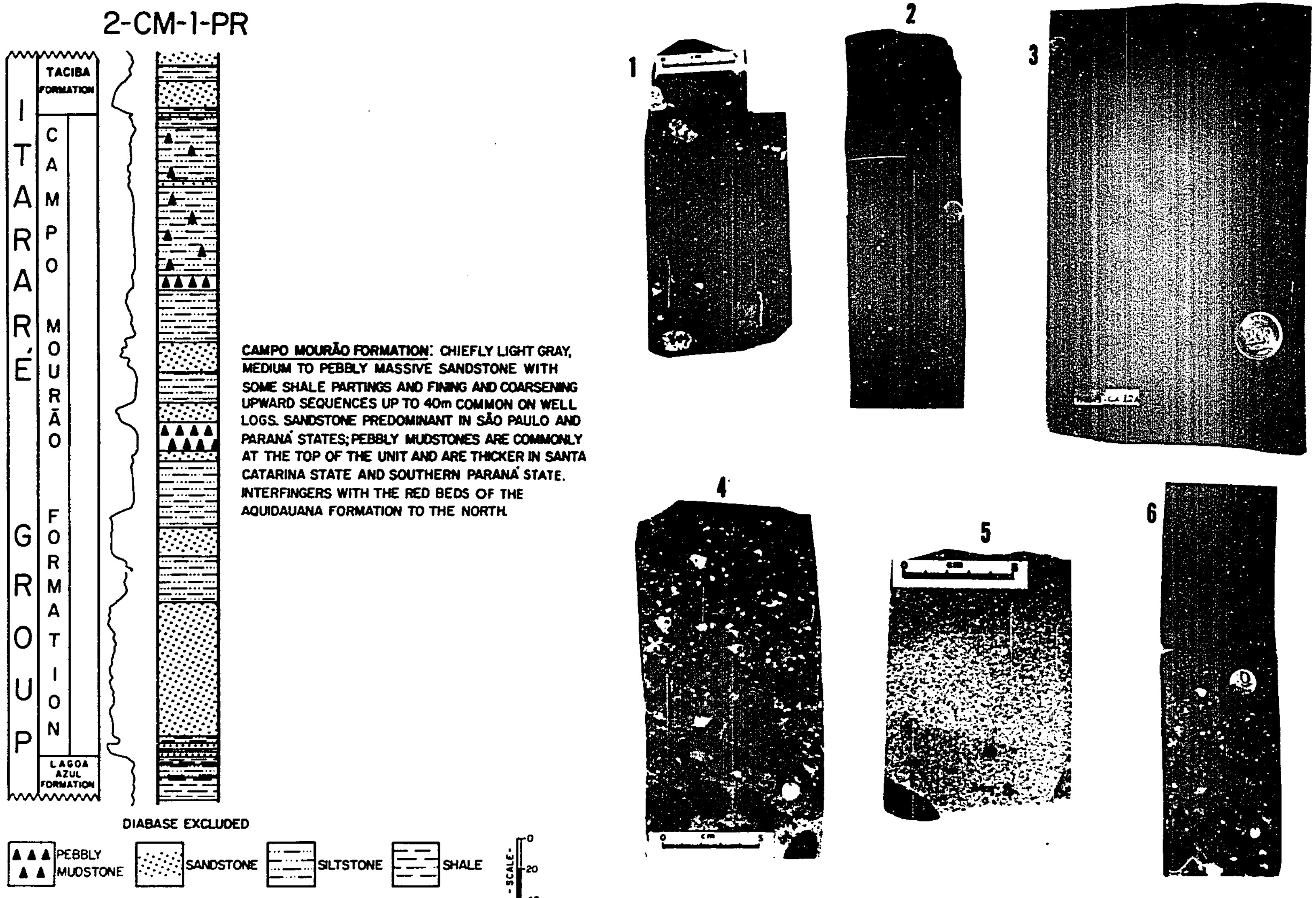
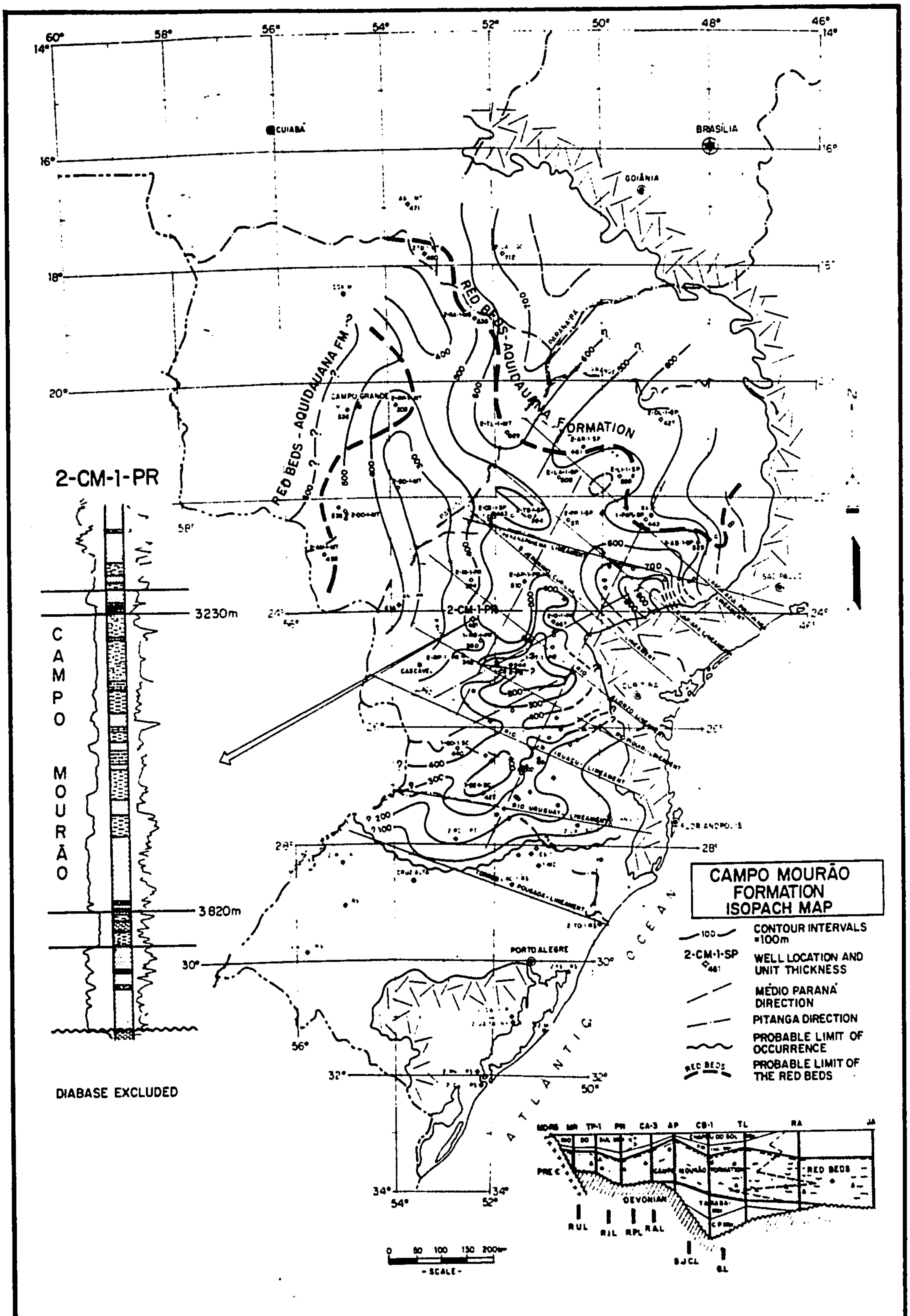

2-CM-1-PR
ITARARÉ GROUP
TACIBA FORMATION
CAMPO MOURÃO FORMATION
LAGOA AZUL FORMATION
CAMPO MOURÃO FORMATION: CHIEFLY LIGHT GRAY, MEDIUM TO PEBBLY MASSIVE SANDSTONE WITH SOME SHALE PARTINGS AND FINING AND COARSENING UPWARD SEQUENCES UP TO 40m COMMON ON WELL LOGS. SANDSTONE PREDOMINANT IN SÃO PAULO AND PARANÁ STATES; PEBBLY MUDSTONES ARE COMMONLY AT THE TOP OF THE UNIT AND ARE THICKER IN SANTA CATARINA STATE AND SOUTHERN PARANÁ STATE. INTERFINGERS WITH THE RED BEDS OF THE AQUIDAUANA FORMATION TO THE NORTH.
DIABASE EXCLUDED
PEBBLY MUDSTONE
SANDSTONE
SILTSTONE
SHALE
- SCALE -
0
20
40m
1
2
3
4
5
6

Fig. 22

Fig. 23 Isopach map of the Campo Mourao Formation.

The Campo Mourao Formation is composed mostly of sandstones and siltstones and covers an area of approximatelly 640,000 km^2. Its major depocenter is aligned northwest-southeast, between the Lagoa Azul-Piratininga and Sao Jeronimo Curiuva lineaments. A positive thin area is defined by the intersection of the Rio Alonzo and Rio Iguacu lineaments with the Medio Parana Direction lineaments in southern realm. The 1-CS-2-PR well, which is located in this positive thin area, has the second best gas production from the Campo Mourao Formation (flow rate of about 600,000 cubic feet a day).



CAMPO MOURÃO FORMATION ISOPACH MAP
CONTOUR INTERVALS =100m
2-CM-1-SP WELL LOCATION AND UNIT THICKNESS
MÉDIO PARANÁ DIRECTION
PITANGA DIRECTION
PROBABLE LIMIT OF OCCURRENCE
RED BEDS PROBABLE LIMIT OF THE RED BEDS
2-CM-1-PR
3230m
CAMPO MOURÃO
3820m
DIABASE EXCLUDED
RED BEDS - AQUIDAUANA FORMATION
RED BEDS - AQUIDAUANA FM
CUIABÁ
BRASÍLIA
GOIÂNIA
CAMPO GRANDE
PORTO ALEGRE
ATLANTIC OCEAN
DEVONIAN
RED BEDS
SCALE

Fig. 23

In well logs, the Campo Mourao Formation has a cylindrical gamma ray pattern in the basal sandstone, which is continuous throughout most of the basin (Figs. 10 to 14). A second characteristic is the repetition of fining-upward and coarsening-upward sequences as seen in the 3-CB-3-SP and 2-TI-1-SP (Cross section DD', Fig. 13).

The Campo Mourao Formation unconformably overlies the basement in Rio Grande do Sul and in southeastern Santa Catarina (Fig. 12). It unconformably overlies the Parana Group in Goias, Mato Grosso and in most of Santa Catarina (Figs. 4 and 11). In Sao Paulo, Parana, and Mato Grosso do Sul States, the Campo Mourao Formation conformably overlies the Lagoa Azul Formation (Figs. 10 and 13).

According to biostratigraphic information in the composite logs, and to Daemon and Quadros (1970, p. 366 and Fig. 4), the section corresponding to the Campo Mourao Formation was deposited in late Stephanian time in the states of Santa Catarina and northern Parana; but, from northern Parana northward, it is younger, with deposition beginning only in the Sakmarian. Near the Sul Riograndense Arch, the deposition of the Campo Mourao Formation began much later, in the Artinskian (Fig. 7).

The spores present in the lower part of the Campo Mourao Formation still suggest continental deposition. However. towards the top of the unit there are marine spores such as **Tasmanites sp** in the 2-0-1-PR, core No.8 (Daemon and Quadros, 1970, p. 377), and 2-TB-1-SP in shales of the interval 3204 to 3300m (Oliveira and Neto, 1984, p. 53). Therefore, there is evidence of a marine transgression in the Itarare Group during the deposition of the upper part of the Campo Mourao Formation. According to Daemon and Quadros (1970, p. 377), the transgression in the Itarare Group began in interval H_2 of the Artinskian.

Well logs also show evidence of transgression in the upper part of Campo Mourao Formation in Rio Grande do Sul, Santa Catarina and Parana states. The gamma ray logs show a fining-upward sequence in some wells such as 1-MA-1-RS, 1-RS-1-PR and 2-AL-1-PR (cross section CC', Fig. 12). Towards eastern Santa Catarina the transgression seems to have began earlier, based on log character of wells such as 1-TP-1-SC, and the 2-TG-1-SC (cross section BB', Fig. 11). This suggests that the marine invasion during the deposition of the Campo Mourao Formation came from the vicinity of eastern Santa Catarina State.

There is great variety in sandstone types in the Campo Mourao Formation. Gas at the rate of 600,000 cfd was recovered on a DST in the 1-CS-2-PR (3075 to 3103m) in central Parana State. this reservoir was partially cored, and the reservoir rock is a greenish gray (5B 7/1) sandstone, medium to fine grained, hard, and mostly massive, but with some incipient subhorizontal laminations composed of very fine, grayish sandstone. There is also a bed (5cm) of conglomerate containing pebbles of quartz and quartzites. There are two small diabase intrusions (1m each) intercalated with the sandstone body. The sandstone is fractured, silicified and brecciated, suggesting proximity to a fault zone and the effects of the diabase intrusions. Fractures are partially or totally filled with calcite and chlorite. Apparently the sandstone itself is not a good reservoir and perhaps the gas produced from this interval from a drill stem test was stored in fractures and or micropores.

Core No.10 (2658 to 2672m) recovered from the 2-LA-1-SP (Fig. 19) in northwestern Sao Paulo contains a dark-gray conglomerate (N3/N5) and with rounded to subangular pebbles and cobbles (up to 8cm) composed of granites, gneisses, rhyolites, and sedimentary rocks. Conglomerate beds may reach 80cm and may be either fining-upward (predominant) or coarsening-upward. Several layers of pebbly mudstone containing fluidized structures are commonly interbedded with the conglomerates.

Core No.8 (2284 to 2302m - corrected depth) in the 2-AA-1-SP in central Sao Paulo State contains predominantly light-gray, coarse to medium-grained, massive, sandstone composed of quartz, feldspar, and lithics, cemented by calcite and anhydrite. Locally it contains angular shale clasts which are sub horizontally oriented. Towards the base there are two fining-upward conglomeratic beds with pebbles (over 5cm) composed mainly of sedimentary rocks and pink granite.

Core No. 4 (3163 to 3168m) from the 1-RO-1-PR was recovered from the upper part of the Campo Mourao Formation in central Parana State, contains medium-to dark-gray (N3/N5), coarse to conglomeratic sandstone. Pebbles and coarser material consist of quartzites, schists, and sedimentary rocks. Also present are irregular lenses of medium to coarse sandstone, with flow structures such as sand dikes. Laminations are defined by minor subhorizontal shaly partings and some cross laminations. Microfaults, stylolites and small vertical fractures filled with hematite are common, especially towards the top.

Siltstones in the Campo Mourao Formation are commonly grayish (N3/N4), micaceous and laminated. The laminations are predominantly subhorizontal, but locally may be disturbed by flow structures, convolute laminations, and bioturbation.

Core No.9 (2627 to 2641m, Fig. 19) in the 2-LA-I-SP in northwestern Sao Paulo State shows intercalation of grayish and red siltstones (5R 6/2), and probably represents an interfingering between the Campo Mourao Formation and the red beds of the Aquidauana Formation. (Fig. 7).

Pebbly mudstones in the Campo Mourao Formation are similar to those previously described in the Tarabai Member - medium to dark gray (N3/N5) containing rounded to subrounded pebbles of granites, quartzites and sedimentary rocks. In the Northern part of the basin grayish and brownish to red pebbly mudstones interfinger each other as shown by core No 11 (782 to 788m, Fig. 19) recovered from the 2-PN-1-SP in southeastern Sao Paulo State. The interfingering between grayish sediments of Campo Mourao Formation and the red beds of the Aquidauana Formation is shown in cross sections AA'and EE' (Figs. 10 and 14), and in Figure 7.

Three beds of grayish massive anhydrite, are present in the upper section of the Campo Mourao Formation in well 2-RP-1-PR. Each of the beds are about 2m thick.

Shales varying from 1m up to 10m in thickness are common throughout the Campo Mourao Formation in almost all wells. They are easily identified in well logs, because they usually have higher gamma ray values than the pebbly mudstones, and in some wells they have even anomalously high gamma ray peaks, such as in the 2-AB-1-SP (Cross Section DD', Fig. 13).

In eastern Santa Catarina and Parana States shales occur predominantly in the upper portions of the unit. The shales of Campo Mourao Formation in this area of the basin are dark-gray to black, well laminated, micaceous, fissil and varved. Schneider et al (1974, p. 48), working in the outcrop belt in eastern Parana and Santa Catarina, described a similar section - dark gray shale/claystone that is locally varved and contains cone-in-cone structures. The thickness is constant

(50 to 60m) in all mapped areas. They called the unit the Lontras Shale, including it in what they defined as the Rio do Sul Formation.

Lontras Member It is proposed to extend the 'Lontras Shale' into subsurface as shown in cross section BB'(Fig. 11), changing the status to Member as described below.

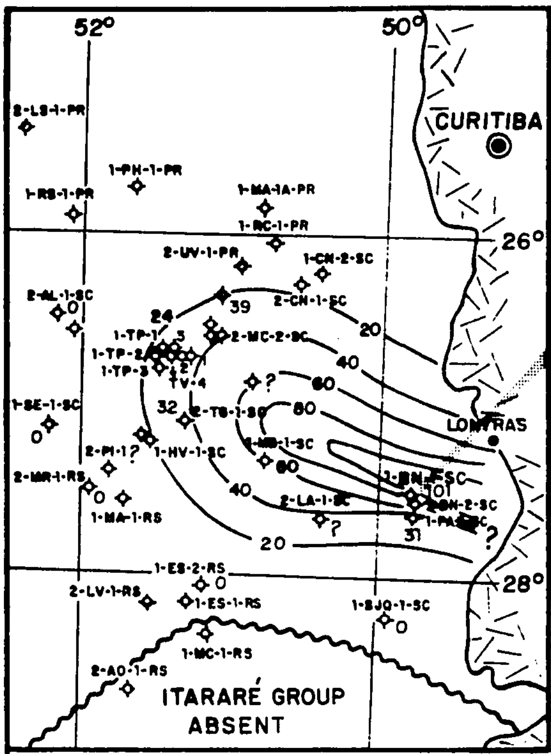
The cross section BB' (Fig. 11) is an attempt to correlate wells with the outcrop area. The sedimentary column proposed by Schneider et al (1974, p. 49) is shown in the right hand margin of the cross section at the same vertical scale as the well logs. The Lontras Shale in outcrop correlates fairly well with shales in subsurface found in the 1-PA-1-SC, 1-MB-1-SC, 1-TG-1-SC, and 1-TP-1-SC. The cross section BB' (Fig. 11) shows the Lontras Shale changing laterally into pebbly mudstones of the Campo do Mourao Formation. For this reason, the Lontras Member is considered as a unit within the Campo Mourao Formation, rather than part of the Rio do Sul Member.

The Lontras Shale type section is about 60m thick according to Schneider et al (1974, Fig. 6) and is located northeast of the towns Rio do Sul and Lontras in Santa Catarina State. The subsurface reference section is the interval from 820 to 921m in the 1-BN-1-SC (Fig. 24). The distribution of the Lontras Shale Member is shown on the isopach map (Fig. 24). The Lontras Member covers an area of about 25,000 km^2. The maximum known thickness is 101m in the 1-BN-1-SC, but typical thicknesses are 30 to 50m.

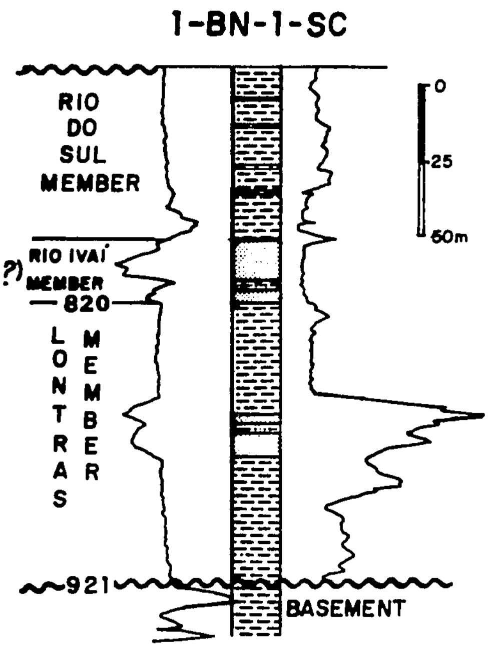
There is no core available from Lontras Member for this study; however, according to Schneider et al (1974, p. 49) the varved shale of the Rio do Sul Formation (Lontras Shale), was deposited in a marine environment.

Fig. 24 Isopach map and subsurface reference section for the Lontras Member.

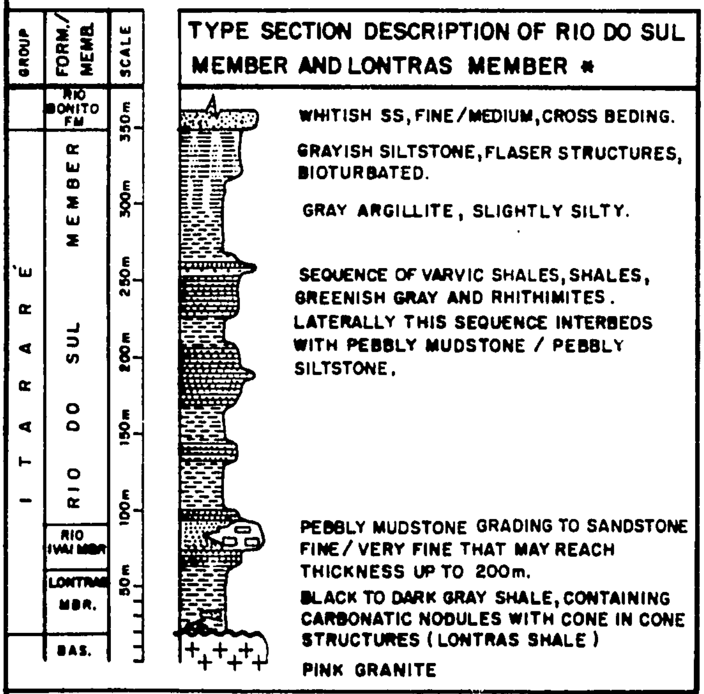
The Lontras Member covers an area of about 25,000 km^2. The type section of the Lontras Member (bottom left of the figure) was defined in the outcrop by Schneider et al (1974, p. 49). The proposed subsurface section is the interval from 820 to 921, in the 1-BN-1-SC well.



CAMPO MOURÃO FM - LONTRAS MBR
ISOPACH MAP



Proposed subsurface reference section
for the Lontras Member



* AFTER SCHNEIDER et al (1974, p.49)

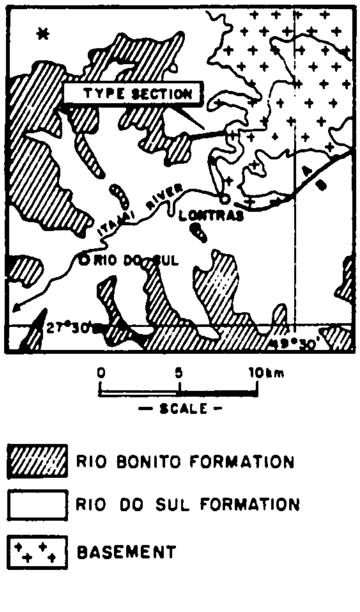


Fig. 24

Des. L.Caligaris Netto.

The isopach map of the Campo do Mourao Formation (Fig. 23) shows the distribution of this unit. There appears to be some minor tectonic control on the sedimentation by the northwest-southeast and northeast-southwest structural lineaments. The major depocenter is aligned northwest-southeast between the Lagoa Azul-Piratininga and the Sao Jeronimo-Curiuva lineaments. The isopach contours in the major depocenter suggest an extension of the Campo Mourao Formation towards the southeast. This extension was eroded in the Parana Basin due to the Ponta Grossa Arch uplift; however, part of the extension might be still preserved in its African counterpart or even beneath Mesozoic sediments in the Brazilian offshore.

Taciba Formation: It is proposed to designate the upper section of the Itarare Group as Taciba Formation. This Formation is composed of pebbly mudstones, sandstones, shales and a few siltstones. The proposed type section is the interval from 2792 to 3089m in the 2-TB-1-SP (Taciba No.1, Fig. 25). The correlation of the Taciba Formation is shown on cross sections AA' to EE' (Figs. 10 to 14). The maximum known thickness is 420m in the 1-MO-1-PR in the eastern part of Parana State (Fig. 26) and typical values are between 200 and 300m. Taciba Formation covers a minimum area of about 710,000 km^2 (Fig. 26).

The Taciba Formation conformably overlies the Campo do Mourao Formation over most of the basin except near the Sul Riograndense Arch, where it unconformably overlies Precambrian basement (Fig. 12). The upper contact of the Taciba Formation is conformable with the Guata Group (Rio Bonito and Tatui formations, Fig. 4) over most of the Parana Basin, except in the northeast parts of Parana and Sao Paulo States. Here the contact is unconformable with both the Rio Bonito and Tatui

Fig. 25 Proposed type section for the Taciba Formation with some typical lithological examples from cores.

1 Pebbly mudstone from core No. 5 (box 5), 2-TB-1-SP in Sao Paulo State (2830m).

2 Pebbly mudstones from core No. 7 (boxes 12 and 14), 2-AA-1-SP in Sao Paulo State (2000m).

3 Laminated shale with dropstone from core No. 8 (box 5), 1-SE-1-SC in Santa Catarina State (2505m).

4 Finning-upward sandstone with inclined beedding from core No. 7 (box 7), 2-TB-1-SP in Sao Paulo State (3004m).

5 Bioturbated sandstone and siltstone from core No. 7 (box 6), 2-TB-1-SP in Sao Paulo State (3003m).

6 Conglomerate containing pebbles of metamorphic, and sedimentary rocks (including pebbly mudstone fragmenmts) from core No. 5, 2-CB-1-SP in Sao Paulo State (3784m).

7 Pebbly mudstone and sand dike from core No. 6 (box 2), 2-AA-1-SP in Sao Paulo State (1970m).

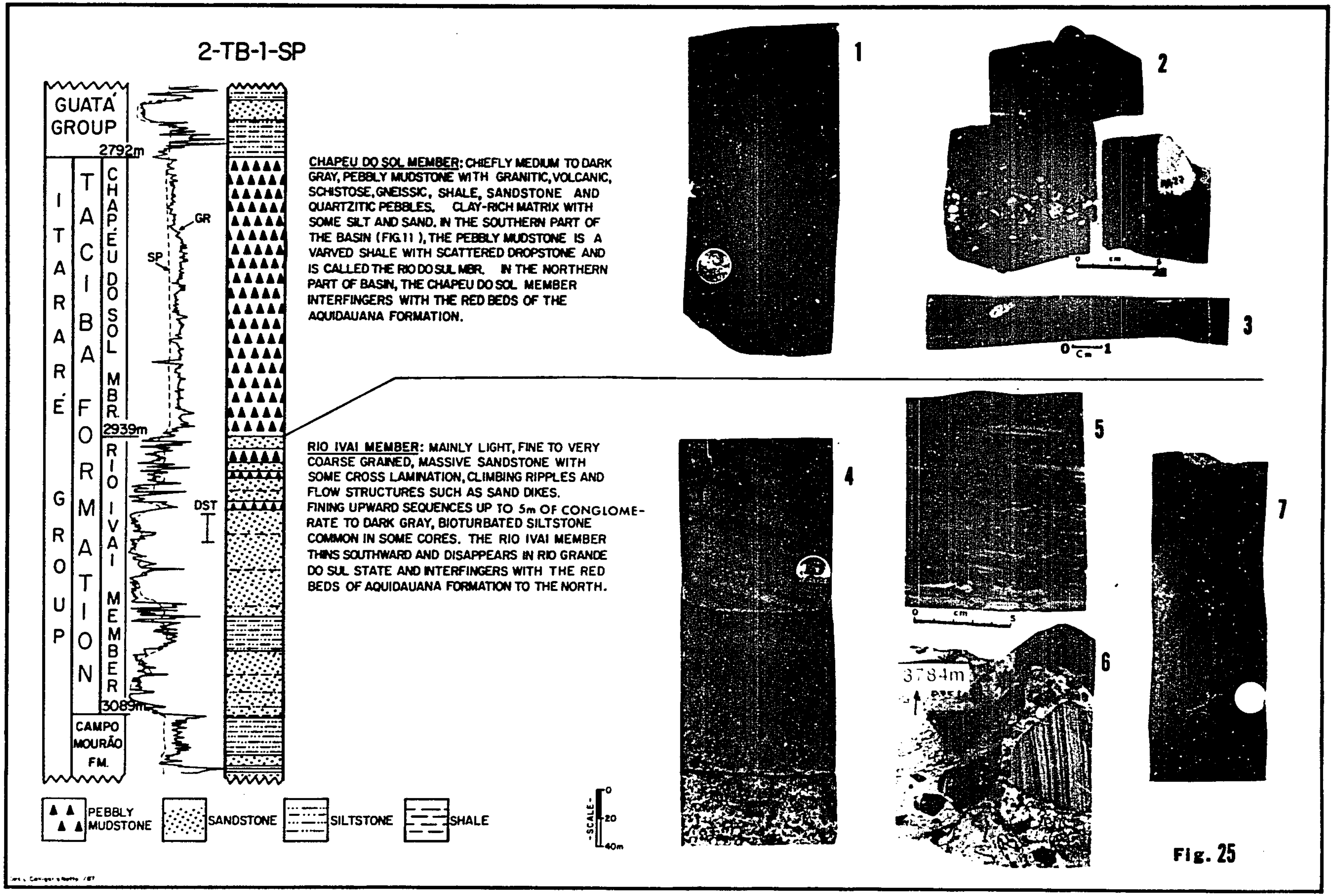

2-TB-1-SP
GUATÁ GROUP
2792m
ITARARÉ GROUP
TACIBA FORMATION
CHAPÉU DO SOL MBR.
2939m
RIO IVAÍ MEMBER
3089m
CAMPO MOURÃO FM.
GR
SP
DST
CHAPEU DO SOL MEMBER: CHIEFLY MEDIUM TO DARK GRAY, PEBBLY MUDSTONE WITH GRANITIC, VOLCANIC, SCHISTOSE, GNEISSIC, SHALE, SANDSTONE AND QUARTZITIC PEBBLES. CLAY-RICH MATRIX WITH SOME SILT AND SAND. IN THE SOUTHERN PART OF THE BASIN (FIG.11), THE PEBBLY MUDSTONE IS A VARVED SHALE WITH SCATTERED DROPSTONE AND IS CALLED THE RIO DO SUL MBR. IN THE NORTHERN PART OF BASIN, THE CHAPEU DO SOL MEMBER INTERFINGERS WITH THE RED BEDS OF THE AQUIDAUANA FORMATION.
RIO IVAI MEMBER: MAINLY LIGHT, FINE TO VERY COARSE GRAINED, MASSIVE SANDSTONE WITH SOME CROSS LAMINATION, CLIMBING RIPPLES AND FLOW STRUCTURES SUCH AS SAND DIKES. FINING UPWARD SEQUENCES UP TO 5m OF CONGLOMERATE TO DARK GRAY, BIOTURBATED SILTSTONE COMMON IN SOME CORES. THE RIO IVAI MEMBER THINS SOUTHWARD AND DISAPPEARS IN RIO GRANDE DO SUL STATE AND INTERFINGERS WITH THE RED BEDS OF AQUIDAUANA FORMATION TO THE NORTH.
PEBBLY MUDSTONE
SANDSTONE
SILTSTONE
SHALE
-SCALE-
0
20
40m
1
2
3
4
5
6
7
0 cm 2
0 cm 1
0 cm 5
3784m
Fig. 25

Fig. 26 Isopach map of the Taciba Formation.

An important feature in this map is the large positive thin area striking northeast-southwest for about 350 km, as defined by the 2-CM-1-PR, 1-AP-1-PR, and the 2-AA-1-SP wells. This positive feature is parallel to the Pitanga Direction Lineament, which has probably influenced the deposition of the Taciba Formation.

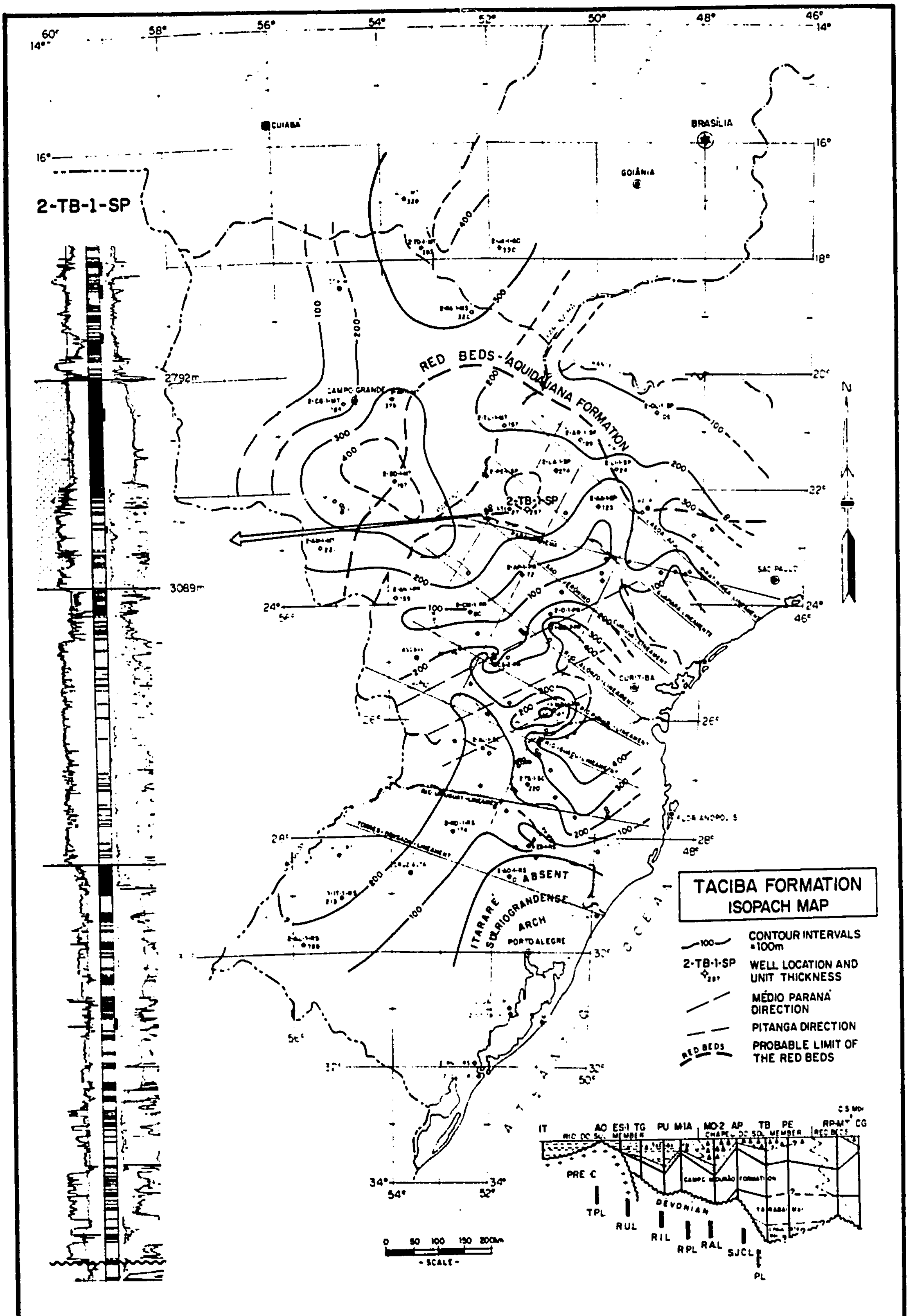

TACIBA FORMATION
ISOPACH MAP
CONTOUR INTERVALS =100m
2-TB-1-SP
WELL LOCATION AND UNIT THICKNESS
MÉDIO PARANÁ DIRECTION
PITANGA DIRECTION
PROBABLE LIMIT OF THE RED BEDS
RED BEDS - AQUIDAUANA FORMATION
ABSENT
ITARARÉ - SULRIOGRANDENSE ARCH
PORTO ALEGRE
CURITIBA
CAMPO GRANDE
CUIABÁ
BRASILIA
GOIÂNIA
2792m
3089m
SCALE
PRE C
DEVONIAN
TPL
RUL
RIL
RPL
RAL
SJCL
PL

Fig. 26

formations (Schneider et al, 1974, p.49; Gamma Jr. et al, 1982, p. 35; and Fulfaro et al, 1984, p. 715).

The Taciba Formation is present in relatively shallow wells close to the outcrop belt in the States of Sao Paulo, Parana and Santa Catarina and probably comprises the major part of the Itarare Group in outcrop. Consequently, most of the rocks exposed in the outcrop areas probably correlate with the Taciba Formation.

According to Daemon and Quadros (1970, Fig. 4) and to the new biostratigraphic zonation in the composite well logs, the section belonging to what is considered here as the Taciba Formation is dated as Permian (Later Artinskian and Kungurian), corresponding to the biostratigraphic intervals H_2, H_3 and I_1 to I_4 (Fig. 7).

In addition to typical continental flora such as **Vitatina** and **Limitisporites, Tasmanites sp** is also abundant as observed in cores recovered from wells in eastern part of Parana State, such as core No. 6 in the 2-0-1-PR, cores No. 7 to 9 in 1-RC-1-PR, and in core No. 13 in 1-M-1A-PR (Daemon and Quadros 1970, p. 377). This suggests that the marine transgression which had started during the deposition of the Campo do Mourao Formation continued during the deposition of the Taciba Formation.

The isopach map of the Taciba Formation (Fig. 26) shows a northeast-southwest positive thin area extending for about 350km as defined by the 2-CM-1-PR, 2-AP-1-PR, and 2-AA-1-SP. This positive area is parallel to the Pitanga Direction Lineaments (Soares et al 1982, p. 9; Saad, in prep.) indicating its possible influence on the deposition of the Taciba Formation.

Other lineaments active during the deposition of previous units, has no apparent influence on Taciba Formation deposition, perhaps, because of a relative quiescent tectonic stage prevailing in later stages of deposition of the Itarare Group.

The fourth-degree trend surface map for the Taciba Formation (Fig. 27) shows a major depocenter in the northwestern poart of the basin, whereas in the eastern side of the basin, the contours open towards the Atlantic Ocean; this suggests the presence of another depocenter which was either eroded after the Ponta Grossa Arch uplift, or could be present in South Africa.

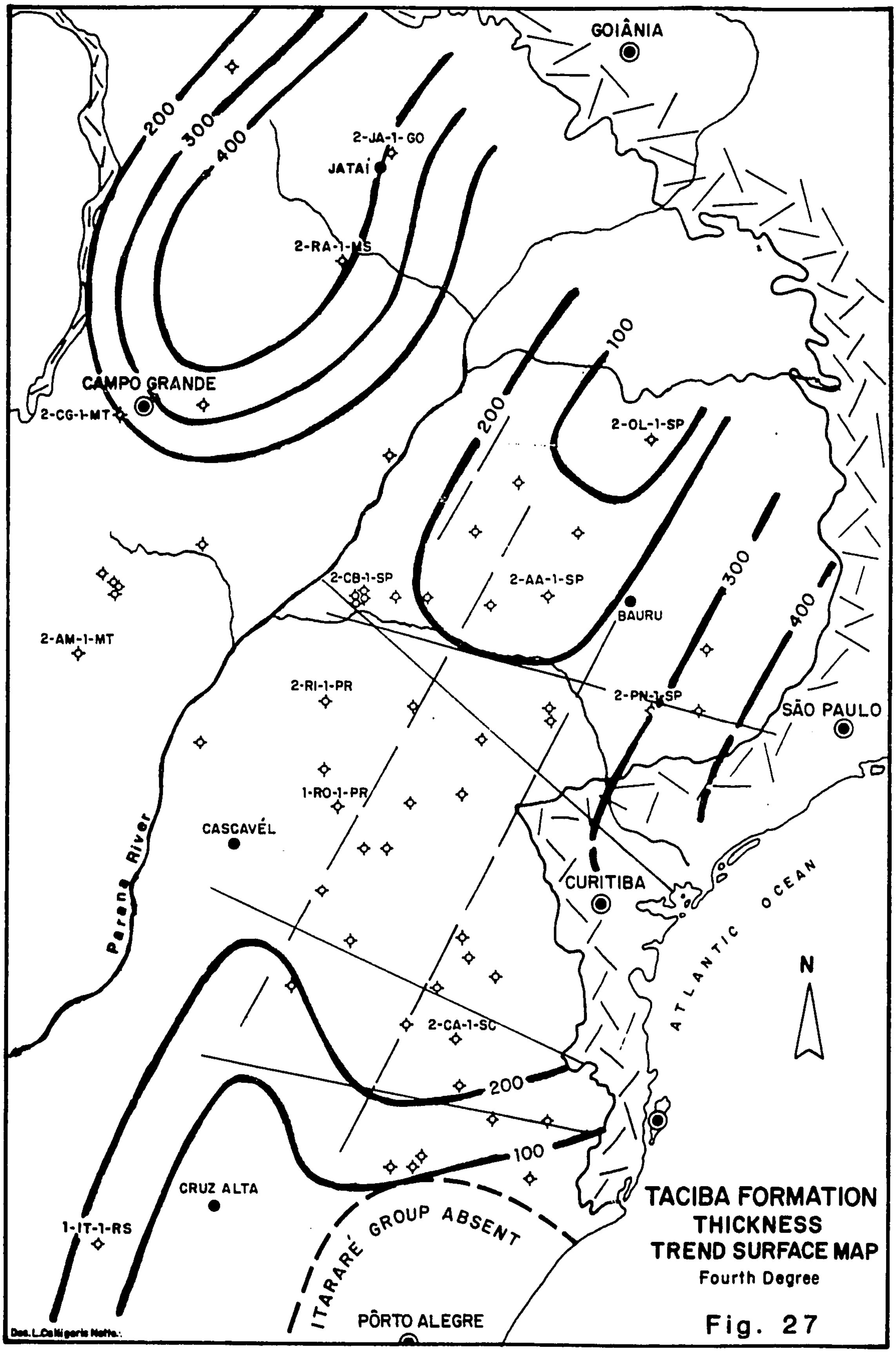
The fourth-degree residual map for the Taciba Formation (Fig. 28) has negative values which form a northeast-southwest pattern, parallel to the Pitanga Direction Lineament. This pattern is also apparent in the isopach map (Fig. 26). The northeast-southwest direction is almost perpendicular to the trends of the residuals in the Lagoa Azul Formation, the lowermost unit in the Itarare Group (Fig. 17). This fact suggests a switching in the tectonic influence of the structural lineaments during the deposition of the Itarare Group, form the lowermost to the uppermost unit.

Rio Ivai Member. The Rio Ivai Member is the name proposed to designate the sandy unit that occurs just below the massive sequence of pebbly mudstone in the upper part of the Itarare Group. The proposed type section is the interval from 2921 to 3043m in the 1-RI-1-PR (Rio Ivai no.1, Fig.10). This member covers about 510,000 km^2 and is shown in the isopach map (Fig. 29). The maximum known thickness is 349m in the 2-AT-1-SP in eastern Sao Paulo State. The Rio Ivai Member is typically 100 to 150m thick.

The Rio Ivai Member is composed mainly of sandstone with

Fig. 27 Fourth-degree trend surface map of the Taciba Formation.

The fourth-degree trend surface map of the Taciba Formation shows a major depocenter in the northwest part of the basin, near Campo Grande city. The Sul Riograndense Arch in southeast part of the basin, appears as a positive area (where the Itarare Group is absent). The Sul Riograndense Arch was probably a source area for the Taciba Formation. See also cross section CC' (Fig. 12).



TACIBA FORMATION THICKNESS TREND SURFACE MAP

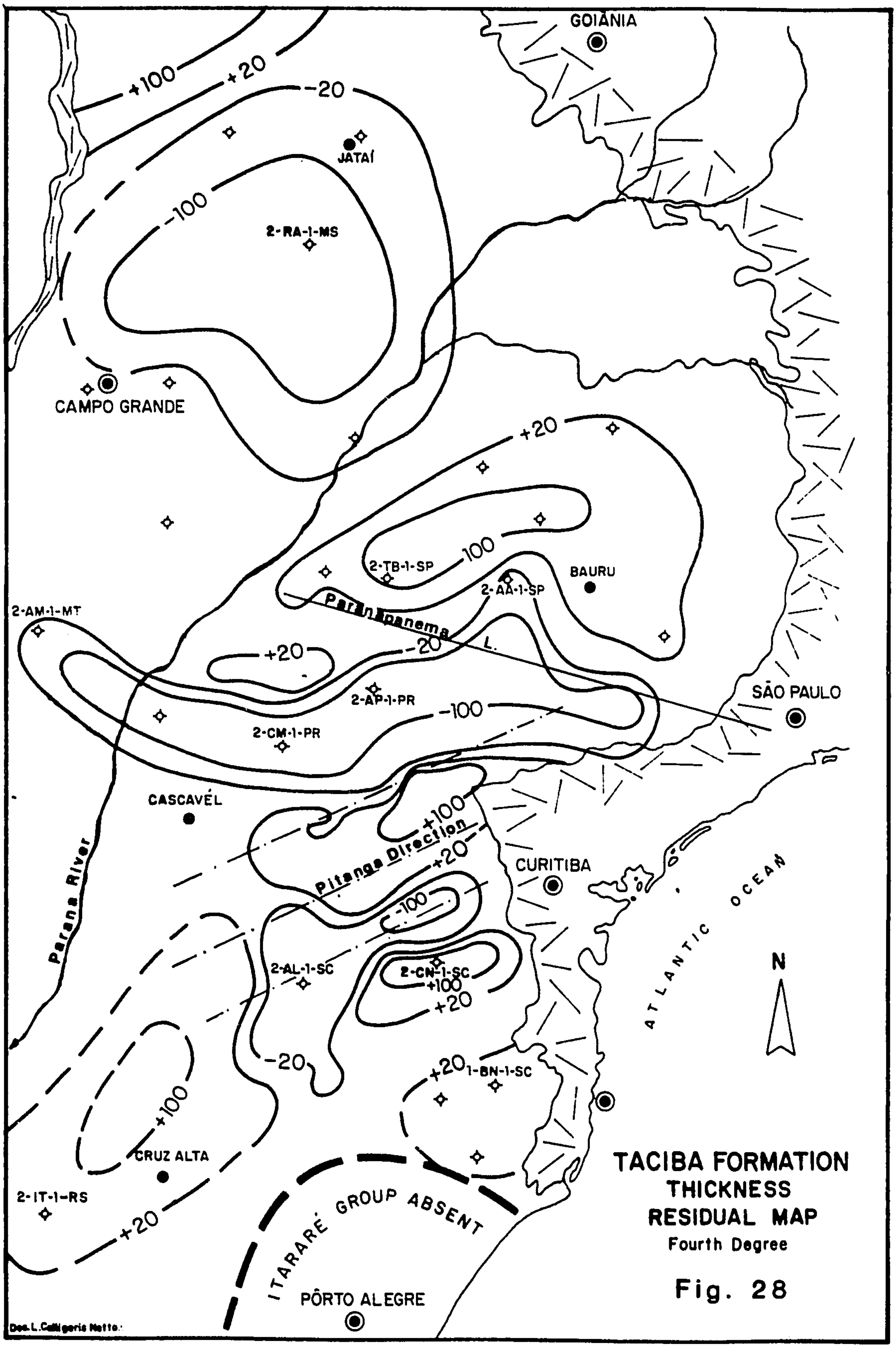
Fourth Degree

Fig. 27

Fig. 28 Fourth-degree residual map of the Taciba Formation.

The thin positive area that extends for about 350km from the 2-CM-1-PR to the 2-AA-1-SP well, already mapped in the isopach map of the Taciba Formation, appears also here in its residual map.

The contours are preferentially oriented northeast-southwest, suggesting influence of the Pitanga Direction Lineaments (Fig. 5) on the deposition of the Taciba Formation.

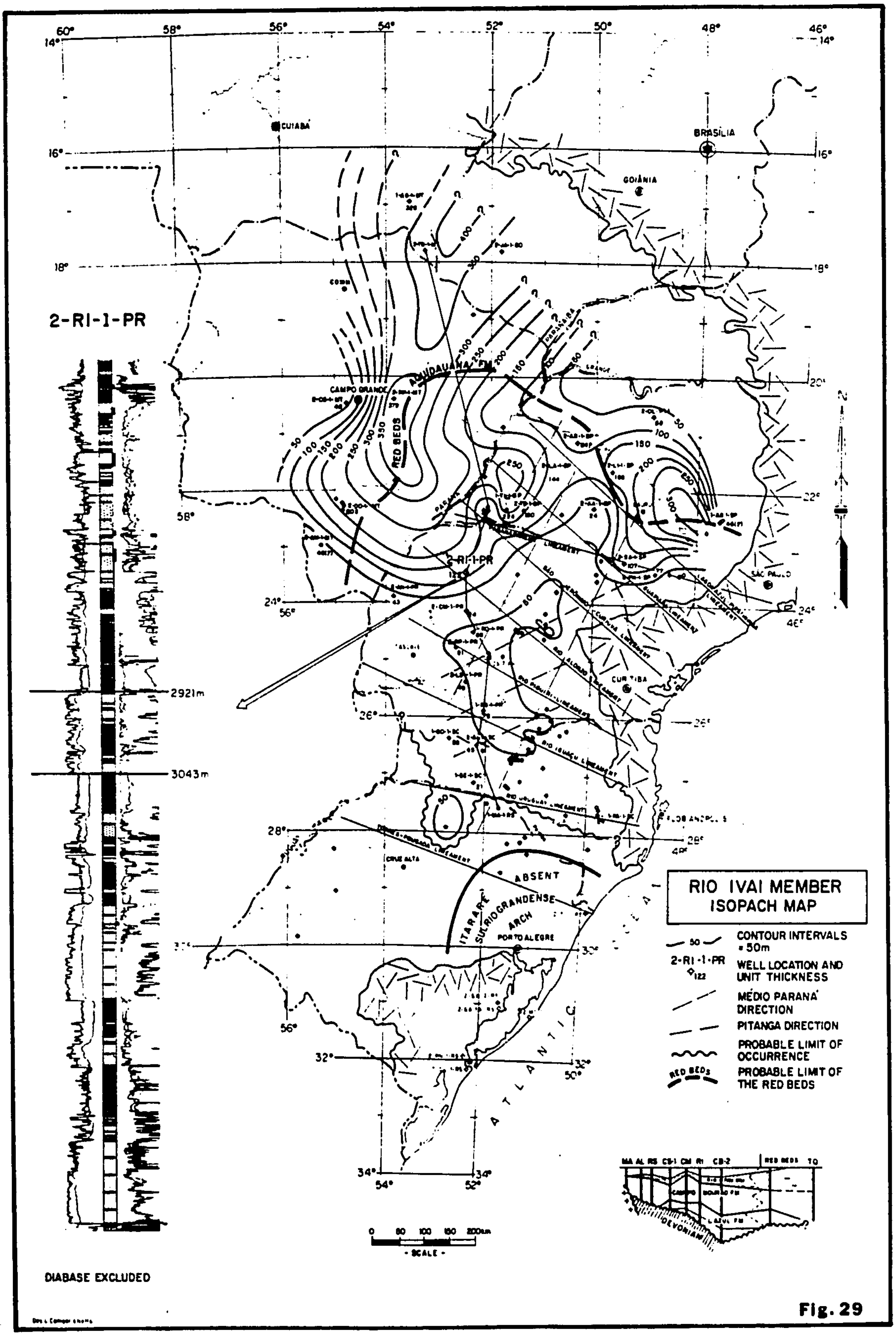


TACIBA FORMATION THICKNESS RESIDUAL MAP
Fourth Degree

Fig. 28

Fig. 29 Isopach map of the Rio Ivai Member.

The Rio Ivai Member is composed mostly of sandstones and covers an area of approximatelly 510,000 km^2. The thickness of the Rio Ivai Member is fairly constant from southern areas of the basin up to the positive area defined by the 2-CM-1-PR and 2-AA-1-SP wells (Fig. 26). From this area towards north the Rio Ivai Member becomes thicker and interfingers with the red beds of the Aquidauana Formation.


RIO IVAI MEMBER
ISOPACH MAP
2-RI-1-PR
2921m
3043m
DIABASE EXCLUDED
CONTOUR INTERVALS = 50m
WELL LOCATION AND UNIT THICKNESS
MÉDIO PARANÁ DIRECTION
PITANGA DIRECTION
PROBABLE LIMIT OF OCCURRENCE
PROBABLE LIMIT OF THE RED BEDS
RED BEDS
AQUIDAUANA
ABSENT
ITARARÉ SULRIOGRANDENSE ARCH
CUIABÁ
BRASÍLIA
GOIÂNIA
CAMPO GRANDE
SÃO PAULO
CURITIBA
PORTO ALEGRE
CRUZ ALTA
ATLANTIC
SCALE
DEVONIAN
Fig. 29

intercalations of siltstones, shales, and some pebbly mudstone. The correlation of the Rio Ivai Member is readily apparent in the central part of the basin, mainly in Sao Paulo and northwestern Parana states (Fig. 10). In the southern parts of the basin the correlation is less distinct (Figs. 11 and 12) where the Rio Ivai Member pinches out towards south and disappears in Rio Grande do Sul State (Fig. 29). In the Northern part of the Parana Basin the Rio Ivai Member interfingers with red beds of the Aquidauana Formation (Fig. 14).

There are six cores available in the Rio Ivai Member (Fig. 19).

Sandstone is the dominant lithology of the Rio Ivai Member. Cores Nos. 8 and 9 (3074 to 3085m) in the 2-RP-1-PR (Fig. 19) recovered sandstone with two fining-upward sequences of 5m each. The base of each sequence starts with a whitish conglomeratic sandstone with pebbles up to 4mm which are predominantly composed of sedimentary rocks. The conglomeratic sandstone grades upwards into a light-gray (N7), mostly massive, coarse to medium sandstone, containing incipient horizontal laminations defined by carbonaceous material. A DST run in the 2-RP-1-PR in this sandy body (15m above the cored interval) shows the interval to have low permeability and non-commercial volumes of gas.

Core No.28 (2713 to 2722m) in the 2-CS-1-PR (Fig. 19) is composed of light-gray sandstone, fine to very fine grained and has abundant cross laminations, climbing ripples, and microfaults. The basal part is composed of medium to gray siltstone, grading to shale with pyritic nodules up to 4cm.

Core No.7 (2996 to 3005m) in the 2-TB-1-SP (Fig. 19) is composed of light-gray sandstone, coarse to very coarse, locally conglomeratic, massive, and contains some inclined laminations defined by shaly parting commonly associated with stylolites. The top of the fining-upward sequence grades to a dark-gray, bioturbated siltstone. A DST run on the No. 7 core interval showed that the sandstone has excellent permeability, but contains salt water.

Core No. 5 (3784 to 3786m) in the 2-CB-1-SP (Fig. 19) is predominantly a medium-gray conglomerate with pebbles up to 8cm, composed mostly of sedimentary rocks. The conglomerate is massive, and interbeded with medium-gray sandstone, containing abundant flow structures such as sand dikes.

Siltstones, shales, and pebbly mudstones occur in minor amounts in the Rio Ivai Member. Core No.8 (354 to 363m) in the 1-PN-1-SP (Fig. 19) recovered interbed of grayish and reddish pebbly mudstone.

Palynologically the section considered here as the Rio Ivai Member is dated as Permian age (Upper Artinskian to Lower Kungurian), from intervals H_2, to I_2 (Fig. 7).

In most of the wells in Sao Paulo and Mato Grosso do Sul, the contact zone between the Rio Ivai Member and the upper Chapeu do Sol Member is characterized by a fining-upward sequence (2-TB-1-SP, 3-CB-3-SP, and 2-DO-1-MT, Fig. 13), and (2-TL-1-MT, Fig. 14). In the 2-TL-1-MT well, the entire Rio Ivai Member has a fining-upward sequence. All The fining-upward sequences in the Rio Ivai Member grade into the massive pebbly mudstone of the Chapeu do Sol Member (Figs. 13 and 14).

The isopach map of the Rio Ivai Member (Fig. 29) shows a fairly constant thickness from southern areas of the basin up to the positive area located along the 2-CM-1-PR, 2-AP-1-PR and 2-AA-1-SP wells. From this positive area towards northwest, the Rio Ivai Member becomes thicker and interfingers with the red beds of the Aquidauana

Formation.

Chapeu do Sol Member: It is proposed that the uppermost unit of the Itarare Group in Sao Paulo, western Parana, western Santa Catarina, Rio Grande do Sul, and parts of Mato Grosso do Sul (Fig. 7), be called the Chapeu do Sol Member. This member is composed essentially of pebbly mudstone with minor sandstones. The proposed type section is the interval from 2449 to 2655m in the 2-CS-1-PR (Chapeu do Sol no.1, Fig. 30). The maximum known thickness is 333m in the 2-MO-1-PR (Fig. 30). Typical thicknesses are 150 to 200m. The Chapeu do Sol Member is present over an area of about 445,000 km^2 as shown in Figure 30.

The Chapeu do Sol Member pinches out towards the North (Cross section EE', Fig. 14), and is absent in Goias, Mato Grosso and northern Mato Grosso do Sul (Fig. 30).

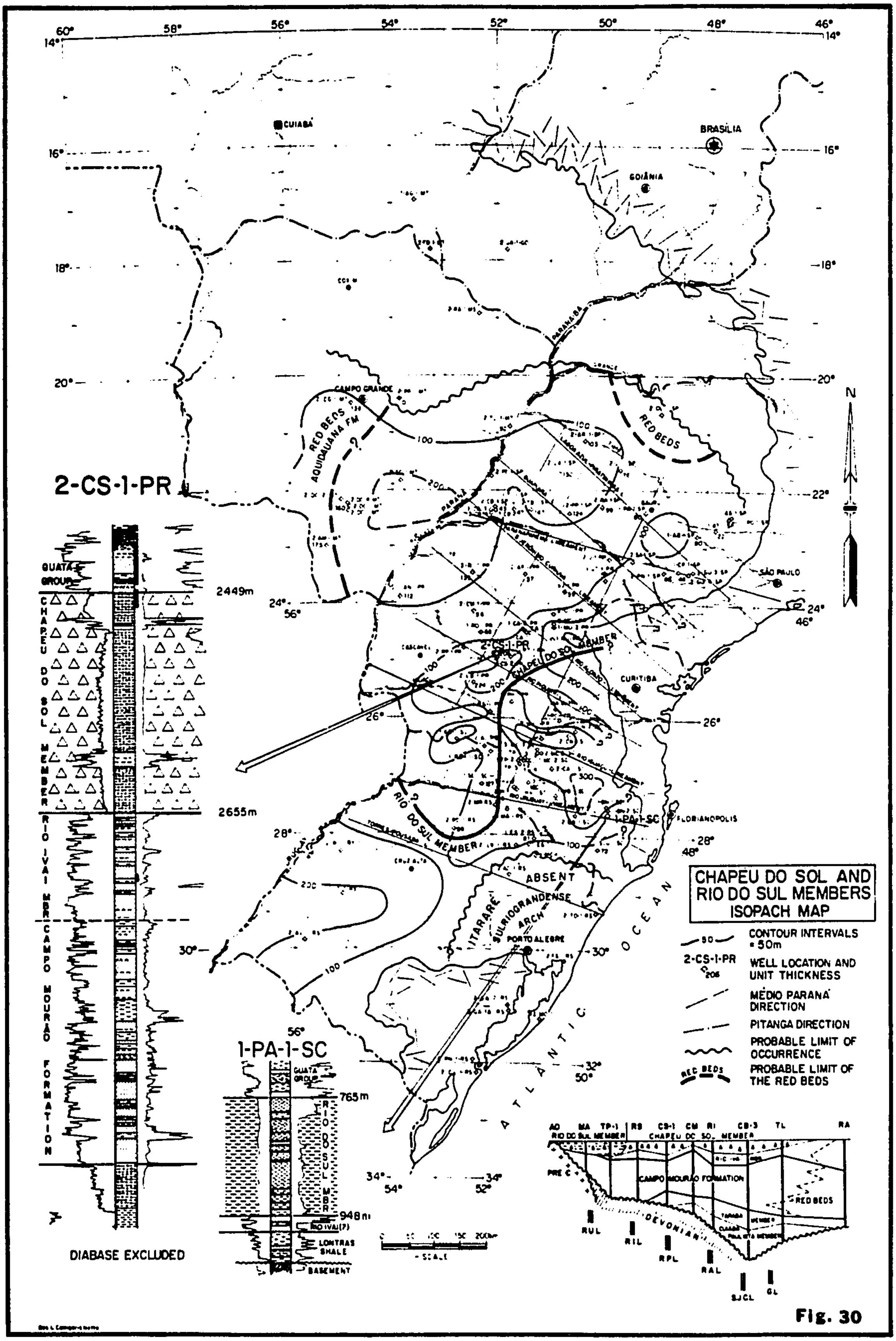
Palynologically, the Chapeu do Sol Member is dated as Permian age (Upper Artinskian to Kungurian), ranging from interval H_3 to I_4 (Fig. 7).

The Chapeu do Sol Member was cored in many wells and there are 19 cores available, totaling approximately 150m (Fig. 19). The predominant lithology is pebbly mudstone. The 2-AL-1-SC (Fig. 19) was continuosly cored from the Palermo Formation in the Guata Group down to the Chapeu do Sol Member. A total of 21 cores (289m) were cut of which 106m were in the Chapeu do Sol Member. The upper contact of the Chapeu do Sol Member with sandstones of the Rio Bonito Formation in the 2-AL-1-SC is sharp and may represent an erosional unconformity. The pebbly mudstone recovered in 2-AL-1-SC (about 106m) is dark gray (N3), massive, and contains pebbles composed mainly of granite. The muddy matrix may

Fig. 30 Isopach map of the Chapeu do Sol and Rio do Sul members.

The Chapeu do Sol Member is composed of pebbly mudstones, whereas the Rio do Sul Member is composed mostly of shales. Combined, both cover an area of about 600,000 km^2.

The northeast-southwest positive thin area mapped in the isopach map of the Taciba Formation (Fig. 26) is also defined in this map. It separates the two major depocenters of the Rio do Sul and Chapeu do Sol members.



CHAPEU DO SOL AND RIO DO SUL MEMBERS ISOPACH MAP
CONTOUR INTERVALS = 50m
WELL LOCATION AND UNIT THICKNESS
MÉDIO PARANÁ DIRECTION
PITANGA DIRECTION
PROBABLE LIMIT OF OCCURRENCE
PROBABLE LIMIT OF THE RED BEDS
2-CS-1-PR
1-PA-1-SC
2449m
2655m
765m
948m
DIABASE EXCLUDED
CAMPO MOURÃO FORMATION
CHAPEU DO SOL MEMBER
RIO DO SUL MEMBER
ITARARÉ SULRIOGRANDENSE ARCH
ABSENT
RED BEDS
AQUIDAUANA FM
ATLANTIC OCEAN
BRASILIA
GOIÂNIA
CUIABÁ
CAMPO GRANDE
SÃO PAULO
CURITIBA
FLORIANÓPOLIS
PORTO ALEGRE
DEVONIAN
LONTRAS SHALE
BASEMENT
SCALE

Fig. 30

occasionally be very silty and even may contain abundant sand grains. The amount of pebbles and sandy material may decrease and the pebbly mudstone can grade to laminated shale as observed in cores of the 1-SE-1-SC and 1-GO-1-SC.

Core No.8 (2500 to 2509m) from the 1-SE-1-SC (Fig.19), is composed of fissile, dark-gray (N2) varved shale which contains pyritic nodules, scarce granules, and small pebbles of granitic rocks. Toward the base of the member, the shale grades to a pebbly siltstone. The middle section of the core has about 80cm of light-gray (N6) silty sandstone with bioturbation.

In the 1-GO-1-SC (Fig. 19), cores No.4 (3115 to 3129m) and 5 (3190 to 3204m) contains a black shale that is massive to slightly fissile. This shale contains many pyrite nodules up to 1cm, as well as scattered pebbles of granite.

All cores from the wells in Sao Paulo State are composed of typical pebbly mudstone, medium to dark gray containing pebbles of granites and sedimentary rocks. Sandstone dikes are common in many cores (picture.). Core No.5 (2828 to 2846m) in the 2-TB-1-SP in central Sao Paulo (Fig. 19) shows an interbeding of grayish and brownish pebbly mudstone.

In Mato Grosso do Sul on western side of the basin in well 2-DO-1-MT (cross section DD', Fig. 13), the Chapeu do Sol Member is predominantly composed of dark-gray, pyritic, varved shale interbeded with grayish pebbly mudstone. This shale does not occur in any other well drilled in this part of the basin. It appears to be stratigraphically in the same position as the Rio do Sul Member in the eastern side of the basin.

The isopach map of the Chapeu do Sol Member (Fig. 30) also shows the positive thin area mapped in the Rio Ivai Member. This positive area, which is parallel to the Pitanga Direction Lineaments (Soares et al 1982, p. 9; Saad in prep.), has segmented the basin at this time into two major depocenters: one to the northwest with maximum known thickness of 175m in the 2-AM-1-MT (southern Mato Grosso do Sul), and a second and more important depocenter to the southeast having a maximum thickness of 333m in the 2-MO-1-PR (eastern Parana State). Towards the southeastern part of the basin, pebbly mudstones of the Chapeu do Sol Member interfinger with shales of the Rio do Sul Member (Fig. 30).

Rio do Sul Member: The name Rio do Sul was given formation status by Schneider et al (1974, p.48) and was defined to include the argillaceous sediments occurring in the top of the Itarare Group in the outcrop area of Santa Catarina and Parana States. The unit was named for the town of Rio do Sul in Santa Catarina.

The type section (350m thick) is located near Rio do Sul (Schneider et al 1974, Fig. 6). The Rio do Sul Formation is described by Schneider et al (1974, p. 48) as composed of claystones, varved shales, fine sandstones, rhythmites and diamictites (pebbly mudstones). The major sedimentary structures are cross lamination, sole marks, parallel bedding, and slump structures in sandstones and siltstones. In the diamictite, slump structures, convolute lamination and irregular bedding are also common. Ripple marks and flaser structures are abundant towards the top, mainly in Santa Catarina.

The Rio do Sul Formation was interpreted by Schneider et al (1974, p. 49) as deposited in a marine environment. Its varved shales are characteristic of strata deposited in quiet water with no influences of waves or currents. The rhythmites are interpreted as turbidites. Scattered pebbles found in the shales are interpreted as dropstones from icebergs.

In the subsurface, the Rio do Sul Formation appears to be correlated with a similar section found in several wells in Santa Catarina and Parana states, such as, 1-PA-1-SC, 1-MB-1-SC, 2-TG-1-SC, and 2-TP-1-SC, (Cross section BB', Fig. 11). The proposed subsurface type section is the interval from 765 to 948m in the 1-PA-1-SC (Fig. 11), located in eastern Santa Catarina. The maximum known thickness in the subsurface is 356m in the 2-CN-1-SC in eastern Santa Catarina State. Typical thickness are 150 to 200m. The Rio do Sul Member covers an area of aproximatelly 145,000 km^2 (Fig. 30).

The shales interfinger with pebbly mudstone of the Chapeu do Sol Member as demonstrated in cross sections BB' and CC' (Figs. 11 and 12), it is proposed, therefore, to change the status of formation to member as shown in the cross section BB' (Fig. 11).

The Rio do Sul Member has some fossiliferous horizons (Schneider et al, 1974, p. 49), such as the 'Guarauna Beds' and 'Passinho Beds' in eastern Parana, which contain brachiopods, pelecypods, gastropods, crinoids, and foraminifers. In Rio Grande do Sul the 'Budo' and 'Cambai Grande' beds contain brachiopods, pelecypods, ostracods, sponge spicules, and fish scales. In addition, the Rio do Sul Member has also great amount of palynomorphs and plant remains. Palynologically the Rio do Sul Member was dated as Permian (Kungurian) Schneider et al (1974, p.49). Rocha-Campos (1967, p.60) provides more information on the fossil content of the upper section of the Itarare Group.

There is only one core available for this study from the Rio do Sul Member (core No. 6, 2261-2280m) in the 1-ES-2-RS in Rio Grande do Sul State (Fig. 19). The core has recovered light-gray (N7), very fine sandstone with plant remains and shale clasts interbeded with medium-gray (N5) siltstone, micaceous, pyritic, and carbonaceous. The siltstone grades to dark-gray (N2) shale. Flaser structures, climbing ripples, load casts, flow structures and bioturbation are commonly found in the core. There are other core descriptions available in composite logs, such as core No. 29 in well 2-PA-1-SC (Fig. 11), which is composed of dark-gray to black shale interbeded with varved, micaceous siltstone; core No.30 contains light-gray, micaceous, very fine sandstone, interbeded with dark-gray peblly mudstones.

Schneider et al (1974, p.45 and 47) defined two more units below the Rio do Sul Member in outcrops exposed in the Sates of Santa Catarina and Parana. these strata are the Campo do Tenente Formation and Mafra Formation. The Campo do Tenente Formation designates the brownish to redish claystones, diamictites (pebbly mudstones) and sandstones at the base of the Itarare Group. The Mafra Formation designates the sandy unit in the middle of the Itarare Group. It was not possible confidently to correlate the Campo do Tenente and Mafra formations with wells drilled close to the outcrop area where these units where defined.

The Chapeu do Sol Member and the Rio do Sul Member are easily mapped in the subsurface. Both are easy to identify in the well logs using the gamma ray and/or spontaneous potential (SP) logs and they are present over most of the basin. In addition, both members have a well-defined stratigraphic position underneath the Guata Group. Because of this, the Chapeu do Sol and Rio do Sul members are used as a stratigraphic datum for correlations (Figs. 10 to 14).

The last unit in the Itarare Group to be discussed is the Aquidauana Formation which occurs in the northern areas of the basin.

Aquidauana Formation: The name Aquidauana was first used by Lisboa (1909) to designate the reddish sandy unit which occurs in the valley of the Aquidauana River in the State of Mato Grosso do Sul. Acording to Schneider et al (1974, p. 46), the Aquidauana Formation is subdivided into three sequences. The lower sequence is characterized by red-purple, medium to coarse sandstone with trough cross bedding. Secondarily, it contains pebbly mudstone, whitish sandstones, and conglomerates. The middle sequence is dominated by red-purple siltstone, is laminated, and contains red pebbly mudstone and a little greenish-gray shale. The upper sequence is predominantly composed of sandstones.

The thickness of the Aquidauana Formation in outcrop varies from 200m up to 700m. In subsurface the maximum known thickness is 799m in well 2-AG-1-MT cross section EE' (Fig. 14).

The red beds of the Aquidauana Formation are the only units of the Itarare Group in the northwestern outcrop belt of the Parana Basin (Fig. 1); whereas, in the southeastern outcrop belt the grayish sediments of the Itarare Group are predominant. The relationship between the reddish and the grayish sediments in subsurface, is not clear. However, well-log correlations between the Aquidauana Formation in the north and the grayish units in the Itarare Group to the south permit the following observations:

- The interfingering of red and gray sandstones, pebbly mudstones, and siltstones occurs mostly in Sao Paulo and Mato Grosso do Sul states. From Sao Paulo to the northern area, the red beds are predominant; whereas, to the south, grayish sandstones, pebbly mudstones, and siltstones are dominant.

- There is no distinct pattern in gamma ray, SP, or other logs that can provide a distinction betweeen the red beds and the grayish sequences. They can only be distinguished visually on the basis of color.

- Reddish sandstones are predominant over reddish shales, pebbly mudstones and siltstones. This is shown in the cross sections AA' and EE' (Figs. 10 and 14), where the reddish sandstones penetrate farther south than the reddish shales. This suggests that part of the southern redish sandstones may be a product of secondary alteration due to percolation of iron-rich water coming from the northern outcrop belt.

Specific studies are still necessary to determine whether the red color of the Aquidauana Formation in outcrops is primary or secondary, and if primary, were they developed at the site of deposition or derived from the source areas?

The presence of trona, which is a sodium bicarbonate ($NaHCO_3.H_2O$), has been reported in outcrops of the Aquidauana Formation by Sousa et al (1983, p. 310). Major occurrences are located in caves along the canyon of the Sao Jose das Cordas Creek, about 45 km east of Caiaponia in southwest Goias. Another occurrence, also in southwest Goias, is located in the Ribeirao Grande Ranch, northwest of Portelandia Village. (Souza et al, 1983, p. 310).

The occurrence of trona in ancient sediments is reported in the Wilkins Peak Member of the Eocene Green River Formation in southwestern Wyoming (Birnbaun and Radlick, 1982). In Recent the occurrence of trona has been reported in the Chadian Basin in Africa by Maglione (1981, p. 7).

Trona is an important paleoenvironment indicator because primary sodium carbonates are specific to the subtropical lacustrine environment (Sonnenfeld, 1984, p. 149). According to the author, sodium carbonates "...are found in neither the polar environment nor marine lagoonal precipitates."

There is only one core available from the Aquidauana Formation: core No. 3 (2338 to 2356m) in the 2-AR-1-SP (Fig. 19), in northern Sao Paulo State. This core recovered 18 meters of fine-to medium-grained red sandstone (with inclined bedding up to 30°) intercalated with layers of light-gray siltstone containing iregular laminations and sand dikes composed of very coarse sand.

My studies will focus the grayish part of the Itarare Group, first because there is not enough data from the red beds, and secondly, because the great majority of the wells were drilled in the realm of the grayish rocks. However, the Aquidauana Formation certainly deserves much more study.

DEPOSITIONAL ENVIRONMENT

General Coments. When the name Itarare was introduced in the stratigraphic classification of Parana Basin by Oliveira (1927, p. 41) its environment was described as being of glacial origin. Later Du Toit (1927, Table I) correlated the Itarare Group to the Dwyka Tillite in South Africa and to the Lafonian Tillites in the Falkland-Malvinas Islands. Currently, it is widely accepted that the **Glossopteris**-bearing glacial deposits (Permo-Carboniferous) of South America, Africa, Australia, Antarctica and India are all correlated (e.g. Crowell and Frakes, 1975, p. 328).

According to Rocha-Campos (1967, p. 28), " The glacial sequence includes diamictites, sandstones, rhythmites (often resembling varved shales), mudstones, shales, conglomerates and coal." Even possible fossil eskers have been described in Sao Paulo State by Frakes et al (1968, p. 5).

Glacial features, such as "roches moutonees" and striated pavements are rare in the Parana Basin, and according to Rocha-Campos (1967, p. 83) this is probably due to long weathering acting on the rocks. However, there are some localities where the contact between diamictites and basement rocks show striated pavement. The most important locality is probably the striated pavement on the Furnas Sandstones at Colonia Wittmarsum, Parana State (Rocha-Campos, 1967, Fig. 11). Striae at this locality suggest that the main direction of ice movement was from South to North. Other directions of ice-movements according to Rocha-Campos (1967, p. 83) are from southeast to northwest (Sao Paulo and Santa Catarina State); and to northwest (Sao Paulo State).

In South Africa and South West Africa, the record of the late Paleozoic glaciation in the Gondwana is more complete with many striated pavements, scoured glacial valleys and a better understood pattern of the Dwyka Tillites (Crowell and Frakes, 1975, p. 320). Based on this information and on paleomagnetic studies, Crowell and Frakes (1975, Figs. 22.3 and 22.4) presented a reconstruction of the late Paleozoic geography and climatology in Africa and South America that is reproduced here on Figure 2.

The Parana Basin, according to Crowell and Frakes (1975), had two major ice lobes coming from the east and one coming from the south (Fig. 2). The northern lobe was interpreted as the Brazilian end of the Kaokoveld lobe of Africa. The western side of the Parana Basin should have glaciers located on the Assuncion Arch, which has affected the deposition of the Bolivian Basin, west of the Assuncion Arch (Crowell and Frakes, 1975, p. 324).

Gravenor and Rocha-Campos (1983, Table 1) presented an interpretation of the patterns of glacial sedimentation on southeast Parana Basin. According to their view the glacial sediments found in the margins of the Parana Basin were deposited from terrestrial grounded ice and are composed of diamictite of flow origin interbedded with mudstones and minor amount of lodgement tillite. During ice retreat in the terrestrial environment, the deposition of conglomerates, fluvial sandstones, and varvites took place. Within the subsiding Parana Basin the authors suggested that most of the glacial deposits were deposited in a subaquatic environment. These sediments are composed of sandstones, siltstones, shales, mudstones, interbedded with massive and laminated diamictites. Gravenor and Rocha-Campos (1983, p. 35) suggested that units of massive structureless diamictite up to 10m or more in thickness were deposited at the base of advancing glaciers, whereas during glacial retreating the major deposits were deltaic sandstones, subaquatic outwash, turbidites, shales, and siltstones. According to them (p. 23), the coastline during Itarare time was indented and the basin itself was shallow with the exception of localized deeper sub-basins.

A detailed study of glaciation in the Gondwana was made by Caputo and Crowell (1985). Based on the age and distribution of glacigene strata Caputo and Crowell (1985, p. 1033) concluded that the ice age in the Gondwana "...lasted at least 90 m.y., perhaps from 340 or 350 m.y. ago until aproximatelly 240 m.y.a., but at no time was there a single huge ice cap. Instead, ice centers waxed and waned across different sites during this long interval." In addition, the authors presented the path of the intermittent glacial centers as they migrated across western Gondwana (Caputo and Crowell, 1985, Fig. 12).

Canuto (1985) conducted work in the States of Parana and Santa Catarina to understand the origin of the diamictites. He found three different lithological associations: terrestrial-grounded glacier facies represented by lodgement tillites in lateral contact with fluvio-glacial deposits; internal shelf-grounded glacial facies with lodgement or basal tillites covered with subaquatic sediments, including marine ones; and an external shelf-basinal facies represented by glacigenic mass gravity flow sediments.

However, one question still remains - how many times have glaciers advanced into the Parana Basin? The number of diamictite bodies, reported by many authors, varies from 5 to 23 (Gravenor and Rocha-Campos 1983, p.11). However, as pointed out by the authors, how many of these diamictites are related to glacial advances? Some may be the result of local debris flows associated to one single glacial event. A suggestion made by Gravenor and Rocha-Campos (1983, p. 1) is that in Sao Paulo State there were at least nine glaciations.

So far all sedimentological work in the Itarare Group was done in outcrops. What can be inferred from the Itarare Group in the subsurface? In subsurface the environmental interpretation is made mostly using log signatures following models proposed by Schlumberger. An update work is Gilreath (1985). Selley (1978), Colleman and Prior (1980), and Cant (1984) are also good papers on subsurface analysis. However, there are no references to subsurface interpretation of glacial deposits using log patterns in ancient rocks. The present work is probably the first attempt at interpreting glacial deposits from well logs.

Environmental Interpretation in Subsurface. Well logs are the subsurface geologist's most important tool; some logs are used for lithological purposes such as the gamma ray, other indicates porosity (sonic, density and neutron logs), the spontaneous potential log (SP) indicates relative permeability of the rocks; the resistivity log is used to indicate fluid types, and when associated with other parameters (porosity and water resistivity), it is possible to calculate the hydrocarbon saturation in the reservoirs. The dipmeter log gives strike and dip of the beds in the subsurface. Seismic reflectors can be checked and tied to stratigraphic horizons through the integrated travel time in the sonic log.

For stratigraphers and sedimentologists, wireline logs, especially the gamma ray log are essential and sometimes the only available information to correlate wells. The gamma ray log measures the natural radioactivity of the rock - a primary property acquired during deposition. In sedimentary rocks the radioactive elements tend to concentrate in fine materials such as clay minerals and so that the gamma ray provides a measure of clay content. Thus a sandstone with little clay will have low gamma ray producing a deflection to the left, such as in the interval 3710/3913m in well 2-LA-1-SP (Fig. 9). On the other hand, clay-rich lithologies will have a high gamma ray (deflection to the right) as observed in the pebbly mudstone and siltstones of the interval 3144 to 3710m in well 2-LA-1-SP (Fig. 9).

Absolute values of radioactivity are not necessary for stratigraphic purposes; rather the shape of the curve is the key for correlation and facies studies.

It is fundamental in log correlation to understand the meaning of the curve's shape in the gamma ray log. For instance, a sandstone that was deposited in a relatively homogeneous and constant depositional energy level, such as eolian sandstones, or braided river channels, will show slight or no variations in the clay content. This will give a low gamma ray response in a cylindrical pattern (Fig. 31). See, for example, the section between 3348 and 3500m in well 2-RO-1-PR (Cross section CC', Fig. 12), and the interval from 2165 to 2295m in 2-AA-1-SP (Cross section DD', Fig. 13).

Because no pattern is unique to a particular environment, it is necessary to calibrate the log shape to cores. Log shapes calibrated and related to depositional environments are the key to successful subsurface correlations. Wells lacking cores can be correlated and then environment may be interpreted this way (Cant, 1984, p. 306).

In the examples mentioned above, the interval from 2165 to 2295m in 2-AA-1-SP well has a core which is composed of massive, poorly sorted sandstone, and matrix content about 5 percent. Texturally, this

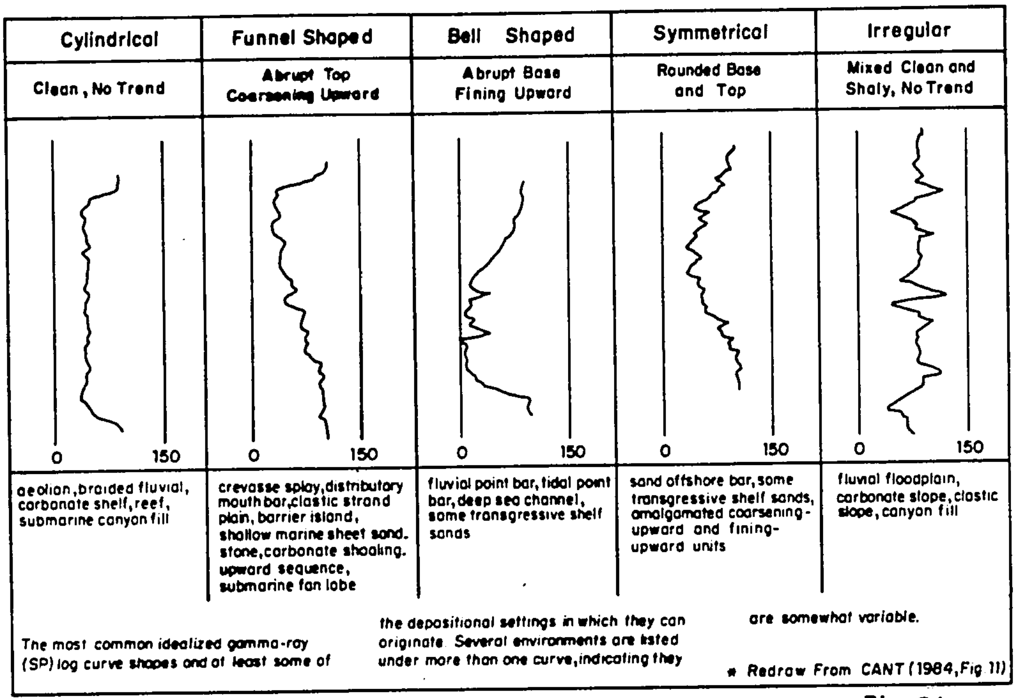


Fig. 31

sandstone is more likely fluvial (stacking of braided river channels) than eolian. Another possibility, according to Figure 31, is a submarine canyon fill, however, the absence of marine fossils and the presence of terrestrial pollen and spores, argue against this interpretation.

A sandstone deposited on a point bar has a fining-upward sequence with a bell-shaped curve (Fig. 31). Another possibility for a fining-upward sequence is a transgressive sequence (Cant 1984, p. 306, and Selley 1978, Fig. 1.2). In the Itarare Group a transgressive sequence is possible, mainly where the bell-shaped curve is covered by marine deposits such as the Rio do Sul Member in Santa Catarina State.

Conversely, a funnel-shaped curve has a coarsening-upward curve and represents depositional environments where clay removal increases upwards. The most common environment producing a coarsening-upward sequence is a distributary-mouth-bar in a delta (Coleman and

Prior, 1980, Fig. 31), and in bay-fill deposits (Coleman and Prior, 1980, Fig. 20).

Fining and coarsening upward sequences in the Itarare Group are indicated in cross sections AA' to EE' (Figs. 10 to 14).

Depositional Cycles. Log correlation presented in this work (Fig. 10 to 14) suggest that the Itarare group in the central part of the Parana Basin is subdivided into three major depositional cycles, each of which is well defined on gamma ray and spontaneous potential logs, and in rocks. Each has the following features:

1 The lower cycle starts with a sandy unit commonly with cylindrical gamma ray pattern, overlain by a "shaly" unit (Fig. 32). The best examples of this lower depositional cycle in the Itarare Group are in the intervals from 3395 to 3720m in 2-RI-1-PR in Parana State; 3483 to 4043m in 2-TB-1-SP in Sao Paulo State; and from 3144 to 3913m in 2-LA-1-SP in Sao Paulo State (Fig. 10).

2 The middle and upper cycles essentially repeat the lower cycle. The middle cycle in the 2-RI-1-PR is the interval from 3043 to 3395m and the upper cycle is the interval from 2778 to 3043m (Fig. 32). In the 2-TB-1-SP well the middle cycle is from 3089 to 3483m and the upper cycle is from 2792 to 3089m (Fig. 10).

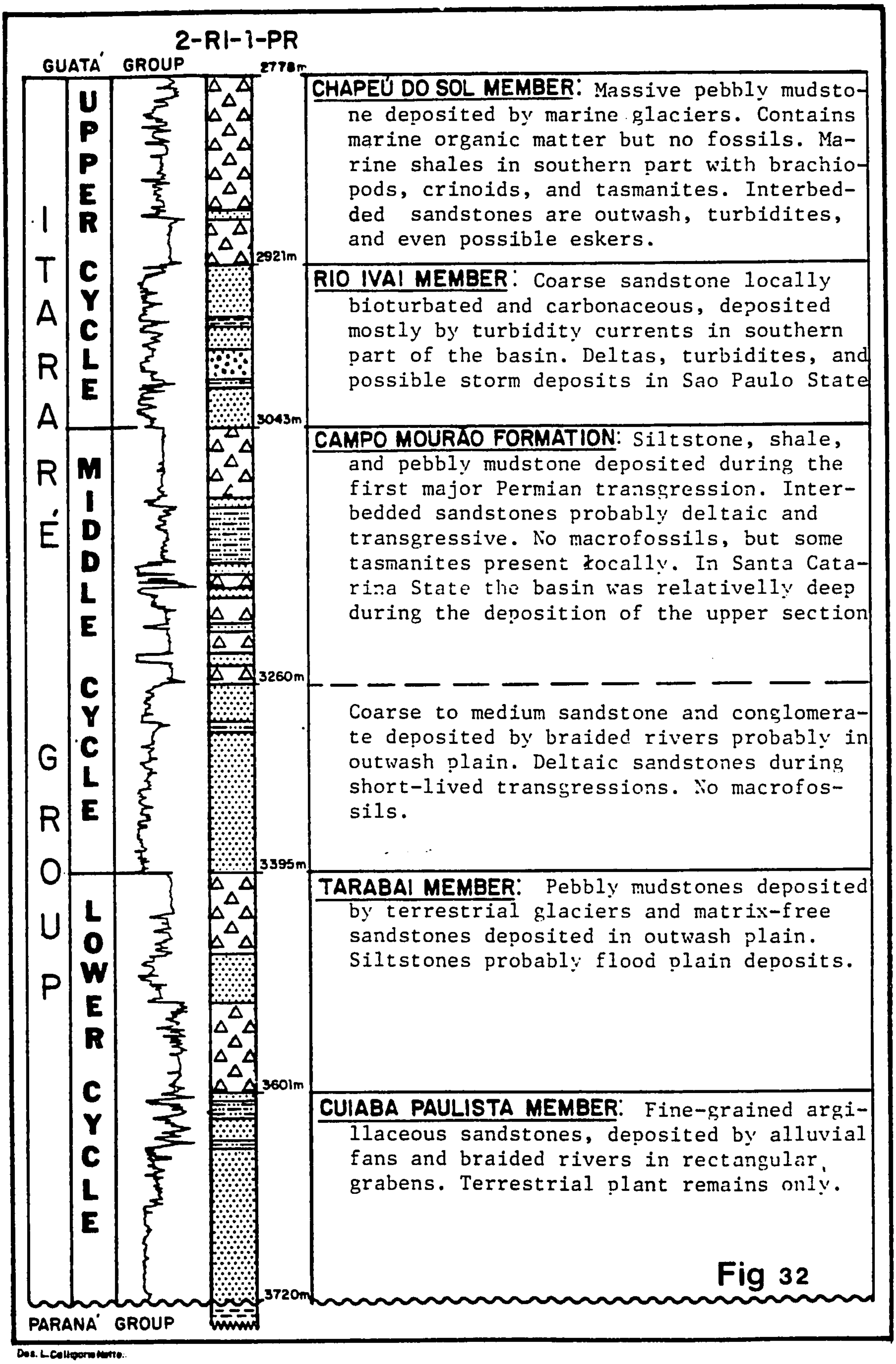
Therefore, the Itarare Group in the central part of the Parana Basin, appears to be the product of vertical stacking of these three depositional cycles.

Fig. 32 Depositional cycles of the Itarare Group.

The 2-RI-1-PR was chosen as a representative well because it clearly shows the three depositional cycles.

Note that the depositional cycles are composed of a sandy basal unit covered by a "shaly" unit, creating an interesting relationship between possible reservoir and seal rocks.

Note also that the proposed stratigraphic subdivision of the Itarare Group matches with the depositional cycles.


2-RI-1-PR
GUATÁ GROUP
2778m
ITARARÉ GROUP
UPPER CYCLE
MIDDLE CYCLE
LOWER CYCLE
2921m
3043m
3260m
3395m
3601m
3720m
PARANÁ GROUP
CHAPEÚ DO SOL MEMBER: Massive pebbly mudstone deposited by marine glaciers. Contains marine organic matter but no fossils. Marine shales in southern part with brachiopods, crinoids, and tasmanites. Interbedded sandstones are outwash, turbidites, and even possible eskers.
RIO IVAI MEMBER: Coarse sandstone locally bioturbated and carbonaceous, deposited mostly by turbidity currents in southern part of the basin. Deltas, turbidites, and possible storm deposits in Sao Paulo State
CAMPO MOURÃO FORMATION: Siltstone, shale, and pebbly mudstone deposited during the first major Permian transgression. Interbedded sandstones probably deltaic and transgressive. No macrofossils, but some tasmanites present locally. In Santa Catarina State the basin was relativelly deep during the deposition of the upper section
Coarse to medium sandstone and conglomerate deposited by braided rivers probably in outwash plain. Deltaic sandstones during short-lived transgressions. No macrofossils.
TARABAI MEMBER: Pebbly mudstones deposited by terrestrial glaciers and matrix-free sandstones deposited in outwash plain. Siltstones probably flood plain deposits.
CUIABA PAULISTA MEMBER: Fine-grained argillaceous sandstones, deposited by alluvial fans and braided rivers in rectangular grabens. Terrestrial plant remains only.
Des. L. Calligaris Netto.
Fig 32

The lower and upper depositional cycles are well defined in most of the wells in the Parana Basin (Cross sections AA' to EE' - Figs. 10 to 14). However, the middle cycle has some deviations from the ideal shape, which is shown in Figure 32. The cylindrical pattern typical of sandstones from the lower and upper depositional cycles, is present in the middle depositional cycle however, it can change into a fining and coarsening-upward sequences, such as in 2-LA-1-SP (Fig. 10), 2-AB-1-SP, and 1-TI-1-SP (Fig. 13) or into thick, massive sandstone bodies (more than 300m thick) making correlation difficult. Such thick sandstone occurs in the area of the 2-AR-1-SP well (Fig. 10) and in the 1-CS-2-PR (Fig. 12). Still another possibility is the stacking of "thin" depositional cycles as for instance in the 2-PP-1-SP well (Fig. 13).

The stratigraphic subdivision of the Itarare Group (Figs. 10 to 14), proposed earlier in this work, matches with the depositional cycles in such a way that the lower depositional cycle includes the **Lagoa Azul Formation** (Cuiaba Paulista and Tarabai members), the middle cycle is the **Campo Mourao Formation**, and the upper cycle unit comprises the **Taciba Formation** (Chapeu do Sol, Rio Ivai, and Rio do Sul members).

The environmental significance of these depositional cycles is not well understood; however, some suggestions can be proposed by combining log morphology, outcrop information, petrological, and paleontological data. This suggestions are seen in detail in Figure 32, and summarized in Table 2.

Lagoa Azul Formation. The Lagoa Azul Formation, which was deposited in the palinostratigraphic interval G + H_1 (Fig. 7), has no macrofossils observed to date, and its palynological content is continental according

Table 2. Relationships between the depositional cycles, environments of deposition, and hydrocarbon potential of the Itarare Group.

This table is an integration of data in an attempt to visualize the evolution of the deposition of the Itarare Group. The last column shows how this evolution may have created conditions for hydrocarbon accumulation in the Itarare Group.

Table 2

GAMMA RAY		ENVIRONMENT	CLIMATE (warm – cold)	RELATIVE SEA LEVEL (low – high)	HYDROCARBON POTENTIAL
UPPER CYCLE	Taciba Fm.	Deep marine in southern part of the basin. Marine glaciers in northern part.			Seal of pebbly mudstone and shale Source rock (?)
		Deltas, Turbidites, and Shelf Storm deposits.			Good Reservoirs
MIDDLE CYCLE	Campo Mourao Fm.	Transgressive deposits and Minor Glaciers			Seal of pebbly mudstones
		Braided Rivers and Outwash deposits			Good Reservoirs
LOWER CYCLE	Lagoa Azul Fm.	Terrestrial Glaciers			Seal of pebbly mudstones
		Alluvial Fans and Braided Rivers			Fair to Poor Reservoirs

to Daemon et al (1983, Anexos I and II). In addition, it contains reworked fossils from the Devonian - Ponta Grossa Formation (Daemon et al 1983, p.7).

Sandstones cored from the Cuiaba Paulista Member, the basal part of the lower cycle are fine-grained, massive (Fig. 9), and locally have dish structures which are interpreted as a product of post-depositional escape of water from the sand (Collinson and Thompson, 1982, p. 147).

Because the pollen content suggests terrestrial environment and dish structures suggest underwater sedimentation, it is likely that the environment of deposition of the sandy part of the lower cycle is the coalescence of alluvial fans, whose development is linked to the structural lineaments and the "rectangular grabens". It is possible that the distal sediments of the alluvial fans could have been reworked by braided rivers flowing over the fans. An interpretation as braided stream deposits fits the cylindrical pattern (Fig. 31), proposed by Cant (1984, p. 306).

The shaly part of the lower cycle, which corresponds to the Tarabai Member, is composed of siltstones, some pebbly mudstones and locally sandstones (Figs. 10 to 14).

As mentioned earlier, the pebbly mudstones (diamictites) from the Itarare Group in the outcrop area have been interpreted as tillites by several authors (e.g. Oliveira, 1916, p. ; Rocha-Campos, 1967, p. 28; Crowell and Frakes, 1975, p. 322). Lately, Gravenor and Rocha-Campos (1983, p. 12) based on outcrop evidence, have differentiated the diamictites of the Itarare Group into lodgement tillites (deposited by direct action of glacier) and flow-tillites (supraglacial deposits). In subsurface, however, the understanding of glacial deposits is limited compared to other sedimentary environments, because the petroleum industry has assessed glacial deposits as non-productive and consequently their research on glacial sediments is minor.

It is suggested that in subsurface the pebbly mudstones from the lower depositional cycle are also glacially derived; however, there are not enough data to classify them as lodgement tillite or flow tillite.

Sandstones present in the Tarabai Member occur within the pebbly mudstones. The thickness of these sandstones ranges from one to 35 meters. Petrographically, they are moderately sorted and matrix-free (see petrographic description for details), and produced gas at a rate of 3MMcfd in the 2-CB-1-SP well in Sao Paulo State. It is suggested that these sandstones were deposited in outwash plains (Smith, 1985, p. 85). Outwash plains are broad alluvial plains where multiple braided stream systems redeposit sediments commonly issuing from glacial meltwater streams. The braided streams would have enough energy to wash clay particles and deposit the matrix-free sandstones of the Tarabai Member.

The **Roncador Shale Lens** (Fig. 21), which is composed of laminated pyritic black shale and has a high gamma ray signature is probably lacustrine, deposited in anoxic conditions in a sulfidic environment (Maynard, 1982, Fig. 1).

In summary, alluvial fans and braided river deposits are proposed for the sandy part of the lower cycle (Cuiaba Paulista Member), and glacial deposits associated to outwash plain for the upper part of the lower cycle (Tarabai Member -Fig. 32).

Campo Mourao Formation. The Campo Mourao Formation that corresponds to the middle cycle is more complex than the lower and upper ones, because of the laterally persistent changes of facies as discussed earlier.

The basal sandy sequence of the middle cycle consists of medium to coarse poorly sorted sandstone, containing many rock fragments but is mostly matrix-free (see reservoir analysis for details). Locally, it is interbbeded with conglomerates containing pebbles up to 8 cm. Thickness ranges from 5m up to 200m. The gamma ray signature of the Campo Mourao Formation can be cylindrical or either, coarsening-upward (funnel shaped) and fining-upward (bell shaped) sequences.

Typical examples of cylindrical patterns are the intervals 3348-3500m in 1-RO-1-PR and 2771-3004m in 1-SE-1-SC (Fig. 12). Locally, the massive sandstone that forms the cylindrical pattern contains thin siltstones and shales which have high gamma ray peaks within the massive sandstones. Possibly the sandstones with cylindrical gamma ray signatures in the Campo Mourao Formation were deposited by braided rivers. There is no direct indication of glacial influence on these sandstones; hence, it is possible that the braided rivers were fed by meltwater streams carrying debris from retreating glaciers. The thin siltstones layers interbedded in the sandstones can be interpreted as flood plain deposits, that make vertical acretion deposits during major floods (Walker and Cant 1984, p. 81). This interpretation is also in agreement with the log pattern in Figure 30, proposed by Cant (1984, p. 306).

Typical fining-upward sequences in the middle cycle are indicated in cross sections AA' to EE' (Figs. 10 to 14). Thicknesses of these fining-upward sequences range from 10m up to 100m, although typical thicknesses are about 50m. Fining-upward sequences are present mostly in the upper section of the Campo Mourao Formation. Good examples occur in 2-AL-1-SC, 1-RS-1-PR (Fig. 12); 2-LA-1-SP (Fig. 10); 1-TP-1-SC, and 2-TG-1-SC (Fig. 11).

Fining-upward sequences can be formed on fluvial point bars, tidal point bars, deep sea channels and by transgressive sands. Daemon et al (1983, Anexos 1 and 2) proposed, based on palynological data, that the sequence corresponding to the lower Artinskian (upper section of Campo Mourao Formation - Fig. 7), was deposited under marine influence and marks the begining of the Permian transgression over the Parana Basin. The log signature of the upper section of the Campo Mourao Formation (Figs. 10 to 13) certainly fits this interpretation.

Typical coarsening-upward sequences in the middle cycle (Campo Mourao Formation), are indicated in the cross sections AA', DD', and EE' (Figs. 10, 13, and 14). Thickness of the coarsening-upward sequences ranges from 5m up to 100m but typical values are about 25m. Coarsening-upward sequences are predominantly overlaid by siltstone and pebbly mudstone.

These coarsening-upward sequence could either be distributary mouth bars or crevasse splays. Quite possibly, the thicker sequences of about 100m are distributary mouth bars (Coleman and Prior, 1980, Fig. 34), and perhaps related to deltas that have developed during periods of short-lived transgressions into the Parana Basin.

Besides the three major patterns, cylindrical, fining-upward, and coarsening-upward, described above, the middle cycle has also some wells with irregular gamma-ray pattern (Fig. 31) such as in 1-CS-2-PR (Fig. 12). This pattern in the Itarare Group occurs in sandstones interbeded with shale and thin pebbly mudstones. According to Cant

(1984, p. 306), the irregular pattern (Fig. 31), is typical of fluvial floodplain, or cannyon fill. In the Itarare Group, sandstones with irregular gamma ray pattern may represent deposition on a fluvial floodplain. If this interpretation is correct, wells with irregular gamma ray signatures (Fig. 31), such as 1-CS-2-PR represent highs that were not invaded by short-lived transgressions.

The **Lontras Member**, which outcrops in eastern Santa Catarina and Parana states (Fig. 24), is composed of dark gray, varved black shale that contains cone-in-cone structures. According to Schneider et al (1974, p. 49) the Lontras Shale was deposited in a marine environment. Laminated black shales are deposited in anoxic conditions which may be either sulfidic or methanic (Maynard, 1982, Fig. 1). According to the author (p. 1330) carbonate cone-in-cone structures are present in the Devonian-Carboniferous shales of the Appalachian Basin. Here the cone-in-cone are always associated with pyritic black shale, from the sulfidic environment.

The Campo Mourao Formation of the 2-RP-1-PR well has near its top interbedded shale, sandstone, and anhydrite. The presence of anhydrite suggests the existence of local coastal lagoons during the Permian transgression.

In summary, it is proposed that the middle depositional cycle (Campo Mourao Formation) was deposited predominantly in a continental environment, with minor marine influence that becomes more important towards the upper section, where evaporites, and the Lontras Member, are present. The paleontological evidence of Daemon et al (1983, Anexos 1 and 2) supports this conclusion.

Taciba Formation. The Taciba Formation, which corresponds to the upper depositional cycle is certainly the best known of the Itarare Group, because the major outcrops of the Itarare Group chiefly are those of the Taciba Formation, that is, the Rio do Sul and Rio Ivai members in Santa Catarina and Parana states, and the Chapeu do Sol and Rio Ivai members in Sao Paulo State and northern Parana State.

The upper cycle is divided into a sandy basal section, called the Rio Ivai Member, and a "shaly" upper section, the Rio do Sul and Chapeu do Sol members. The sandy basal unit is composed predominantly of coarse to very coarse, massive sandstone, mostly clay-free. It is locally conglomeratic containing some carbonaceous material, flow structures and bioturbation (Fig. 25).

Fining-upward or bell shaped sequences (Fig. 31), are predominant and are well seen in 2-TL-1-MT, interval 2725-2830m (Fig. 14). The example in this well is also a thining-upward sequence (Walker, 1984, p. 180); i.e. the sandy layers become also thinner upwards. According to Walker (1984, p. 181), thining-upward sequences may indicate either gradual channel filling and abandonment or gradual lobe shifting, from a lobe centre to lobe fringe environment.

In the outcrop of Santa Catarina State, Castro (1980, p. 285) and Castro and Medeiros (1980, p. 70), have interpreted the basal sandstones of the Rio do Sul Member, as submarine fans and deposited by deep water turbidity currents. Incomplete Bouma sequences (BCDE) and (CDE) as well as complete Bouma sequence (ABCDE) were described by Castro and Medeiros (1980, p. 71).

Therefore, for Santa Catarina State and parts of Parana State (Cross sections BB' and CC'), the sandstones from the equivalent Rio Ivai Member are interpreted as turbidites deposited in a marine environment (Castro 1980); and Castro and Medeiros, 1980).

Note in cross section BB' (Fig. 11) that sandstones from the Rio Ivai Member are confined by marine shales, but laterally towards the northwest, sandstones are thicker and are bounded by siltstones and pebbly mudstones (Figs. 10 and 13). This may have been caused by shallower water in the basin to the north-northwest.

Sedimentation in the shallow parts of the basin in Sao Paulo State is probably dominated by deltas, and minor turbidites as proposed by Fulfaro et al (1984, p. 715). In this part of the basin, several pebbly mudstones and pebbly sandstones were interpreted in the past as tillites and local names were given such as "Jumirim Tillite" (about 20m thick), "Pitanga Tillite" (about 5m thick) among others. Recent research has shown that most of these tillites are actually turbidity gravitational flows of delta front deposits (Fulfaro et al 1984, p. 715). Storm deposits (Walker, 1984b, p.141) are another possibility in a shallow marine environment such as is proposed for the northern part of the basin.

The highest part of the upper cycle (Fig. 32) has two major lithologies - shales from the Rio do Sul Member and pebbly mudstones from the Chapeu do Sol Member. Thin sandstones beds are present in both members.

A marine environment is widely accepted for the shales and sandstones from the Rio do Sul Member (e.g. Schneider et al 1974, p. 49; Castro, 1980, p. 294); Castro and Medeiros, 1980, p. 70; and Rosler, 1985, p. 17). This interpretation is based on the presence of fossils such as brachiopods, pelecypods, foraminifers, and crinoids (Schneider et al 1974, p. 49), tasmanites (Castro, 1980, p. 284), and Orbiculoidea (Rosler, 1985, p. 17). Pebbles present in the laminated shales (Fig.

25), have been interpreted as dropstones from floating icebergs (Schneider et al, 1974, p. 49).

On the other hand, the Chapeu do Sol Member that interfingers with the Rio do Sul Member (Fig. 11) is composed of massive, structureless pebbly mudstones, as much as 200m thick (Fig. 25) interbedded with a few sandstones. These sandstones become thicker in wells located near the outcrop belt in Sao Paulo State, such as in 1-PA-1-SP and 2-AB-1-SP (Fig. 13). In contrast to the Rio do Sul Member, no macrofossils have been found so far in the Chapeu do Sol Member. However, marine organic matter (amorphous - type I) is present in some wells, such as in 2-RP-1-PR (3009-3051m), and in 2-CS-1-PR (2485-2655m), according to Oliveira and Neto (1984, p. 53).

Gravenor and Rocha-Campos (1983, p. 34) suggested that thick, massive, structureless diamictites such as the pebbly mudstones describe above were deposited from the base of glaciers in subaquatic environments. Sandstones interbedded in the pebbly mudstones can be outwash deposits (Shaw, 1985, Fig. 2-39), or even fossil eskers. Frakes et al (1968, p. 9) have described possible fossil eskers in the Itarare Group in outcrops of Sao Paulo State. Resedimented facies such as debris flow and turbidites (Eyles and Miall, 1984, Fig. 8), are generally present in subaquatic glaciers and in this case it will be difficult to distinguish between three possible types of pebbly mudstones. Pebbly mudstones deposited directly by glaciers (tillites), pebbly mudstones deposited indirectly by glaciers and resedimented pebbly mudstones.

Figure 33 is a composite thickness map of pebbly mudstones, shales, and sandstones from the highest part of the upper genetic unit

Fig. 33 Composite map of thickness of pebbly mudstones in the Chapeu do Sol Member and percentage of shales in the Rio do Sul Member.

The Chapeu do Sol and Rio do Sul members interfingers each other and comprise the uppermost unit of the Itarare Group (Fig. 11). This figure shows a relative deep marine environment in southeastern part of the Parana Basin, where marine shales and turbidites were deposited (Rio do Sul Member). To the north and northwest the basin was shallower and pebbly mudstones deposited from marine glaciers and deltaic sandstones predominate (Chapeu do Sol Member).

Icebergs derived from the main glaciers are probable sources for the dropstones commonly found in the shales of the Rio do Sul Member.

The arrows represent mean vector direction of paleocurrents (36 measurements near Sao Paulo City and 70 measurements in Santa Catarina State).

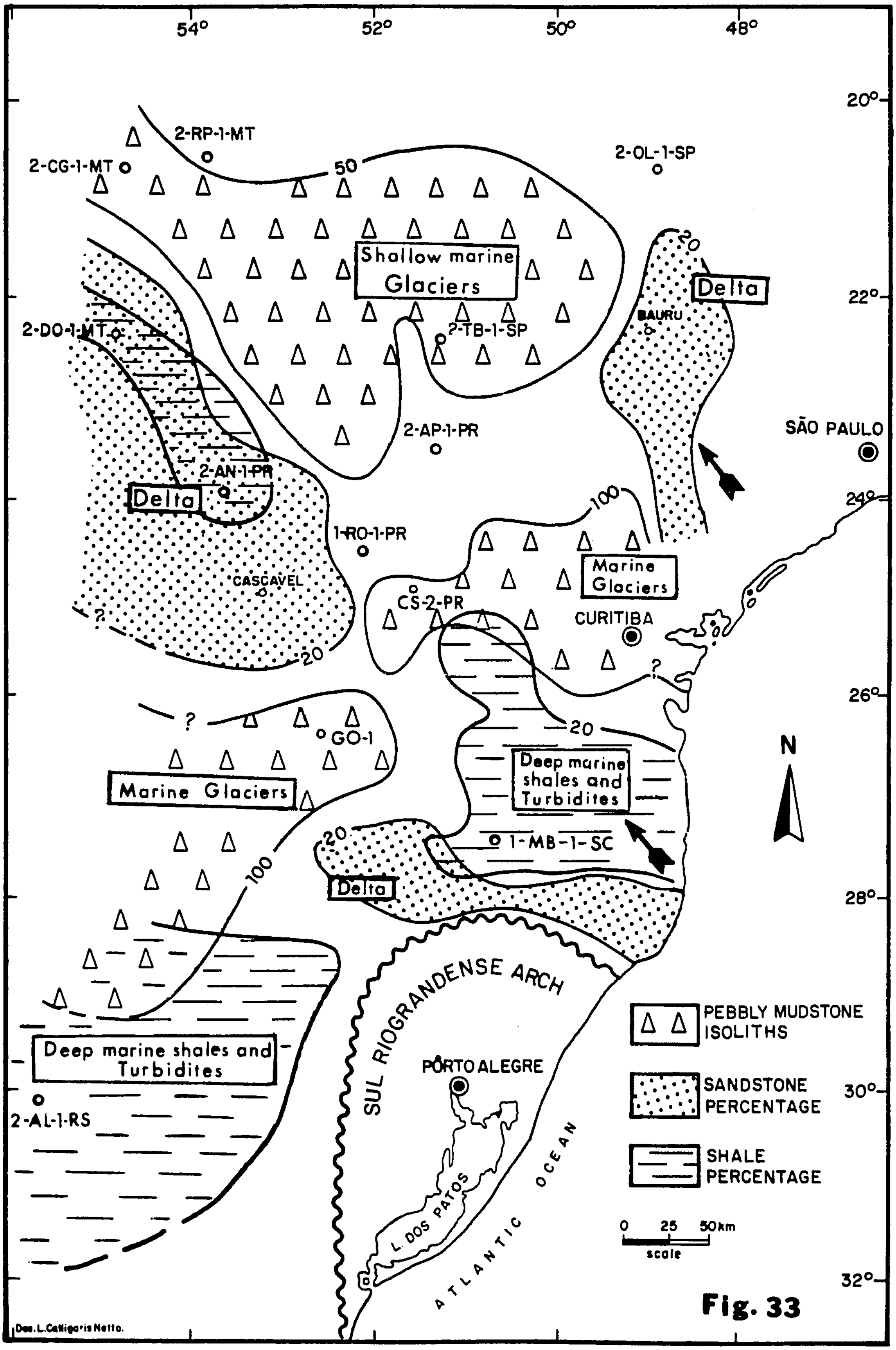

54°
52°
50°
48°
20°
22°
24°
26°
28°
30°
32°
2-RP-1-MT
2-CG-1-MT
50
2-OL-1-SP
20
Shallow marine Glaciers
Delta
BAURU
2-DO-1-MT
2-TB-1-SP
2-AP-1-PR
SÃO PAULO
2-AN-1-PR
Delta
100
1-RO-1-PR
Marine Glaciers
CASCAVEL
CS-2-PR
CURITIBA
20
?
GO-1
20
N
Marine Glaciers
Deep marine shales and Turbidites
1-MB-1-SC
100
Delta
SUL RIOGRANDENSE ARCH
PEBBLY MUDSTONE ISOLITHS
Deep marine shales and Turbidites
PORTO ALEGRE
SANDSTONE PERCENTAGE
2-AL-1-RS
SHALE PERCENTAGE
ATLANTIC OCEAN
L. DOS PATOS
0 25 50km
scale
Des. L. Caligoris Netto.

Fig. 33

(Chapeu do Sol and Rio do Sul members). The composite map suggests that the southeastern part of the basin was probably deep marine where shales with dropstones and probably deltaic sandstones predominate. Based on the distribution of shale thickness, the transgression was probably from the south and east, bordering the Sulriograndense Arch. To the north and northwest, where the basin was shallower, glaciers existed and it appears that they had three major input directions, one from the east and probably related to the Kaokoveld Lobe (Fig. 2) and two from the west, possibly linked to glaciation from the Assuncion Arch (Fig.2).

Furthermore the composite map helps to explain the interfingering between fossiliferous, laminated shale containing dropstones in the Rio do Sul Member with unfossiliferous massive structureless pebbly mudstones deposited from glaciers in the Chapeu do Sol Member.

In summary, the depositional environment proposed for the upper depositional cycle is predominantly deep marine in Santa Catarina State, Rio Grande do Sul State and parts of Parana State where turbidites deposited thick sandstone (Rio Ivai Member). However, a relatively shallow basin with deltaic sandstones and minor turbidites seems to have predominate in the northwest part of the Parana Basin, especially in Sao Paulo State. The pebbly mudstones from the Chapeu do Sol Member were probably deposited by marine glaciers. Subaqueous outwash, debris flow, turbidites, and possibly even eskers (Frakes et al 1968) may have deposited the sandstones interbedded with massive pebbly mudstones.

Crowell and Frakes (1975, Figs. 22.3 and 22.4), using outcrop information from Africa and South America, inferred a pattern of ice movement in the Gondwana, during the deposition of the Itarare Group (Fig. 2). How does the subsurface thickness distribution of pebbly mudstone in the Brazilian portion of the Parana Basin fit this proposed pattern of ice movement?

To answer this question two maps were constructed, total thickness of pebbly mudstones in the Itarare Group (Fig. 34) and pebbly mudstones percentage in the Itarare Group (Fig. 35). Both show that the pebbly mudstones of the Parana Basin had three major sources:

1 An eastern source region which was an important source for Sao Paulo and Parana states, and probably linked to the Kaokoveld lobe (Fig. 2) of Crowell and Frakes (1975).

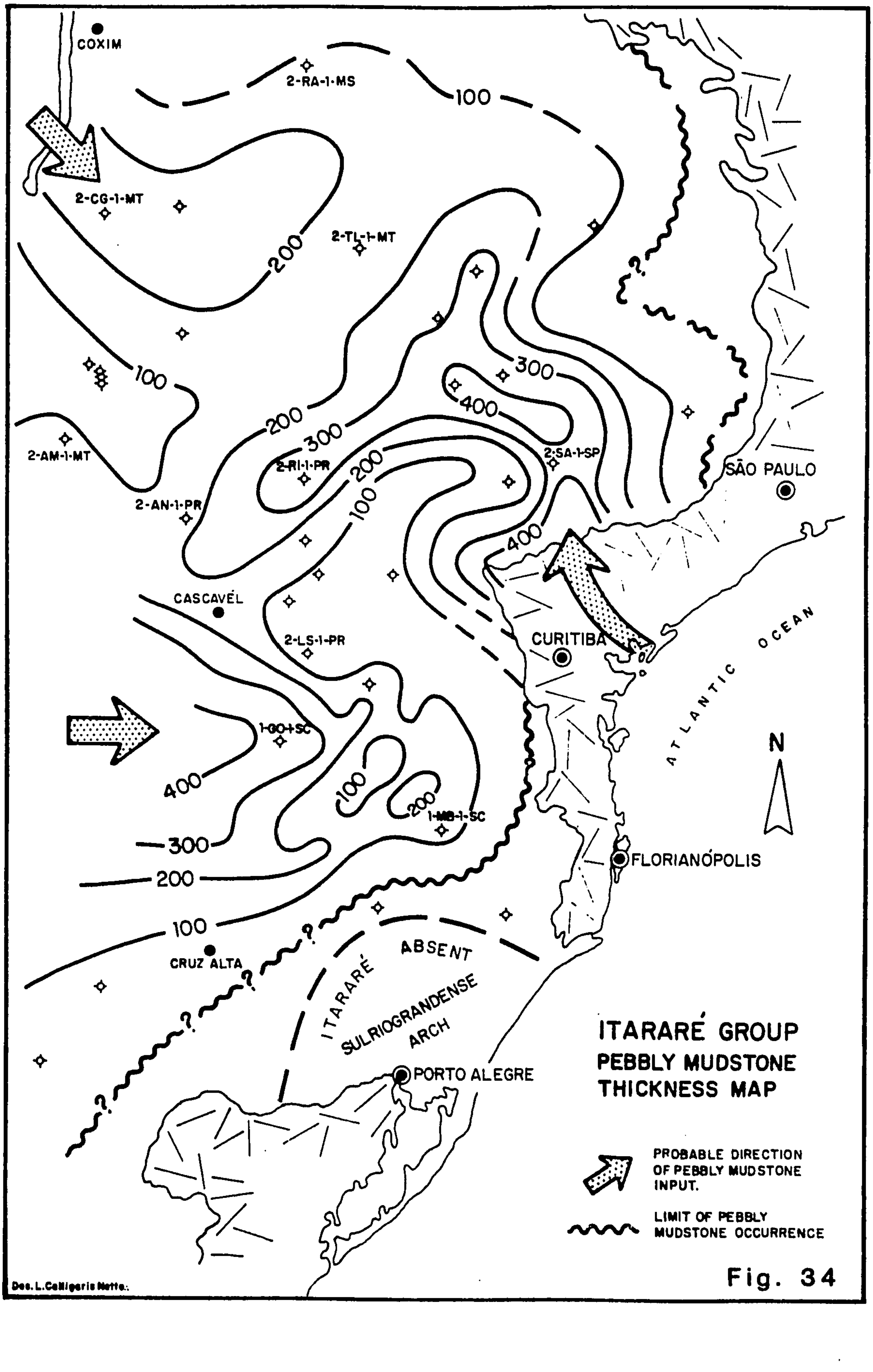
2 A southwestern source region that covers must of Santa Catarina State and parts of Parana and Rio Grande do Sul states. This region which is herein called the Santa Catarina Lobe (Fig. 36), is probably associated with the glaciation of the Assuncion Arch.

3 A northwest source region in Mato Grosso do Sul, here called the Mato Grosso Lobe (Fig. 36), is probably also linked to the glaciation in the Assuncion Arch as well.

Thus the directions of ice movements proposed by Crowell and Frakes (1975, p. 321 and 323), based on outcrop studies in South America and Africa, are broadly corroborated with subsurface maps of thickness and percentage distribution of pebbly mudstone in the Parana Basin. One modification, however is necessary for what they termed the "Parana Lobe" (Fig. 2). Recent wells drilled in western Santa Catarina and

Fig. 34 Isolith map of pebbly mudstones in the Itarare Group.

It is important to note three major input direction of pebbly mudstones. The eastern source is probably associated to the Kaokoveld Lobe from Africa (Fig. 36). The two western sources were identified in this work, using data from new wells drilled in the western side of the Parana Basin. These two western sources were probably linked to glaciation in the Assuncion Arch.

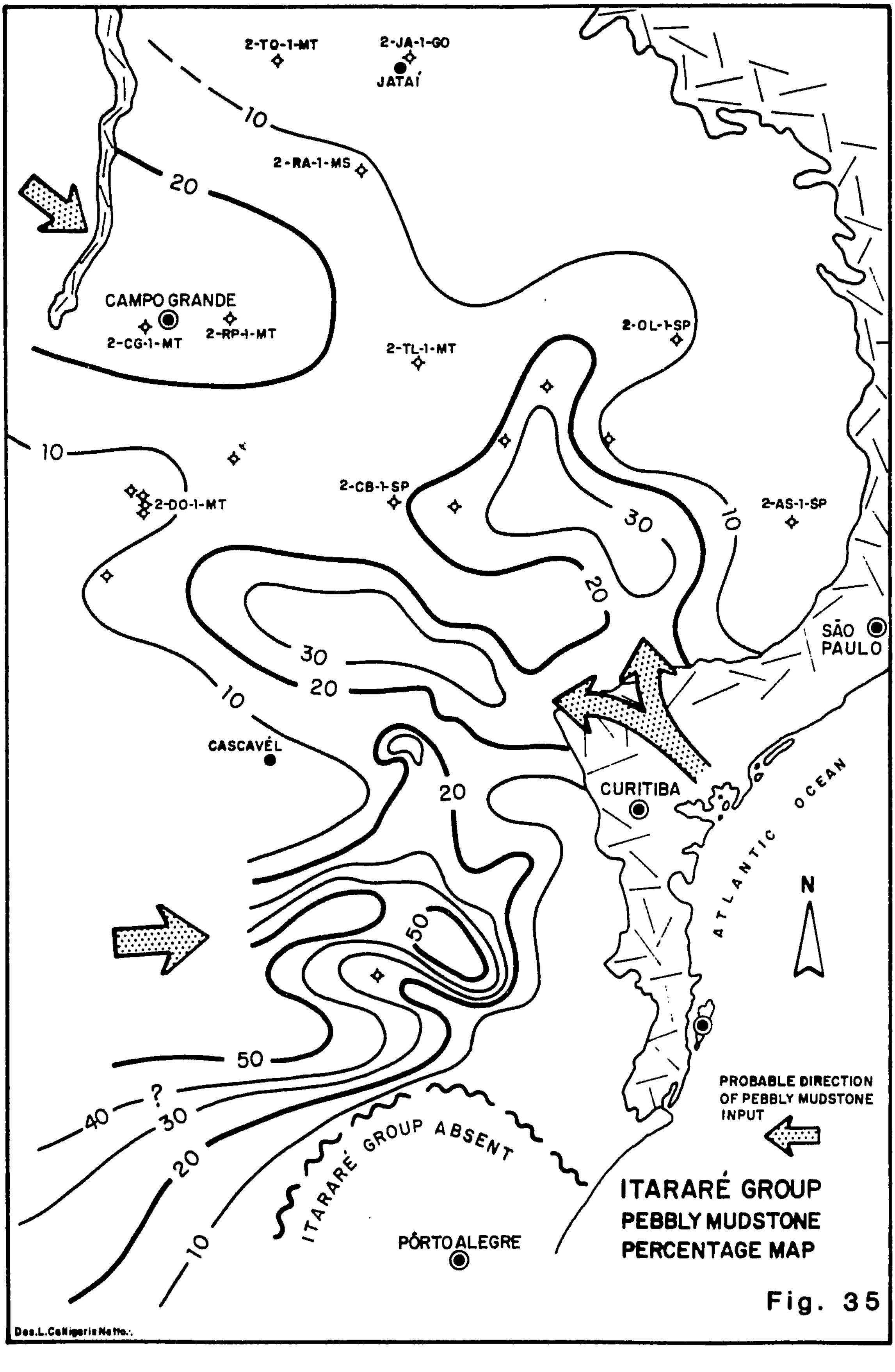


COXIM
2-RA-1-MS
100
2-CG-1-MT
2-TL-1-MT
200
300
400
2-AM-1-MT
2-AN-1-PR
2-RI-1-PR
2-SA-1-SP
SÃO PAULO
CASCAVÉL
CURITIBA
2-LS-1-PR
1-GO-1-SC
1-MB-1-SC
FLORIANÓPOLIS
ATLANTIC OCEAN
N
CRUZ ALTA
ITARARÉ ABSENT
SULRIOGRANDENSE ARCH
PORTO ALEGRE
ITARARÉ GROUP
PEBBLY MUDSTONE
THICKNESS MAP
PROBABLE DIRECTION OF PEBBLY MUDSTONE INPUT.
LIMIT OF PEBBLY MUDSTONE OCCURRENCE
Des. L. Calligaris Netto.

Fig. 34

Fig. 35 Percentage map of pebbly mudstones in the Itarare Group.

The distribution of the isopercentage contours of pebbly mudstones confirms the presence of the two new western source areas proposed in the isolith map (Fig. 34). the two new western lobes were called the Santa Catarina Lobe (southern lobe), and Mato Grosso Lobe (northern lobe), as shown in Figure 36.



2-TQ-1-MT
2-JA-1-GO
JATAÍ
10
2-RA-1-MS
20
CAMPO GRANDE
2-CG-1-MT
2-RP-1-MT
2-TL-1-MT
2-OL-1-SP
10
2-DO-1-MT
2-CB-1-SP
30
10
2-AS-1-SP
20
SÃO PAULO
30
20
10
CASCAVÉL
CURITIBA
20
ATLANTIC OCEAN
N
50
50
?
40
30
20
10
ITARARÉ GROUP ABSENT
PÔRTO ALEGRE
PROBABLE DIRECTION OF PEBBLY MUDSTONE INPUT
ITARARÉ GROUP
PEBBLY MUDSTONE
PERCENTAGE MAP
Fig. 35
Des.L.Calligaris Netto.

Fig. 36 Late Paleozoic Glaciations in South America and Africa.

The Santa Catarina Lobe and Mato Grosso Lobe are new propositions based on subsurface data (isopach and percentage maps of pebbly mudstones in the Itarare Group). After Crowell and Frakes (1975, pgs. 321 and 323).

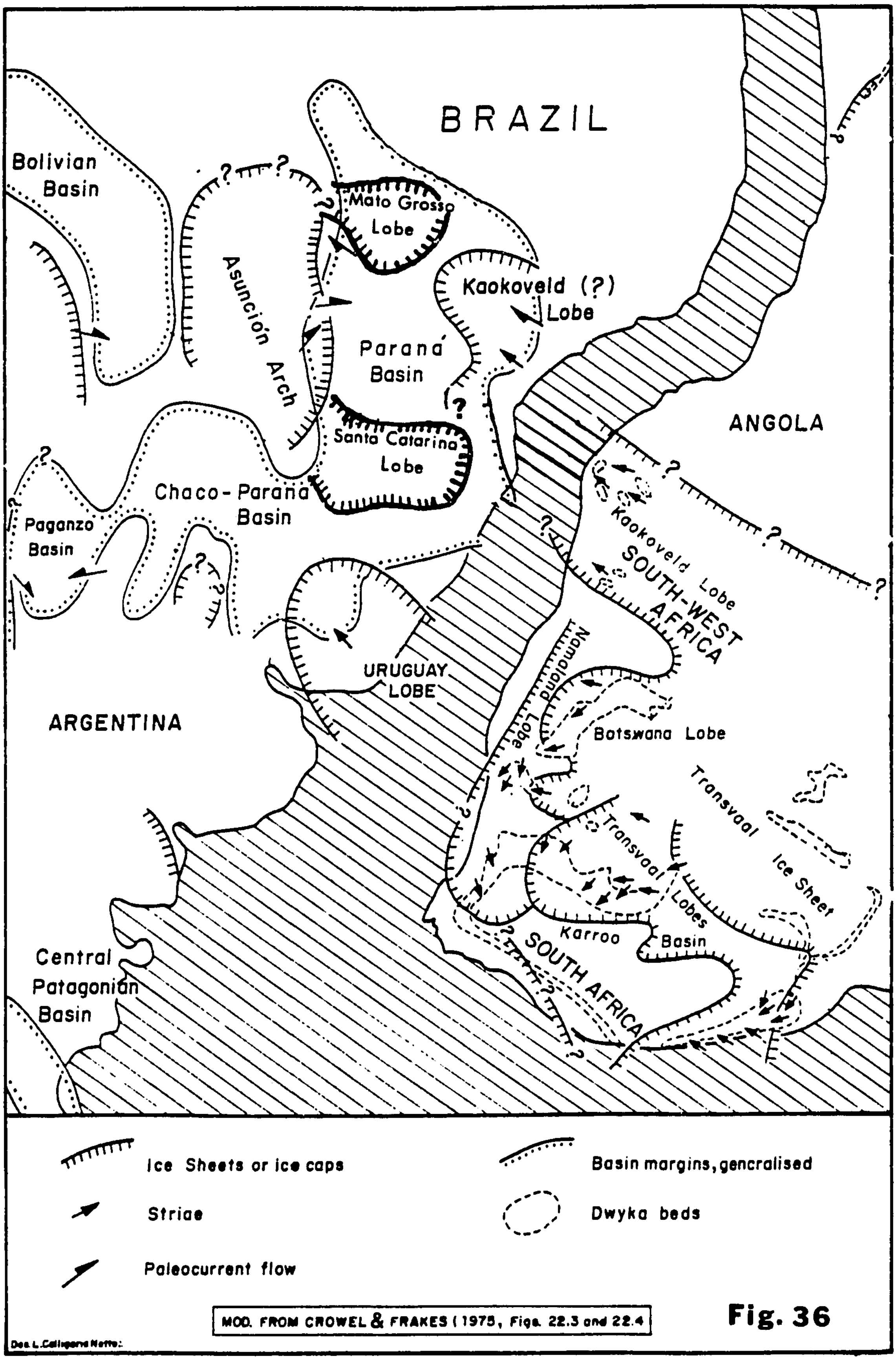

BRAZIL
Bolivian Basin
Mato Grosso Lobe
Asunción Arch
Kaokoveld (?) Lobe
Paraná Basin
Santa Catarina Lobe
Chaco-Paraná Basin
Paganzo Basin
ANGOLA
Kaokoveld Lobe
SOUTH-WEST AFRICA
Namaland Lobe
URUGUAY LOBE
ARGENTINA
Botswana Lobe
Transvaal Ice Sheet
Transvaal Lobes
Karroo Basin
SOUTH AFRICA
Central Patagonian Basin
Ice Sheets or ice caps
Basin margins, generalised
Striae
Dwyka beds
Paleocurrent flow
MOD. FROM CROWEL & FRAKES (1975, Figs. 22.3 and 22.4

Fig. 36

Parana states, show that thickness of pebbly mudstones increase westwards suggesting a better relationship with the glaciation in the Assuncion Arch, rather than with ice coming from Africa.

Based on both subsurface and outcrop data, advances of ice sheets into the Parana Basin during the Permo-Carboniferous are summarized in Figure 36. Economically, the pebbly mudstones of the Itarare Group are important because they may be seal for the good reservoirs generally present underneath. The seal potential will be seen later with more detail, whereas the reservoir qualities of the sandstones are discussed next.

PETROGRAPHY AND RESERVOIR ANALYSIS

Petrographic Descriptions. Very little is known about the petrography of the sandstones and pebbly mudstones of the Itarare Group; this is a subject with much work still to be done. Previous information from outcrop areas (Rocha-Campos, 1967, Fig. 6) showed that the clasts in the pebbly mudstones (diamictites) are predominantly composed of quartzite, sandstone, granite, and gneiss. Sandstones interbedded with the pebbly mudstones are predominantly feldspathic with abundant clay matrix. Heavy minerals are common and garnets are the most abundant, followed by zircon, apatite, tourmaline, epidote, rutile, and corundum (Rocha-Campos, 1967, p. 48).

During the exploration carried out by Paulipetro in the Parana Basin from 1980 to 1983, several cores were taken in the Itarare Group, especially from sandstones. Some of these cores were selected for detailed petrographic studies, including permeability measurements. Results of these studies are filed in unpublished internal reports at IPT (Caixa Postal 7141, Sao Paulo - SP, Brazil).

Franca (1984) provides the only published paper concerning reservoir analysis of the Itarare Group and discusses the development of secondary porosity and cementation of its sandstones.

The present work places emphasis on determining the sandstone type and diagenesis, including cement stratigraphy and porosity types. All sandstone samples were impregnated with blue epoxy to identify porosity and permeability, and stained for calcite and potassium feldspars. Later, additional samples were stained with potassium ferrocyanide to determine the presence of iron-rich carbonates. A total of ninety-five thin sections were analyzed and 70 of them selected for

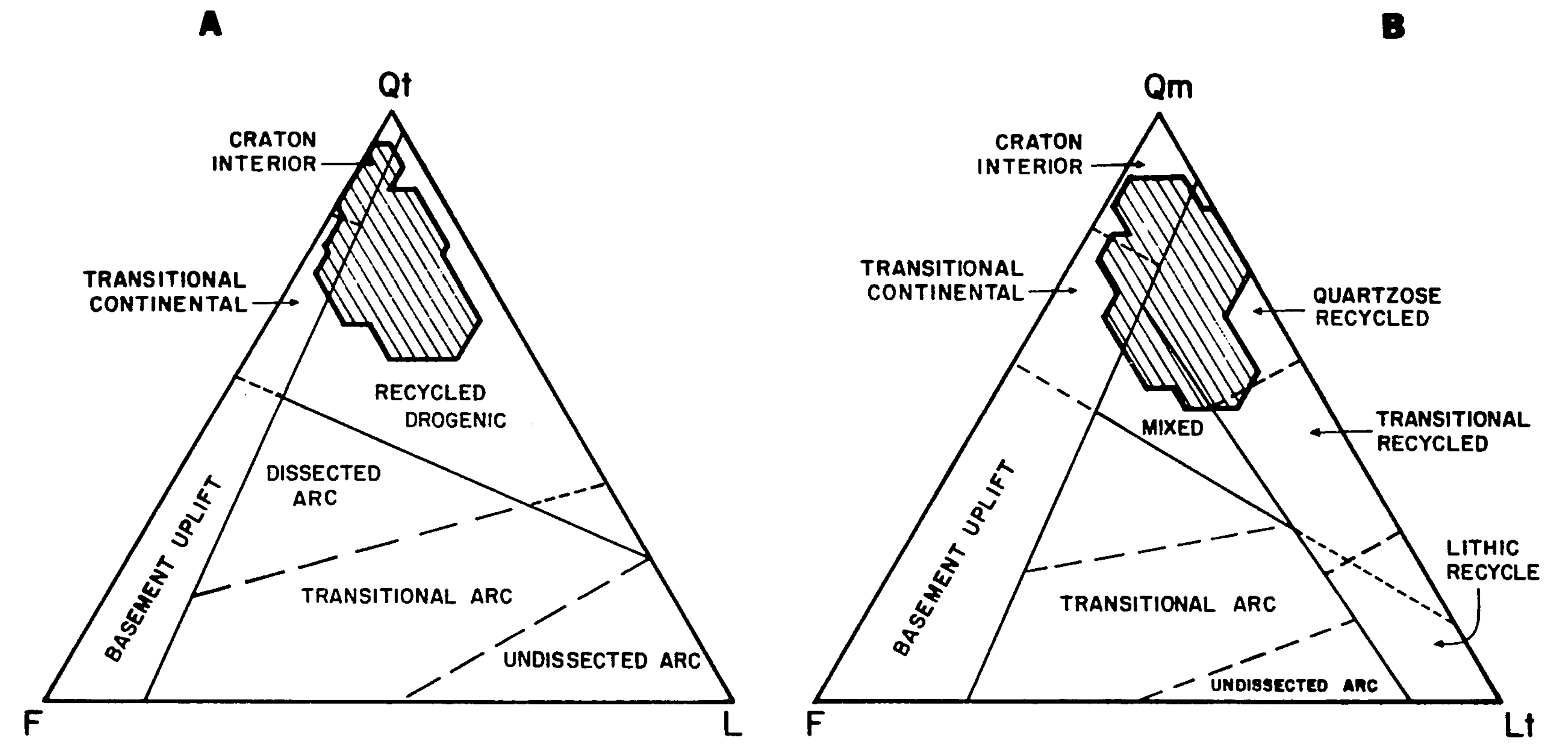
200-point counts. Each thin section was counted for monocrystalline quartz, polycrystalline quartz, plagioclase, potassium feldspar, rock fragments, matrix, porosity, and cement. A total of 14000 points were counted. Twenty-two samples with more than 5 percent of rock fragments were point counted (100 points) for volcanic, sandstone, siltstone, shale, granite, and metamorphic fragments. Finally, forty-five samples were selected for 100-point counts for porosity, matrix and cement (Appendex 3).

Provenance. Dickinson et al (1983, p. 223) proposed the use of two ternary diagrams to determine sandstone provenance, based on quantitative detrital modes calculated from point counts of thin sections. These two triangular diagrams were used to plot the result of point counts from the Itarare Group (Fig. 37). Figure 37A shows that the Itarare Group samples plot mostly in the recycled orogenic field, with some in craton interior and transitional continental fields. Figure 37B suggests that the most important source area was related to a quartzose recycled provenance. Craton interior, transitional continental and mixed sources were secondary provenances.

Several factors, such as the depositional environment, relief, climate, transport mechanism, and diagenesis, may play an important role in the final composition of sandstones. In sandstones from the Itarare Group, the presence of secondary porosity is a common feature. Most of this secondary porosity, as will be seen later, is due to the dissolution of cement. However, feldspars and lithics have also experienced dissolution. How many lithic and feldspars fragments have been dissolved is almost impossible to determine. However, in sandstones with a high matrix content, secondary porosity is poorly developed or

Fig. 37 Plots of sandstones from the Itarare Group in the QFL diagrams of Dickinson et al (1983, p. 223).

Dashed areas are the composite confidence limit (one standard deviation) of all four stratigraphic units of the Itarare Group. Seventy thin sections were described (200-point counts each).



Qt = Qm + Qp

F = FELDSPARS (POTASSIC + PLAGIOCLASE)

L = TOTAL UNSTABLE LITHIC FRAGMENTS

Qm = QUARTZ MONOCRYSTALINE

F = FELDSPARS (POTASSIC + PLAGIOCLASE)

Lt = UNSTABLE LITHIC FRAGMENTS + QUARTZ POLYCRYSTALINE

QFL Diagrams of Dickinson et al (1983, Fig. 1)

Fig. 37

Des. L. Calligaris Netto.

may even be absent. In these sandstones later leaching had very little or no influence on the final composition of sandstones.

Sandstone Types. The classification proposed by Dott (1964, p.629) is adopted here (Fig. 38) to classify sandstone types observed in the Itarare Group. Dott's classification has the advantage of using the amount of fine matrix (particles smaller than 30 microns), as a basic factor in sandstone classification. This is especially useful for petroleum geologists who are mostly concerned with the reservoir properties of the sandstones. Determining the amount of matrix is the first step in the analysis of reservoir qualities, not only in sandstones but also in carbonates.

Figure 38 shows that sandstones from the Rio Ivai Member, the uppermost unit of the Itarare Group, have the least matrix (only one percent); whereas, sandstones from the Cuiaba Paulista Member, which is the lowermost unit in the Itarare Group, have the most, averaging 41 percent. Sandstones of the Rio Ivai Member are classified as **arenites** (feldspathic arenites and lithic arenites). Whereas, most of the sandstones from the Cuiaba Paulista Member are **wackes** (feldspathic wackes and lithic wackes)

Sandstones from the Tarabai Member plot in the arenite field and are somewhat distinct from the other three units, because of their relatively high compositional maturity. Most are **quartz arenites** but a few are **feldspathic arenites.**

Sandstones from the Campo Mourao Formation, which is the thickest formation in the Itarare Group, are classified as **wackes,** average 11 percent matrix and are close to the arenite realm.

Fig. 38 Petrographic classification of the Itarare Group sandstones using Dott's (1964) classification.

Sandstones from both the Rio Ivai Member (1 percent matrix average), and the Tarabai Member (7 percent matrix average) are classified as **Arenites.** Sandstones from the Cuiaba Paulista Member (45 percent matrix average) are classified as **Wackes.** Sandstones from the Campo Mourao Formation (11 percent matrix average) are **Wackes**; however, near the arenites realm.

Dashed areas are the confidence limit (one standard deviation) for each stratigraphic unit of the Itarare Group.

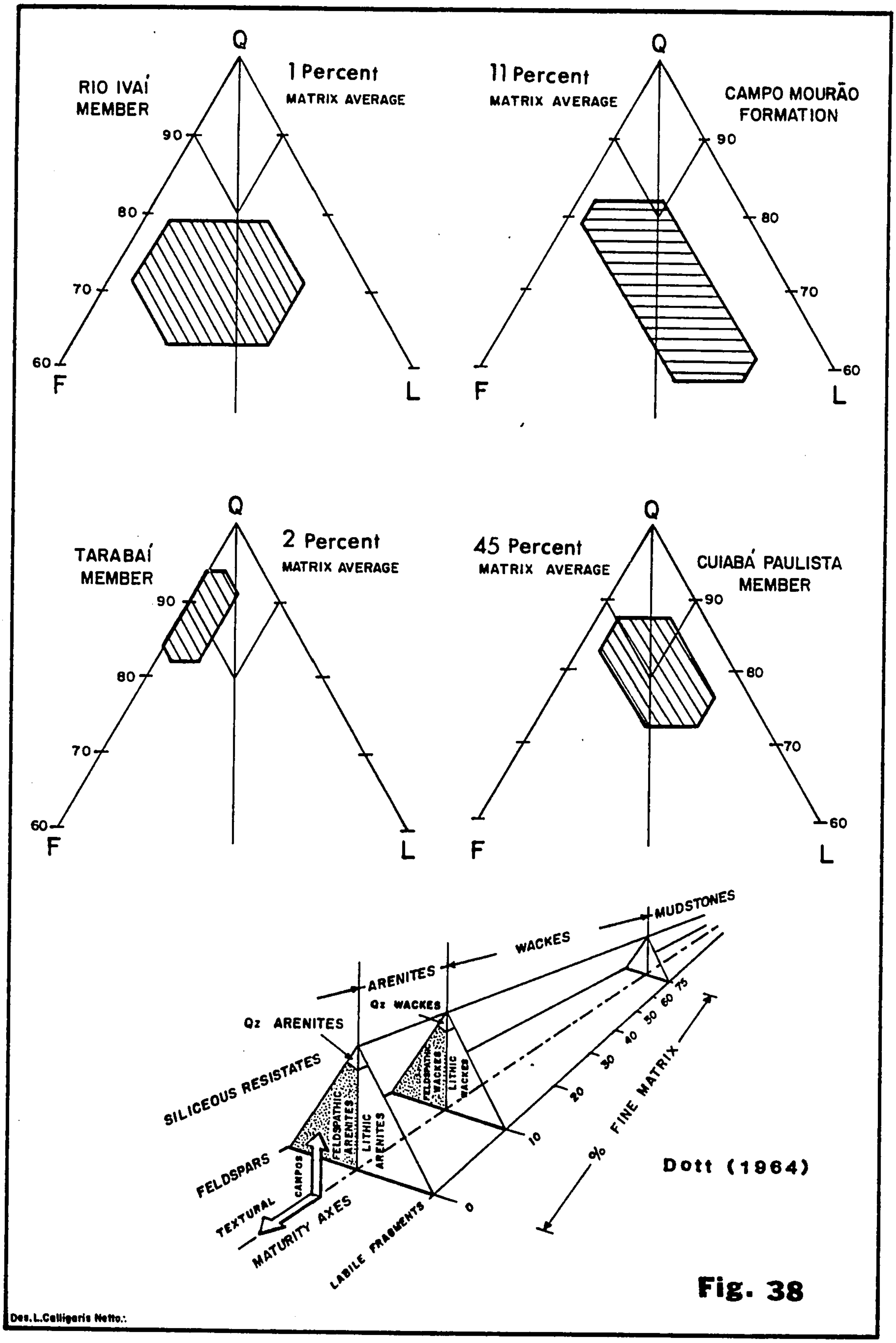

Q
RIO IVAÍ MEMBER
1 Percent
MATRIX AVERAGE
90
80
70
60
F
L
Q
11 Percent
MATRIX AVERAGE
CAMPO MOURÃO FORMATION
90
80
70
60
F
L
Q
TARABAÍ MEMBER
2 Percent
MATRIX AVERAGE
90
80
70
60
F
L
Q
45 Percent
MATRIX AVERAGE
CUIABÁ PAULISTA MEMBER
90
80
70
60
F
L
MUDSTONES
WACKES
ARENITES
Qz WACKES
Qz ARENITES
SILICEOUS RESISTATES
FELDSPATHIC WACKES
LITHIC WACKES
FELDSPATHIC ARENITES
LITHIC ARENITES
FELDSPARS
CAMPOS
TEXTURAL
MATURITY AXES
LABILE FRAGMENTS
0
10
20
30
40
50
60
75
% FINE MATRIX
Dott (1964)
Des. L. Calligaris Netto.

Fig. 38

Table 3 shows the average composition of sandstones from the Itarare Group and a summarized description of predominant porosity and cement types.

Table 3

AVERAGE COMPOSITION OF SANDSTONES FROM THE ITARARE GROUP

Formations and Members	Q	F	L	MATRIX	POROSITY	CEMENT
Rio Ivai Member	60	14	11	1	8	6
					Predominantly secondary Intergranular and intraparticle	Anhydrite, Fe-dolomite, quartz, chlorite, and siderite
Campo Mourao Formation	53	11	11	11	8	6
					Predominantly secondary Intergranular, intraparticle, and fractures	Anhydrite, Fe-dolomite, quartz and feldspar overgrowths, Fe-calcite, chlorite, siderite, and kaolinite
Tarabai Member	75	8	2	2	6	7
					Predominantly secondary Itergranular and intraparticle	Anhydrite, Fe-dolomite, siderite, chlorite, and quartz
Cuiaba Paulista Member	42	6	3	45	2	2
					Predominantly secondary Intergranular and intraparticle	Quartz overgrowth, chlorite, pyrite (?), siderite, and locally anhydrite

Therefore, considering matrix content as an initial approach for reservoir analysis, the Rio Ivai Member with only one percent average matrix and the sandstones from the Tarabai Member with only 2 percent average matrix, has the best reservor potential in the Itarare Group. Whereas, the Cuiaba Paulista Member with an average matrix of 45 percent, has the lowest reservoir potential.

Matrix content, however, is not the only factor to be considered in reservoir analysis. Additional information such as effective porosity (interconection of pores), cementation (matrix-free sandstone may be completely cemented), presence of fractures (clay-rich sandstone may be a good reservoir, if fractured), and drill-stem test (in-situ measurement of the permeability), are necessary before a sound conclusion about reservoir potential can be made.

Porosity. Sand, when deposited, has initial porosity of 35 to 40 percent; however, typical reservoir sandstones have porosities ranging from 10 to 25 percent (Hayes, 1979, p. 127). Therefore, primary porosity and consequent permeability can be reduced or perhaps totally eliminated as a result of diagenesis. The process by which porosity is reduced after deposition involves many physical and chemical aspects including mineral reactions, diagenetic environment (both early and late), the flow of fluids, compaction, and precipitation of cements.

However, during later stages of diagenesis, secondary porosity can be produced by dissolution of grains or cements composed of unstable minerals, mainly carbonates and sulfates. Feldspars and some rock fragments, (e.g. volcanics) can also undergo dissolution, creating secondary porosity. Therefore, porosity can be restored, and even enhanced, at depth.

The dissolution and leaching of carbonate cement is widely attributed to the action of carbon dioxide, which in the presence of water produces carbonic acid. The carbonic acid lowers the pH, increasing the solubility of carbonates, and brings about the dissolution of calcite (Schmidt and Mcdonald, 1979a, p. 179). However, according to Surdam et al (1984, p. 142) carbonic acid can be neither the cause of dissolution of aluminosilicates nor the mobilizer agent of the aluminum, which is a product from the dissolution of feldspars. They conducted experiments using organic acids (carboxylic acids) in concentrations common in oil-field waters, under typical thermal conditions (75 to 200°C). The results show that carboxylic acid not only dissolves feldspars, but also increases significantly the mobility of aluminum, transporting it as an organic complex. Moreover, Surdam et al (1984, p. 142) concluded that the same carboxylic acid solution dissolves carbonate minerals as well.

Carboxylic acid is produced during organic matter maturation (Tissot et al 1974, p. 505; Surdam et al 1984, p. 142). The production of carboxylic acid from the thermomaturation of kerogen starts at about 75°C, and reaches a maximum concentration at about 90° (Surdam et al 1984, Fig. 19). At higher temperatures, carboxylic acids such as acetic acid are destroyed as a result of thermal decarboxylation, producing carbon dioxide and methane according to the following reaction rewritten from Surdam et al (1984, Fig. 11):

$$\underset{\text{acetic acid}}{CH_3COOH} + \text{Heat} \rightarrow CO_2 + \underset{\text{methane}}{CH_4}$$

Therefore, the initial stage of organic matter maturation produces carboxylic acid which is corrosive to feldspars and carbonate minerals. Later, the decarboxylation produces carbon dioxide, which in the presence of water, forms carbonic acid and is corrosive to carbonate minerals.

These reactions begin before hydrocarbon generation, so that porosity can be generated or enhanced early, producing conditions favorable for the migration and accumulation of oil and gas in sandstones that would normally not be considered as favorable reservoirs.

According to Surdam et al (1984, p. 146), "The ideal conditions for the development of secondary porosity are to have source rocks adjacent to the reservoir rocks and to have some primary porosity remaining". The presence of primary porosity enables fast penetration and circulation of fluids through the rocks. This may explain why secondary porosity is best developed in reservoirs that had the best primary porosity (Surdam et al 1984, p. 146).

Another possible source for CO_2 are igneous intrusives as proposed by Parker (1974, p.75), who concluded that CO_2 released from plutonic intrusives in the Gulf Coast (Mississippi Salt Basin) is responsible for the development of secondary porosity in the Smackover Sandstone (Jurassic). This is an interesting point considering the great number of sills and dikes in the Parana Basin.

Secondary porosity can be identified in thin section using the petrographic criteri presented by Schmidt and Mcdonald (1979b). According to the authors, secondary porosity appears in five major groups of pore textures.

Intergranular Pores: Intergranular pores originate from the dissolution of preexisting cement. This type of pore is easily identified if remanants of the early cement are present, otherwise it is difficult to distinguish from primary porosity. Commonly what happens is deposition of sand, followed by cementation and then leaching of the cement, creating what Feazel and Schatzinger (1985, p. 102) termed "rejuvenated" or "resurected" porosity.

Intergranular porosity is the most abundant type of porosity in the Itarare Group and is divided into: secondary, and hybrid.

Intergranular secondary porosity can be identified by the presence of early carbonate cement, for example, partially dissolved siderite is commonly observed (Pl. 1-A). Siderite will be discussed in

Plate 1

A - Siderite Cement: Example of siderite cement in partial dissolution creating secondary porosity. Note partial dissolution of the siderite (S), forming intracement porosity, and the corrosion of framework grains (arrow) by the cement. 4478m (2-CB-1-SP), Tarabai Member, Natural Light (NL).

B - Interparticle Porosity: Example of secondary porosity (P) created by the dissolution of cement, probably siderite. The presence of early cementation is suggested by the corrosion on the grains (arrows). 2294m (2-AA-1-SP), Campo Mourao Formation. NL.

C - Inhomogeneity of Packing: Example of irregular packing suggested by the fragment of shale squeezed between framework grains adjacent to relatively unpacked grains. The inhomogeneity of packing suggests secondary porosity. Large grain in the center (V)is a volcanic rock fragment. 2295m (2-AA-1-SP), Campo Mourao Formation. NL.

D - Moldic Porosity: Example of moldic pore where the feldspar (F) grains were dissolved, as indicated by remaining resistant overgrowth. 775m (2-PN-1-SP), Campo Mourao Formation. NL.

E - Intraparticle Porosity: Example of plagioclase (Pl) partially dissolved along cleavage planes. In some cases, feldspars are first replaced by calcite and then the replacive carbonate is dissolved. 2295m (2-AA-1-SP), Campo Mourao Formation. NL.

F - Oversized Porosity: Example of oversized pore (P) that was formed by the complete dissolution of early cement and or adjacent soluble grains. 2997m (2-AA-1-SP), Campo Mourao Formation. NL.

Plate 1

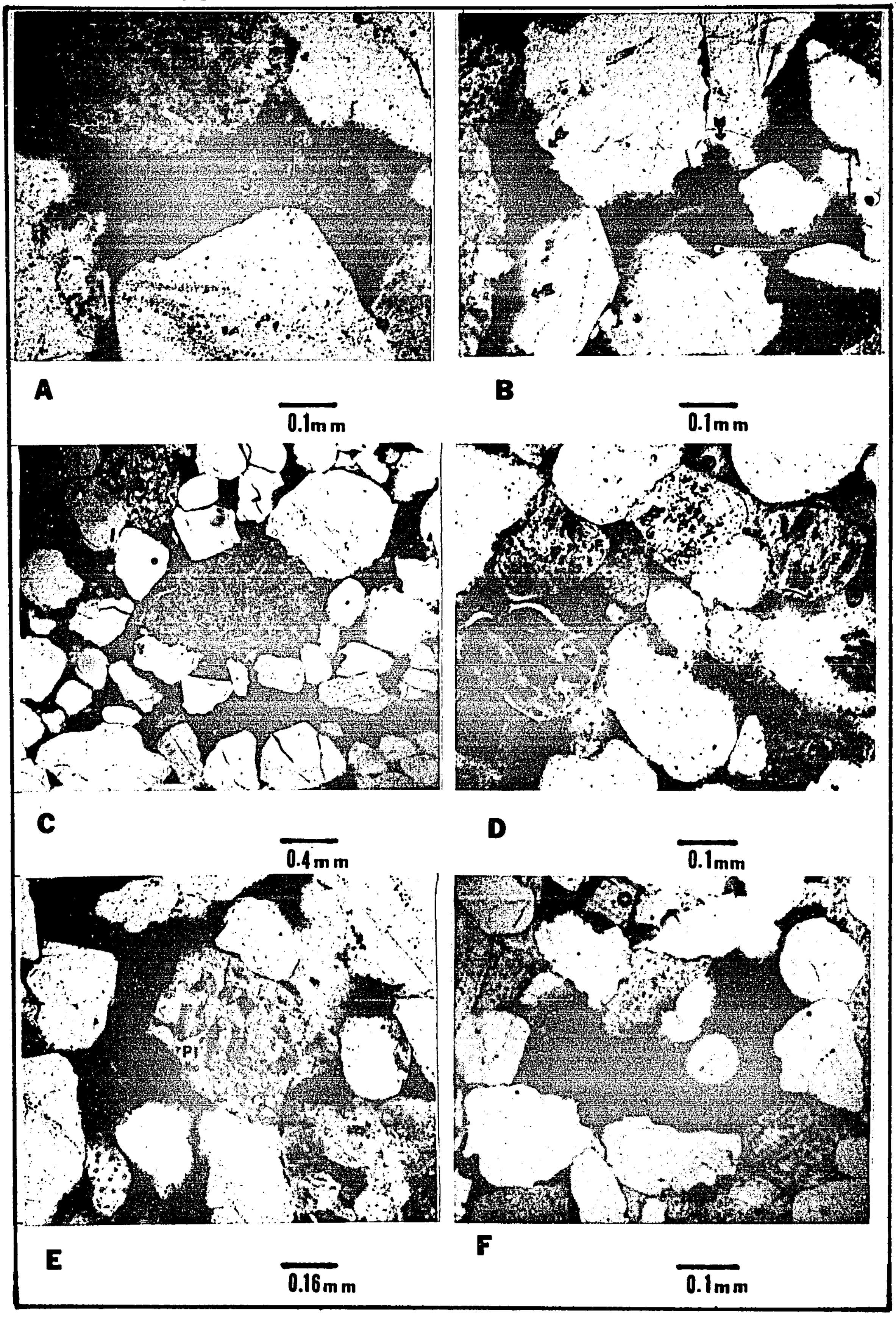
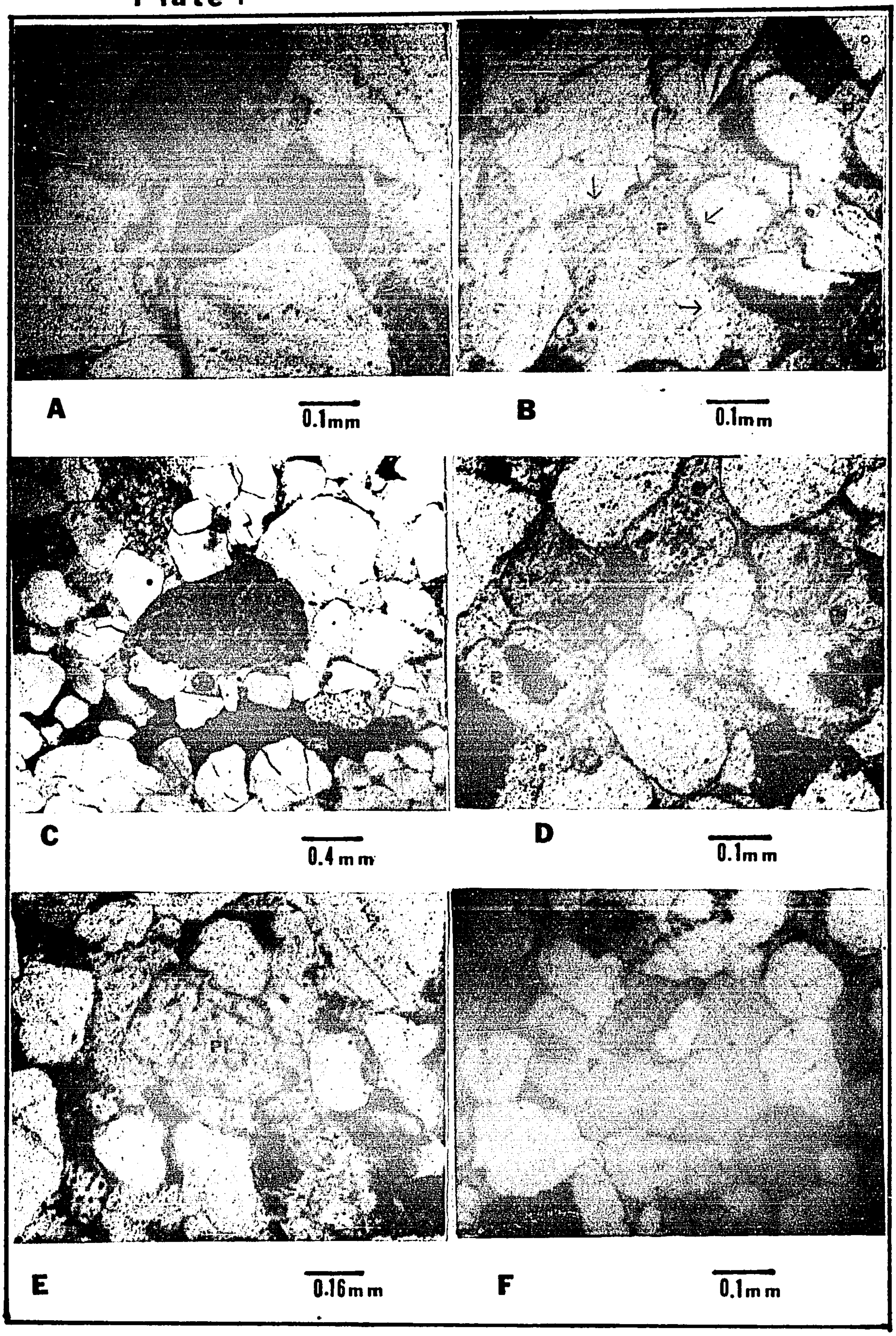


Plate 1



greater detail in a later section. Secondary porosity may also be indicated by the presence of corroded grains in contact with pore space. In cases such as this the suggested sequence of diagenesis is probably: (1) cementation (probably carbonate), (2) corrosion of the framework grains, and (3) total dissolution of the cement, leaving an enlarged, rejuvenated pore (Pl.1-B). A third type of evidence is inhomogeneity of packing - areas of loosely-packed grains and high intergranular porosity adjacent to areas of highly compacted grains (Pl.1-C). Irregular packing reflects an irregular distribution of soluble cement, which has prevented the compaction and grain interpenetration elsewhere in the thin section. Later the dissolution of the cement can generate secondary porosity between the loose grains. A "floating-grain" texture may even occur adjacent to a highly compacted area.

In the absence of evidence of dissolution, it is difficult to classify intergranular porosity; it can be primary porosity in rocks that were never cemented or it may be actually secondary porosity resulting from complete dissolution of cement. Even a combination of both primary and secondary porosity is possible. Such complex pores were termed "hybrid pores" by Schmidt and Mcdonald (1979b, p. 210).

Moldic Pores: Pores that show the outline of their precursors. The outline commonly is apparent because of the presence of either an insoluble film of coating minerals, such as illite, chlorite or hematite. In some instances the outline can be identified by the presence of a resistent overgrowth (Pl. 1-D).

Moldic porosity is present in the Itarare Group, although it is not as abundant as interganular porosity. Commonly, the precursor grain is completely leached away, leaving only the film of clay or the overgrowth that once coated the precursor grain (Pl. 1-D). However, in some grains, the precursor grain can be still identified. Feldspar grains and volcanic rock fragments are the most likely to be dissolved.

Intraconstituent Pores: Pores of this type includes all those within individual grains. They can be intragranular, intra-matrix, intra-cement, and intra-replacement (Schmidt and Mcdonald 1979b, p. 217). Intragranular porosity can be formed by either partial dissolution of the mineral, or by selective leaching of certain soluble minerals in rock fragments, such as the dissolution of plagioclase in volcanics, which may leave moldic laths within the rock fragment.

Intraconstituent pores in the Itarare Group are most common in the feldspathic and lithic sandstones in clasts of feldspars (Pl. 1-E), volcanics, and shale. Argillaceous matrix may also have micropores, which can be primary or secondary. Intraparticle porosity may have poor interconnection with the major porosity network, and may not be as effective as the intergranular porosity with respect to reservoir quality.

Oversized Pores: Oversized pores are those pores "...that exceed the diameter of adjacent grains by a factor of at least 1.2" (Schmidt and Mcdonald, 1979b, p. 213). Oversized pores generally develop because of selective dissolution of cement and adjacent grains. The percolation of carboxylic acid through a feldspathic sandstone cemented by calcite would probably form oversized pores by leaching calcite cement and those feldspar grains in contact with the calcite cement. Oversized pores, although present (Pl. 1-F), are not a common type of secondary porosity in the Itarare Group. This is probably because most of the oversized pores that may have been created were probably subsequently reduced in size by rearrangement of the framework after the dissolution. In fact, the rearrangement of the framework is one important mechanical process by which secondary porosity can be reduced in later stages of diagenesis (Schmidt and Mcdonald, 1979a, p. 190).

Open Fractures: This type of pore is formed by dissolution of material that fills fractures created in the rock or in single grains.

Open fracture porosity is the least common type of secondary porosity observed in the Itarare Group. Only one well (1-CS-2-PR) in Parana State, has porosity related to fractures. Highly fractured sandstone and diabase bodies (1m thick) were recovered from cores in this well. Porosity in the sandstone from this core seems to have developed at the expense of calcite dissolution along fractures (Pl. 2-G).

Cement. There is a great variety of cement types in the Itarare Group. Descriptions of the different types observed, and some aspects of their relative time of precipitation are presented below, from the earliest to the latest type. Details on the cement stratigraphy will be discussed later, in the diagenetic sequence.

Siderite: Although not abundant, siderite is frequently present as small brownish crystals, always showing partial dissolution. The contact between the siderite and framework grains is commonly corrosive, with cement replacing grains such as quartz and feldspar. The contacts

Plate 2

G - Open Fracture: Example of porosity created along fractures, due probably to dissolution of carbonate cement. This type of porosity was observed only in sandstone interbedded with diabase intrusions. 3113m (1-CS-2-PR). NL.

H - Poikilotopic Anhydrite: Example of poikilotopic crystal of anhydrite (A) enveloping framework grains - note the intensive corrosion in the quartz grains (arrows). 3285m (2-RI-1-PR), Campo Mourao Formation. Crossed Nicols (XN).

I - Anhydrite Cement: Example of isolated single anhydrite (A) crystal. Note the sharp and straigh contact between anhydrite and porosity (arrow). 3285m (2-RI-1-PR). Campo Mourao Formation. XN.

J - Fe-Dolomite Cement: Bluish mosaic of iron-rich dolomite (stained with potassium ferrocyanide). Besides mosaic habit, iron-rich dolomite is present also as poikilotopic crystals. 4484m (3-CB-3-SP), Campo Mourao Formation. NL.

K - Zoned Rhombs of Fe-Dolomite: Rhombs of iron-rich dolomite occurs filling pore space. Iron zonation suggests the fluctuation of different diagenetic environmental conditions during the crystal growth. 2664m (2-LA-1-SP), Campo Mourao Formation. XN.

L - Quartz Overgrowth: The overgrowth is evidenced by the straight and sharp edges of the quartz grains. There is no clay film between detrital grains and syntaxial cement. Note the intensive fracturing of the quartz grains (overgrowth apparently not affected). Fracturing may be related to glacier transportation. 2999m (1-TB-1-SP), Rio Ivai Member. XN.

Plate 2

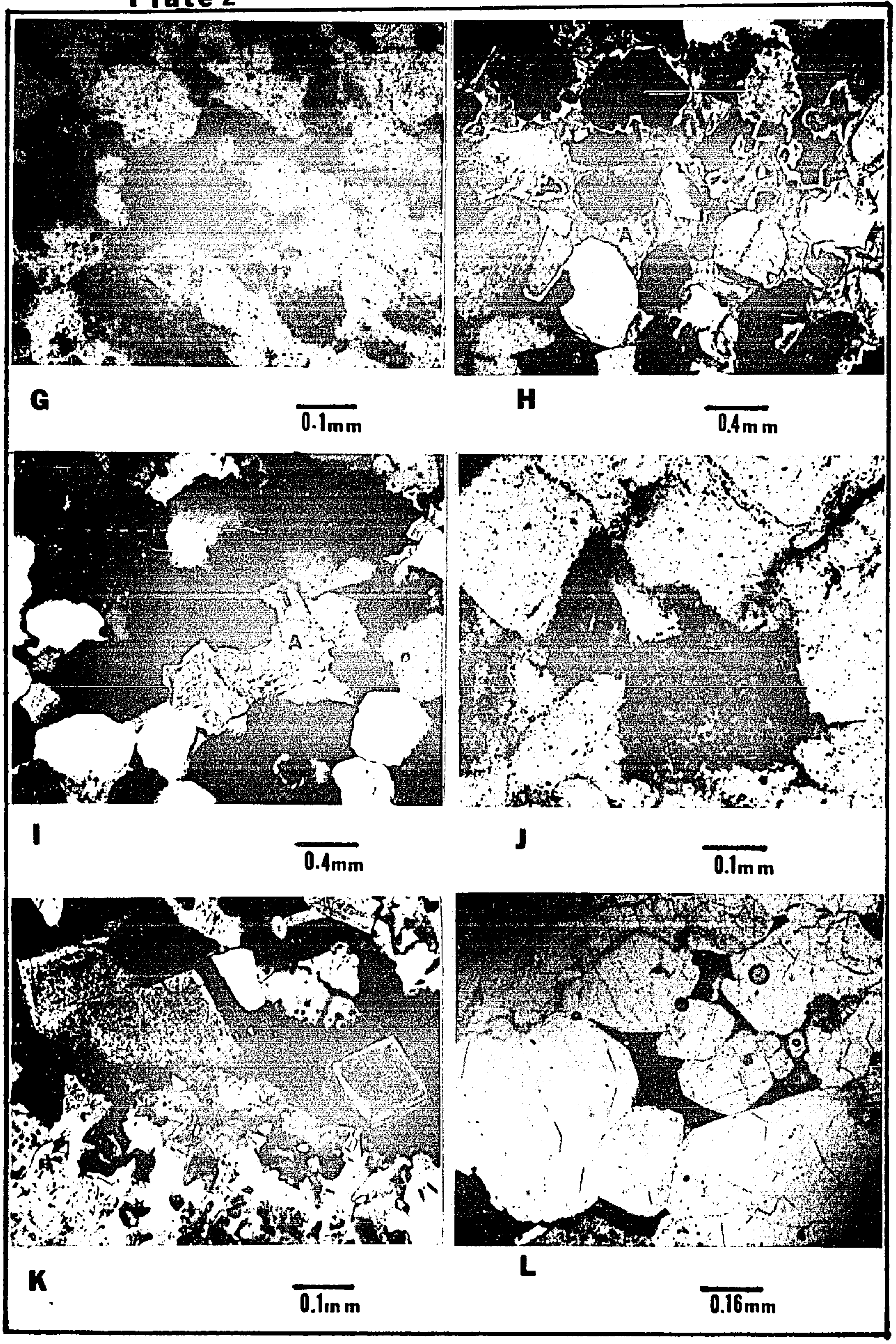
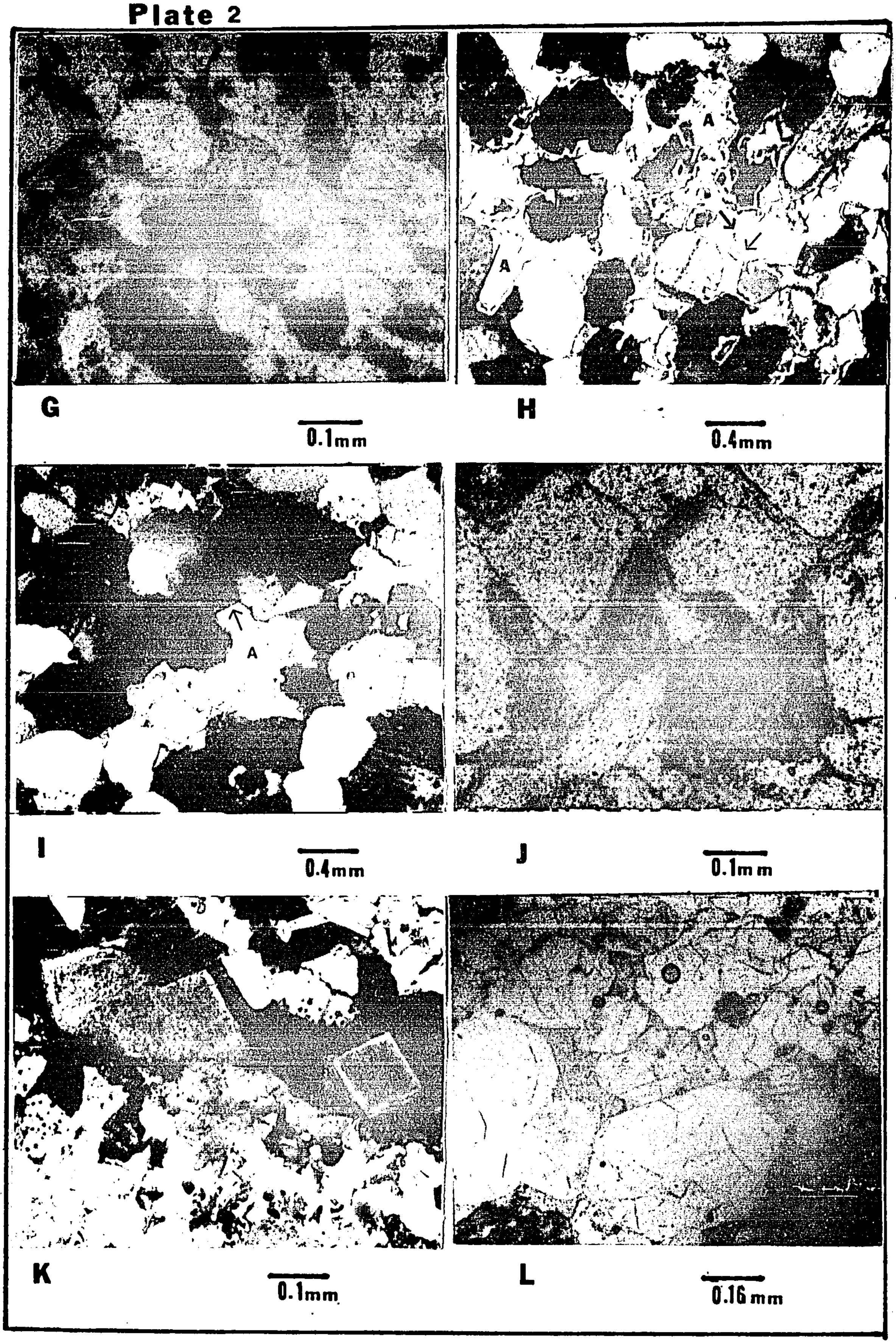


Plate 2



between siderite cement and pore space are always irregular, showing dissolution. Internal dissolution (intra-cement dissolution) is common as well (Pl. 1-A). These features are interpreted as evidence that siderite is the earliest visible cement in the thin sections studied from the Itarare Group.

Therefore, siderite although relatively rare when compared with other cements, is the most important for the development of reservoirs in the Itarare Group. Its presence early in the diagenetic sequence has held the framework grains apart during compaction. Later, because of organic acids or CO_2-rich water, siderite cement dissolved creating most of the secondary porosity present in the Itarare Group. Sandstone with good primary porosity that did not have early cementation by siderite or other soluble minerals, probably has undergone high compaction and, perhaps, explains the extensive quartz cementation.

Quartz Overgrowths: This is a fairly common cement whose abundance ranges from localized overgrowths (Pl. 2-L) to extensive quartz cementation that may cover a great part of the thin section (Pl. 3-Q). Quartz cementation was observed to be greatest in the Cuiaba Paulista Member, which is the lowermost unit of the Itarare Group. For instance, samples from 3-CB-4-SP (4466m and 4468m); 2-LA-1-SP (3822m); and 2-TI-1-SP (4473m), show extensive cementation by quartz.

One possible explanation for the high concentration of quartz cement in the deepest unit of the Itarare Group is the higher degree of compaction, which increases pressure solution and consequently release more silica, which would be reprecipitated near the dissolution zone. The relatively high stability of quartz has prevented later dissolution in this zone, consequently decreasing the presence of secondary porosity

Plate 3

M - Chlorite Cement: Example of chlorite needles around the grains and rosettes precipitated inside the pore (arrow). Chlorite needles were observed only below 4400m. (2-CB-1-SP), Tarabai Member. XN.

N - Chlorite Cement: Example of radial chlorite which occurs partially filling pore space and fractures in the 1-CS-2-PR well, Campo Mourao Formation. (3086m). NL.

O - Fe-Calcite Cement: Iron-rich calcite stains purple with potassium ferrocyanide. It is present only in the 2-AA-1-SP well, Campo Mourao Formation (2296m). NL.

P - Calcite Cement: Calcite turns reddish after staining process. Calcite occurs as large crystals filling fractures or as poikilotopic crystals in the 1-CS-2-PR, Campo Mourao Formation (3086m). NL.

Q - Quartz Cement: Example of complete loss of porosity by extensive quartz cementation. The absence of secondary porosity is probably due to the lack of early carbonate cement when the rock was subject to compaction. This type of sandstone is common in the Cuiaba Paulista Member. 4473m (2-TI-1-SP). XN.

R - Kaolinite (?) Cement: Later introduction of kaolinite (?), which precipitated preferentially in the bottom of the pore space (arrows) has created a diagenetic geopetal texture. The digenetic geopetal texture was observed only in the 2-AA-1-SP well (2300m), Campo Mourao Formation. NL.

Plate 3

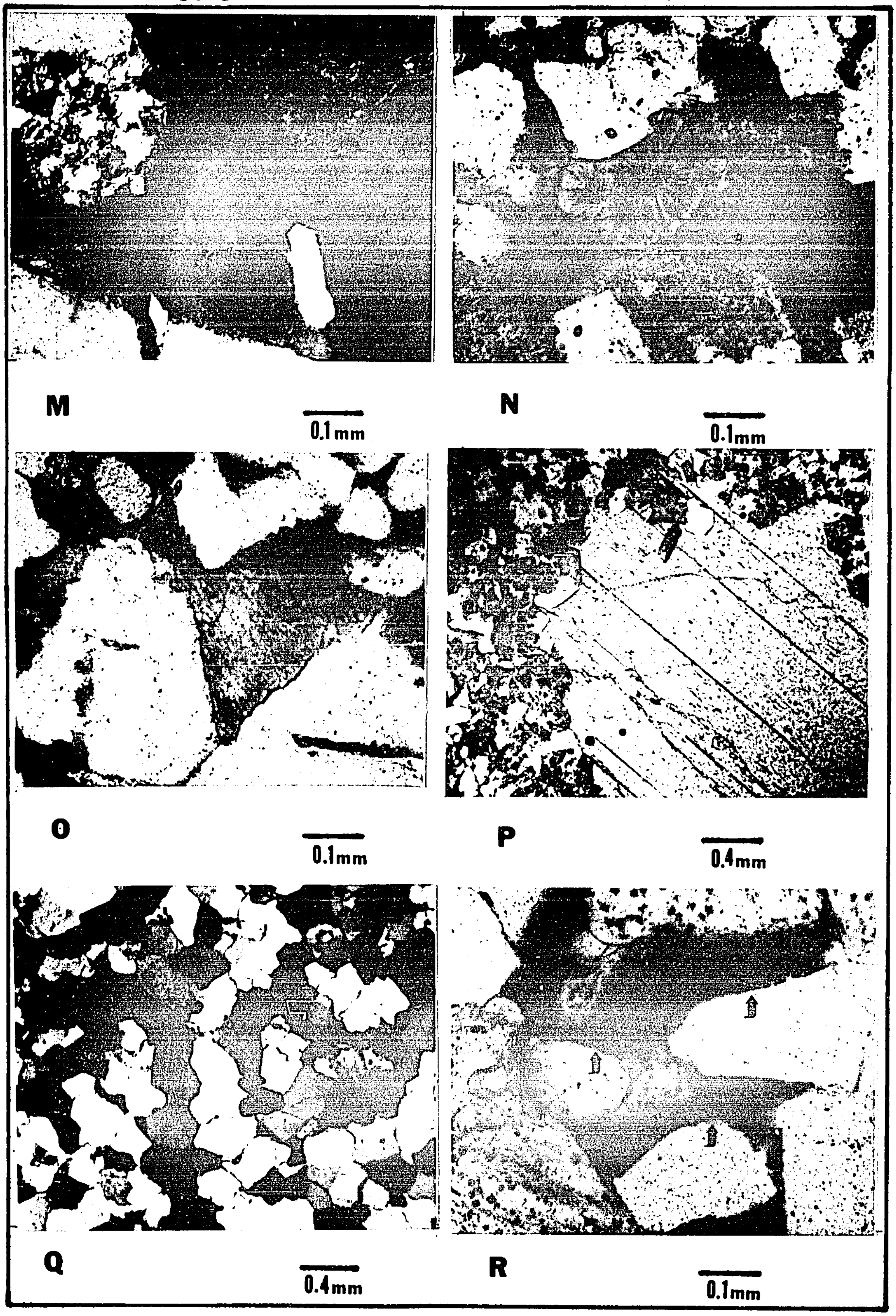
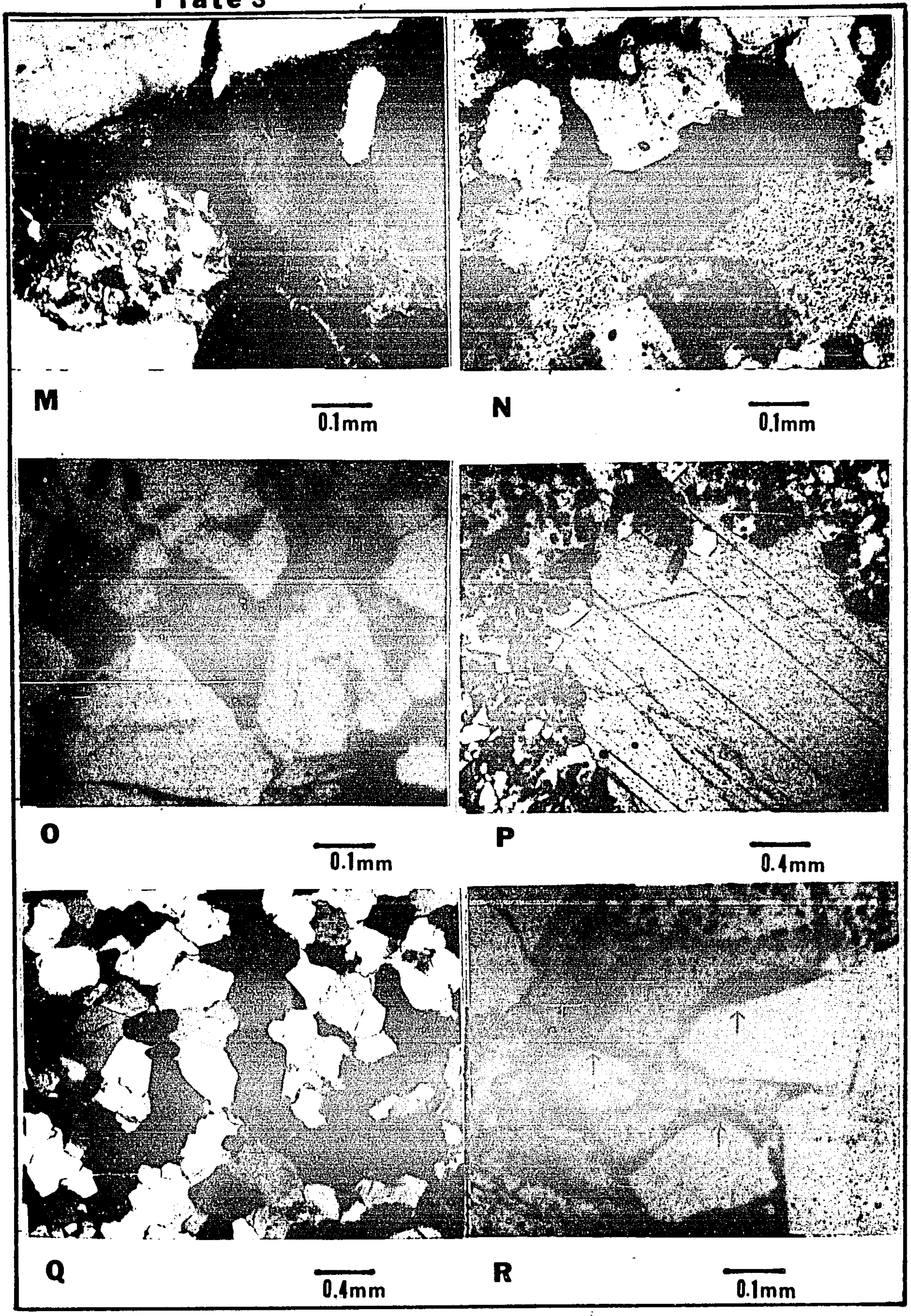


Plate 3



and thus reducing fluid circulation. This may explain the relative scarcity of other cement types in the Cuiaba Paulista Member.

Quartz overgrowths were probably formed early in the diagenesis of Itarare Group; however, in the lowermost unit it is possible that quartz cementation was continuous throughout most of the burial history of the Itarare Group.

Anhydrite: Anhydrite is the most common and abundant cement in the Itarare Group. It is present as deep as 4708m in the 2-CB-1-SP. Anhydrite commonly occurs as large poikilotopic crystals enclosing framework grains (Pl. 2-H), or as single crystals filling pores (Pl. 2-I). The contact between anhydrite cystals and framework grains may be either corrosive, showing penetration of the cement into the grains, or without corrosion. Contacts between anhydrite and carbonate cements are mostly sharp and straight, suggesting penecontemporaneous growth. The crystals edges of anhydrite in contact with pore space are also sharp and straight (Pl. 2-I), an evidence of later temporal relationship with respect to the porosity development (later cement).

Fe-dolomite: Iron-rich dolomite is also a common and abundant type of cement in the Itarare Group. The identification of Fe-dolomite is possible by staining the thin section with potassium ferrocyanide. Fe-dolomite appears blue after staining. Iron-rich dolomite is present as deep as 4547m in the 2-CB-1-SP, and it occurs mostly as large poikilotopic crystals, as isolated large rhombic crystals (either zoned or unzoned), and as a mosaic of equant crystals (Pl. 2-J). The contact of Fe-dolomite with constituent grains may be corrosive; whereas, the edges in contact with pore spaces are sharp and straight, suggesting that the precipitation of iron-rich dolomite took place after the generation of the secondary porosity.

Fe-calcite: Although iron-rich calcite is not common in the Itarare Group, it is present in moderate abundance (2 to 7 percent) in core No. 8 (2284-2302m) in 2-AA-1-SP. Iron-rich calcite appears purple after staining with potasium ferrocyanide. It occurs as large poikilotopic crystals and also as smaller single crystals (Pl. 3-O). Fe-calcite, like the Fe-dolomite and anhydrite cements, has sharp and straight edges in contact with pore space, which is an evidence that it is a later cement.

Kaolinite (?): A low-birrefringence mineral (Kaolinite ?) was observed in the 2-AA-1-SP well, core No. 8 (2284-2302m). It is present filling the basal part of the pores and is considered here as a diagenetic geopetal texture (Pl. 3-R). Based on its mode of occurrence, it is suggested that kaolinite (?) was later introduced into the sandstone by percolation of water. A drill-stem test run in this interval produced water (9,900 ppm NaCl) at a flow rate of about 4,000 cfd indicating good permeability, which could facilitate good subsurface water circulation. The relative time of kaolinite (?) introduction is not clear; however, the relationships among kaolinite (?), quartz overgrowth, and secondary porosity, suggests that kaolinite (?) was introduced sometime after quartz cementation and the development of secondary porosity.

Chlorite: Chlorite is a fairly common mineral in the Itarare Group, and occurs as both matrix and cement. As a cement it was observed only in samples below 3080m (about 65°C, at 2.2°C/100M). Chlorite cements occur in the Itarare Group in three different textures:

Rosettes are the most common type of chlorite cement and occur as total or partial fillings of pore spaces in most sandstones deeper than about 3000m (Pl. 3-M). This mode of occurrence of authigenic clay in sandstone was termed "pore filling" by Wilson and Pittman (1977, Fig. 2).

Needles are a type of chlorite precipitation that was observed only in core No. 7 (4478m) in the 2-CB-1-SP (Pl. 3-M). The needles in thin section are due to the radial alignment of chlorite blades with respect to the walls of detrital grains. Wilson and Pitman (1977, Fig. 2) termed this mode of occurrence of authigenic clay as "pore lining".

Fibrous Radial chlorite with abnormal blue to violet interference color (pennine), is present in cores from the 1-CS-2-PR (3113m) (Pl. 3-N). Fibrous radial chlorite cement was described also by Burn and Ethridge (1978, p. 314) in lithic sandstone of the Umpqua Formation in southwest Oregon.

Determining the presence of chlorite in sandstone is an important step in reservoir analysis, especially if acid treatment is necessary to increase hydrocarbon production. The presence of chlorite makes the use of chemical inhibitors necessary in the treatment fluids in order to prevent the formation of iron-hydroxide, which would precipitate in the pore space, thus decreasing permeability rather than improving fluid production. However, the effects of drilling fluid on a chlorite-rich reservoirs are not well known.

Calcite: Calcite is relatively rare in the Itarare Group but it occurs as fracture fillings and as intergranular cement adjacent to fractures in samples from the 1-CS-2-PR well, cores No. 5 (3086m), and

No. 7 (311 m). Calcite crystals are the largest observed, and may reach 8mm in size in fracture fillings. Poikilotopic crystals are common cementing framework grains (Pl. 3-P).

Others: The most important and dominant cement types are previously described. However, there are other minor cements present in the Itarare Group, such as iron-poor dolomite, feldspar overgrowths, and pyrite.

Diagenetic Sequence. Based on the evidence observed in thin sections, it is hereby proposed that the diagenetic sequence (Fig. 39) for most of the sandstones from the Itarare Group is as follows:

Deposition: The Itarare Group has basically two types of sandstones: Those with little or no clay and generally with a gamma ray response of less than 50 API units and those that are clay-rich with gamma ray response more than 50 API units. The former generally have good porosity and the latter poor.

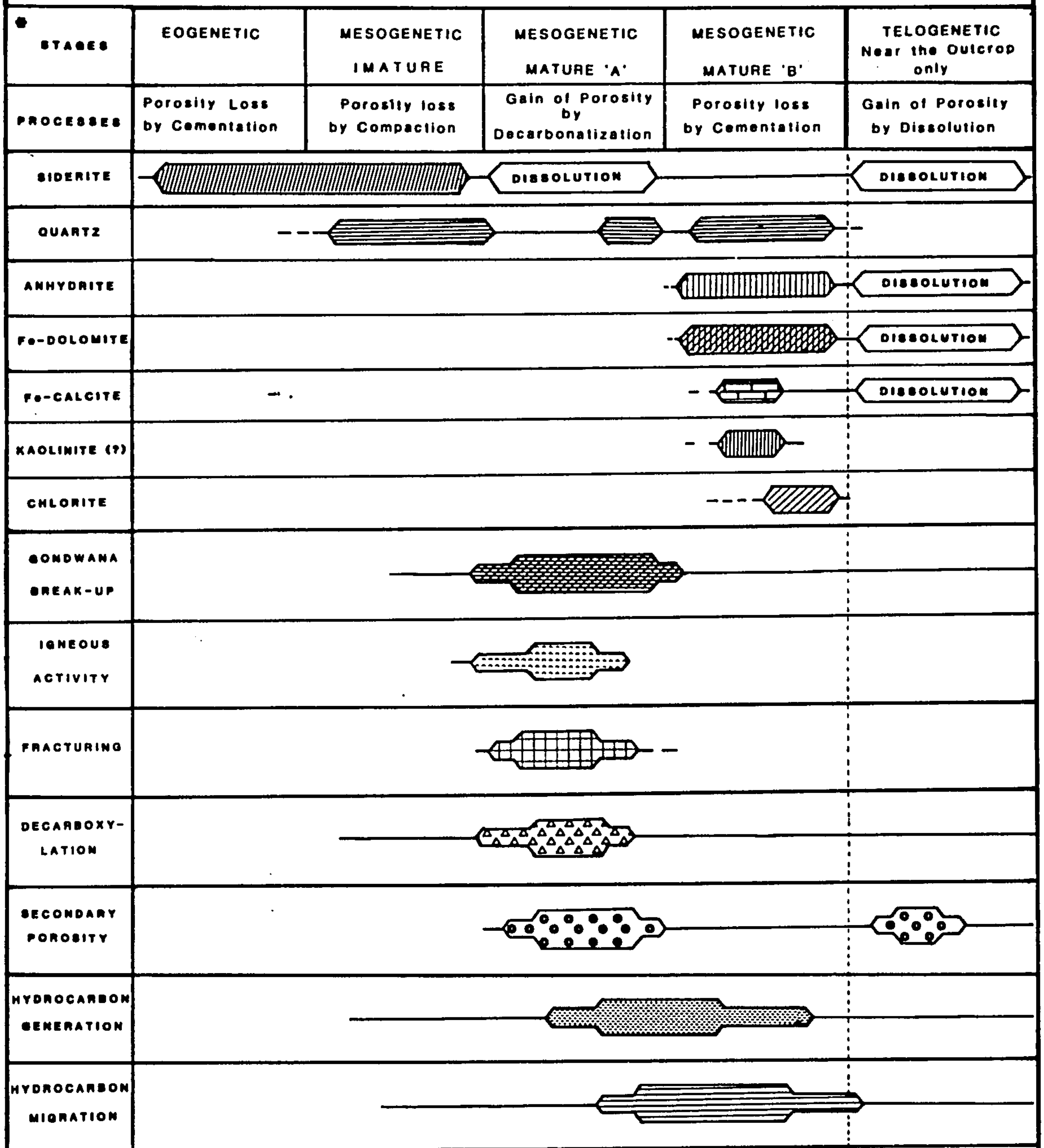
Loss of primary porosity by carbonatization: Siderite is the earliest cement formed in the Itarare Group (Pl. 1-A). However, other cement types may have filled pore spaces and were later totally dissolved. Early cementation was certainly an important event in the clean sandstones with regard to reservoir characteristics. The corrosion by siderite, and replacement of framework grains, increased the intergranular space between grains. In addition, the early cement held the framework grains during compaction.

Loss of primary porosity by mechanical compaction: Mechanical

Fig. 39 Proposed diagenetic sequence for the Itarare Group

Note that diagenetic events such as the creation of secondary porosity and hydrocarbon generation took place contemporaneous with or later than the Gondwana break-up (Jurassic-Cretaceous). This was probably the hottest period in the geologic history of the Parana Basin, triggering maturation of organic matter and consequently decarboxylation releasing acid solutions. These acid solutions percolated through sandstones dissolving carbonate cements creating secondary porosity.

PROPOSED DIAGENETIC SEQUENCE FOR THE ITARARE GROUP



* After Schmidt & MacDonald (1979a, p. 205)

The telogenetic process was observed only in shallow wells near the outcrop belt

Fig. 39

compaction occurs mostly in the lithic sandstones, especially those with considerable amounts of soft material, such as shale clasts (Pl. 1-C). In those zones that were poorly cememted, framework grains were forced into contact with each other bringing about interpenetration, pressure solution, and consequent silica cementation.

Gain of porosity by dissolution: The evidence for dissolution has been previously discussed in detail. Cement dissolution creating effective intergranular secondary porosity was volumetrically more important than grain dissolution in the Itarare Group. The timing of dissolution was probably contemporaneous with, or after the great igneous activity in the Parana Basin in the Jurassic and Early Cretaceous, during the Gondwana break-up. The heat flow suggested here is related not to local heat flow due to diabase intrusions, but to a regional thermal event during the continental rifting as proposed by Jowett (1986, p. 1826). According to Jowett (p. 1826) continental extension is generally caused by "... strechting and thinning of the lithosphere, which raises the astenosphere higher in the section, producing a regional thermal anomaly". He also states that this thermal anomaly may be dissipated through the lithosphere by conduction or by convective cells. Jowett (1986, p. 1823 and 1834) proposed that the secondary porosity and mineralizing event of the Kupferschiefer Cu-Ag deposits in Poland, was due to convective cells coincident with continental rifting associated with the opening of the Tethys Ocean in the Triassic and Jurassic.

In the Parana Basin, heat flows from the regional thermal anomaly produced during the oppening of the Atlantic Ocean, probably reached the Devonian black shale of the Parana Group (Ponta Grossa

Formation), triggering or increasing the speed of earlier processes of organic matter maturation. The initial phase of thermomaturation releases carboxylic acids and/or CO_2-rich water, promoting dissolution. In addition, dikes and sills may have released CO_2, which would be added to the "organic" carbon dioxide, increasing dissolution effects. Organic matter maturation, either contemporaneous with or after igneous activity in the Parana Basin, has been also proposed by Oliveira (1971, p. 156), and by Goulart and Jardim (1982, p. 72).

It was observed extensive dissolution in sandstones from shallow wells drilled near the eastern outcrop belt, such as the 2-PN-1-SP (top of the Itarare Group at 272m). It is likely that the extensive dissolution in the shallow wells is a process associate with meteoric water percolating through reservoirs near the recharge zone in the outcrops.

Loss of porosity by rearrangement of grains: This is a difficult event to identify in thin sections. According to Schmidt and Mcdonald (1979a, p. 198) loss of porosity by rearrangement of grains is characterized by minor compaction of secondary porosity and quartz diagenesis.

Loss of porosity by carbonate and sulfate precipitation: This stage is characterized by cementation by: anhydrite; Fe-dolomite; Fe-calcite; and calcite. The cements in this sequence are characterized by large poikilotopic crystals enveloping grains (Pl. 2-H), mosaics of large equant crystals (Pl. 2-J), or isolated single large crystals (Pls. 2-I and 2-K). Another characteristic of cements formed during this stage is the sharp and straight edges in contact with pore space. The relationships among the four types of cement is not clear but they could be contemporaneous.

Loss of porosity by introduction of kaolinite (?): This event was observed only in core No. 8 from the 2-AA-1-SP well (2300m) and here evidence for the relative timing of the kaolinite (?) introduction is meager. Additional studies with more samples are needed in order to better determine the timing of this event. Although kaolinite (?) precipitation can be considered less important than other cement types because of its relative scarcity, it may be most abundant near the 2-AA-1-SP well.

Loss of porosity by chlorite cementation: The presence of chlorite cement in the Itarare Group was observed only below 3080m. It occurs as pore fill or pore linings. Chlorite is interpreted here as the latest cement formed in the sandstones of the Itarare Group. However, chlorite was probably precipitated before gas and condensate migrated from the source rocks to the reservoirs. This interpretation is based on the occurrence of gas and condensate is in reservoirs with chlorite cement (1-CS-2-PR and 2-CB-1-SP), and the presence of hydrocarbons can inhibit diagenetic reactions in pore spaces.

In summary, Permo-Carboniferous sandstones from the Itarare Group are classified as **arenites** and **wackes** according to the classification proposed by Dott (1964, p. 629). Sandstones with low matrix content has developed **secondary porosity,** mostly of interparticle type due to the dissolution of early carbonate cement (siderite). The dissolution took place possibly after the **Gondwana break-up** in the Upper Jurassic-Lower Cretaceous, when the source rocks received enough heat flow for thermomaturation and consequent releasing of organic acids and carbon dioxide as well. The most common cement is **anhydrite** and **Fe-dolomite**, that are present mainly as poikilotopic crystals. **Chlorite** is also present below about 3000m and may be a problem for fluid production and well stimulations. It is suggested that Fe released from the dissolution of early siderite was probably remobilized to form later Fe-dolomite, Fe-calcite, and chlorite cements.

The flow chart (Fig. 40) depicts the most probable paths followed by the sandstones from the Itarare Group, since their deposition up to the present time.

HYDROCARBON POTENTIAL OF THE ITARARE GROUP:

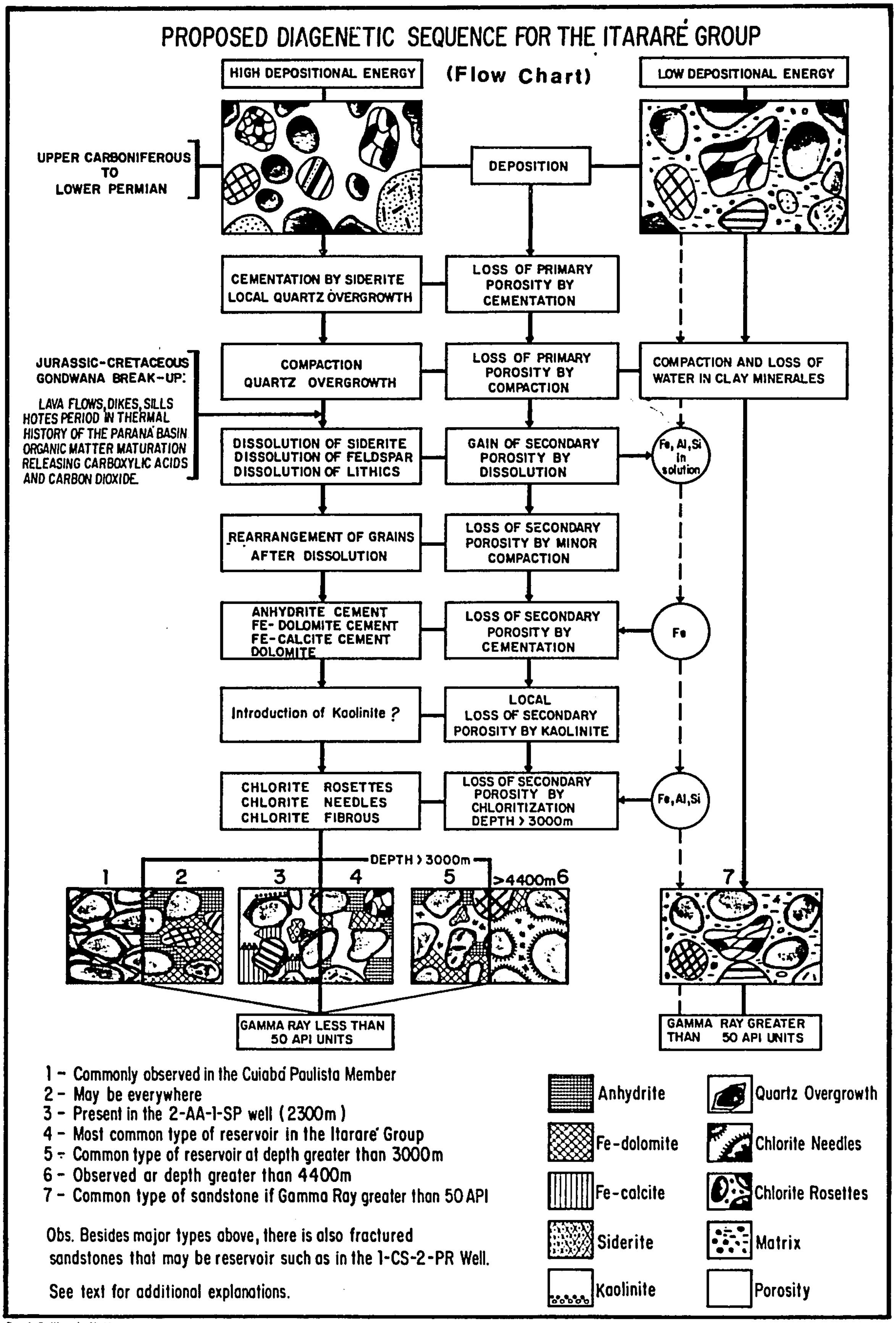
As it was already discussed earlier, the hydrocarbon potential of the Parana Basin is not well understood yet, in spite of some oil shows and relatively good gas production in some wells. The best results regarding gas production, are located in the Itarare Group as will be seen later, however, none are commercial and no well was drilled in closure structure. Therefore, the following discussions is a try of putting together useful information obtained to date, in an attempt to find important keys that must be used along with other data such as geochemistry, structure, seismic, etc., in order to establish an exploratory guide for the Parana Basin.

Log Information The information from petrographic analysis must be calibrated with well logs, such as gamma ray and porosity logs (density, neutron, or sonic log). Using this calibration,logs from wells with no cores cores can then be interpreted. The calibration also takes into account the results of drill-stem tests (DSTs). However, interpretations

Fig. 40 Flow chart showing the most probable path followed by the sandstones from the Itarare Group.

Clay-free sandstones with good to fair primary porosity was early cemented by siderite. Later on the diagenetic history these sandstones developed secondary porosity by dissolution of the carbonate cement. Currently, these sandstones are identified in the gamma ray logs (sandstones with less than 50 API units), and commonly comprise good reservoirs in the Itarare Group.

Clay-rich sandstone with little or no primary porosity did not developed secondary porosity and are poor reservoirs in the Itarare Group. These sandstones have gamma ray greater than 50 API units.



1 – Commonly observed in the Cuiabá Paulista Member
2 – May be everywhere
3 – Present in the 2-AA-1-SP well (2300m)
4 – Most common type of reservoir in the Itararé Group
5 – Common type of reservoir at depth greater than 3000m
6 – Observed ar depth greater than 4400m
7 – Common type of sandstone if Gamma Ray greater than 50 API

Obs. Besides major types above, there is also fractured sandstones that may be reservoir such as in the 1-CS-2-PR Well.

See text for additional explanations.

Des. L. Colligaris Netto.

Fig. 40

and extrapolations using logs must consider the following:

1 Cements such as quartz, carbonates and anhydrite do not influence the gamma ray log response nor does the kaolinite.

2 Sonic logs should not be used in argillaceous sandstones - the density log is more appropriate in this case.

3 The SP log, which is a relative measurement of permeability, is influenced by the presence of hydrocarbon, as well as the relationship between salinity of the drill mud filtrate and formation fluids. Therefore, reservoirs with similar characteristics may develop different SP curves in different wells.

4 Cementation by relatively dense minerals, such as anhydrite (2.98 g/cm^3), requires correction in order to determine porosity from the density log (porosities values will be less than actual values if not corrected).

The following set of logs from the Parana Basin is available to study reservoir quality:

1 Gamma ray logs from 30 wells drilled by Paulipetro from 1980 to 1983, and from 6 wells drilled by Petrobras before 1980.

2 Sonic logs from 30 wells drilled by Paulipetro.

3 Density and neutron logs from two wells drilled by Paulipetro.

4 There are no density/neutron logs from wells drilled by Petrobras.

The best suite of logs for this work is the set of logs from Paulipetro's wells, that is, sonic and gamma ray logs from 30 wells.

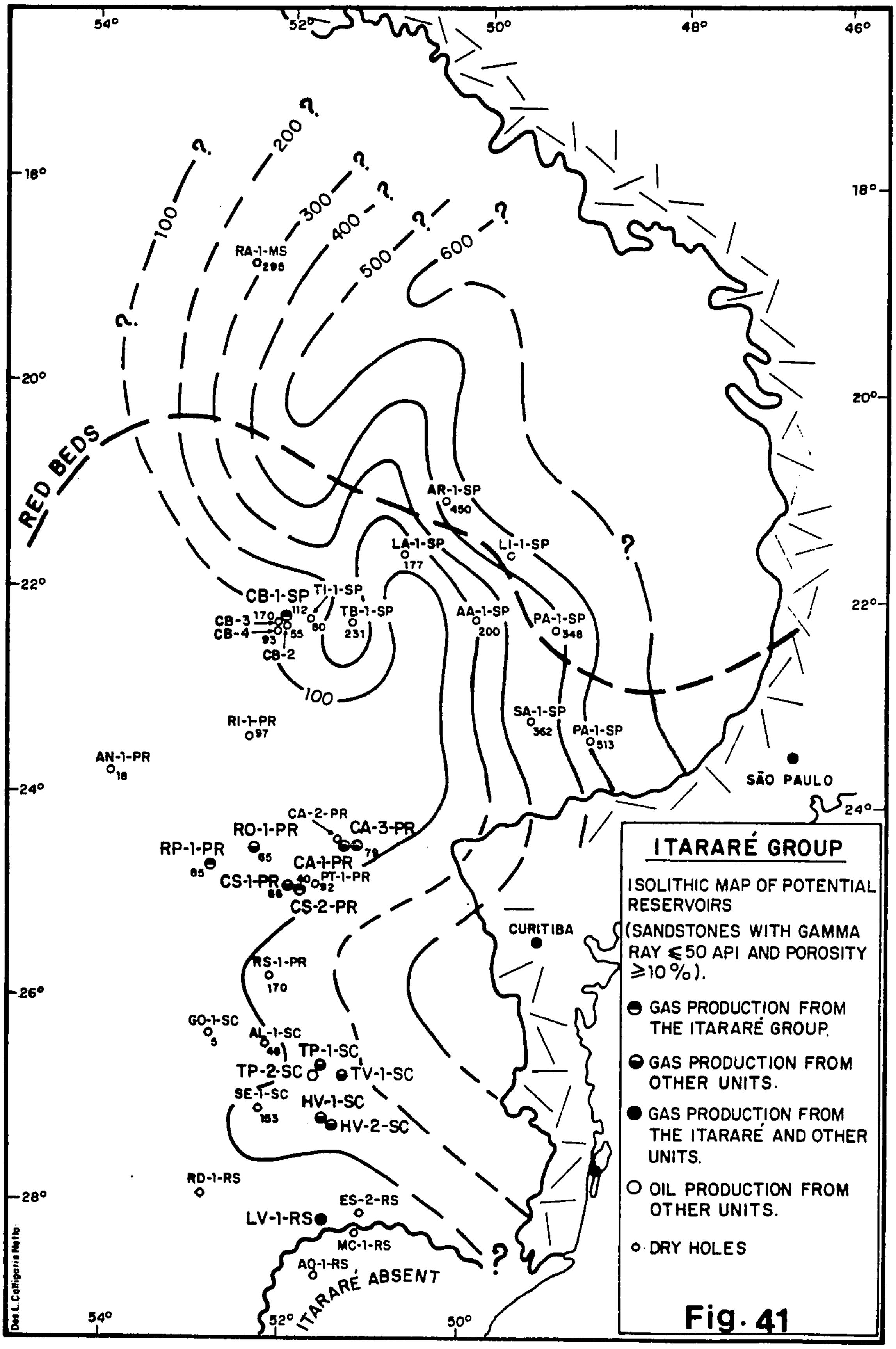
The sonic log is influenced by the clay content in the reservoirs because it is influenced by the slow sonic-transit time of clays and clays have no effective porosity. Thus a cut off in clay content is necessary to work with a porosity as effectively as possible. In order to determine the best cut off for the Itarare Group, two type of diagrams were constructed. In one diagram porosity values from the sonic log (Vma = 19,500 microseconds/foot) was plotted against API units from the gamma ray log. In the second diagram it was plotted porosity determined in point counts from thin sections, against API units from the gamma ray log. Dril stem tests were also considered when available.

The analysis of such diagrams has suggested that most of the sandstones with values of porosity above 10 percent have gamma ray values less than 50 API units. In addition, reservoirs with porosity greater than about 10 percent revealed good permeability in DST. Reservoirs with porosity between 10 percent and about 5 percent have low permeability, and reservoirs with porosity values less than about 5 percent produced no fluid during drill stem tests. Based on these observations it is proposed that for the identification of good reservoir in well logs from the Itarare Group, it is necessary a cut off of about 50 API units in the gamma ray log and about 10 percent of porosity in the sonic log, using a Vma = 19,500 microseconds/foot.

A sandstone isolith map (Fig. 41) was constructed using the limits of less than 50 API units and porosity greater than 10 percent. This attempt of mapping potential good reservoirs in the Itarare Group

Fig. 41 Isolith map of potential good reservoirs in the Itarare Group.

Note that the isoliths are almost parallel to the eastern border of the Parana Basin. Wells with gas production in the Itarare Group are within isoliths of 100m or less, perhaps reflecting an adequate relationship between reservoir thickness and seal.



ITARARÉ GROUP
ISOLITHIC MAP OF POTENTIAL RESERVOIRS
(SANDSTONES WITH GAMMA RAY ≤50 API AND POROSITY ≥10%).
GAS PRODUCTION FROM THE ITARARÉ GROUP.
GAS PRODUCTION FROM OTHER UNITS.
GAS PRODUCTION FROM THE ITARARÉ AND OTHER UNITS.
OIL PRODUCTION FROM OTHER UNITS.
DRY HOLES
RED BEDS
ITARARÉ ABSENT
SÃO PAULO
CURITIBA
RA-1-MS
AR-1-SP
LA-1-SP
LI-1-SP
CB-1-SP
TI-1-SP
TB-1-SP
AA-1-SP
PA-1-SP
CB-3
CB-4
CB-2
RI-1-PR
SA-1-SP
AN-1-PR
CA-2-PR
RO-1-PR
CA-3-PR
RP-1-PR
CA-1-PR
PT-1-PR
CS-1-PR
CS-2-PR
RS-1-PR
GO-1-SC
AL-1-SC
TP-1-SC
TP-2-SC
TV-1-SC
SE-1-SC
HV-1-SC
HV-2-SC
RD-1-RS
ES-2-RS
LV-1-RS
MC-1-RS
AO-1-RS
Des L. Calligaris Netto

Fig. 41

shows that the reservoir thickness approximatelly parallels the eastern outcrop belt of the Parana Basin, and that the reservoir quality in the sandstones from the Itarare Group, decreases towards the central part of the basin. This is probably because in the central part of the basin, the Itarare Group is deepest and, consequently more compacted than sandstones from the basin's edge. Moreover, the outcrop belt is a water recharge area; therefore, it is possible that a flushing zone has been developed in and near the outcrop of the Itarare Group. This flushing zone may have developed a front of dissolution that should have diminished with increasing depth and distance from the outcrop.

Depth plotted versus porosity from the sonic log (only sandstones with gamma ray less than 50 API units) is shown in Figure 42.

Results of Drill Stem tests. Several DST were logged in the Itarare Group, some of which revealed completely tight intervals with no fluid production; the majority of them, however, produced water, some produced water with traces of gas, and a few produced gas.

Wells that have flared gas and/or produced oil during DSTs run in the Parana Basin are shown in Figure 41. The best DSTs run in the Itarare Group are listed below:

Well 2-CB-1-SP: (4600 - 4626m), produced gas from sandstone with a flow rate of about 3 million cubic feet per day (cfd); (4582 - 4595m), produced gas from fractured diabase with a flow rate of about 300,000 cfd.

Well 2-RP-1-PR: (3148 - 3157m), produced gas from sandstone with a flow rate of about 730,000 cfd).

Fig. 42 Plot of depth versus porosity of sandstones from the Itarare Group.

This plot shows porosity decreasing with depth, and indicates that secondary porosity develops as deep as 4500m.

Regression Equation:

Intercepts: 4075
Slope: 94,3
r: 0,627

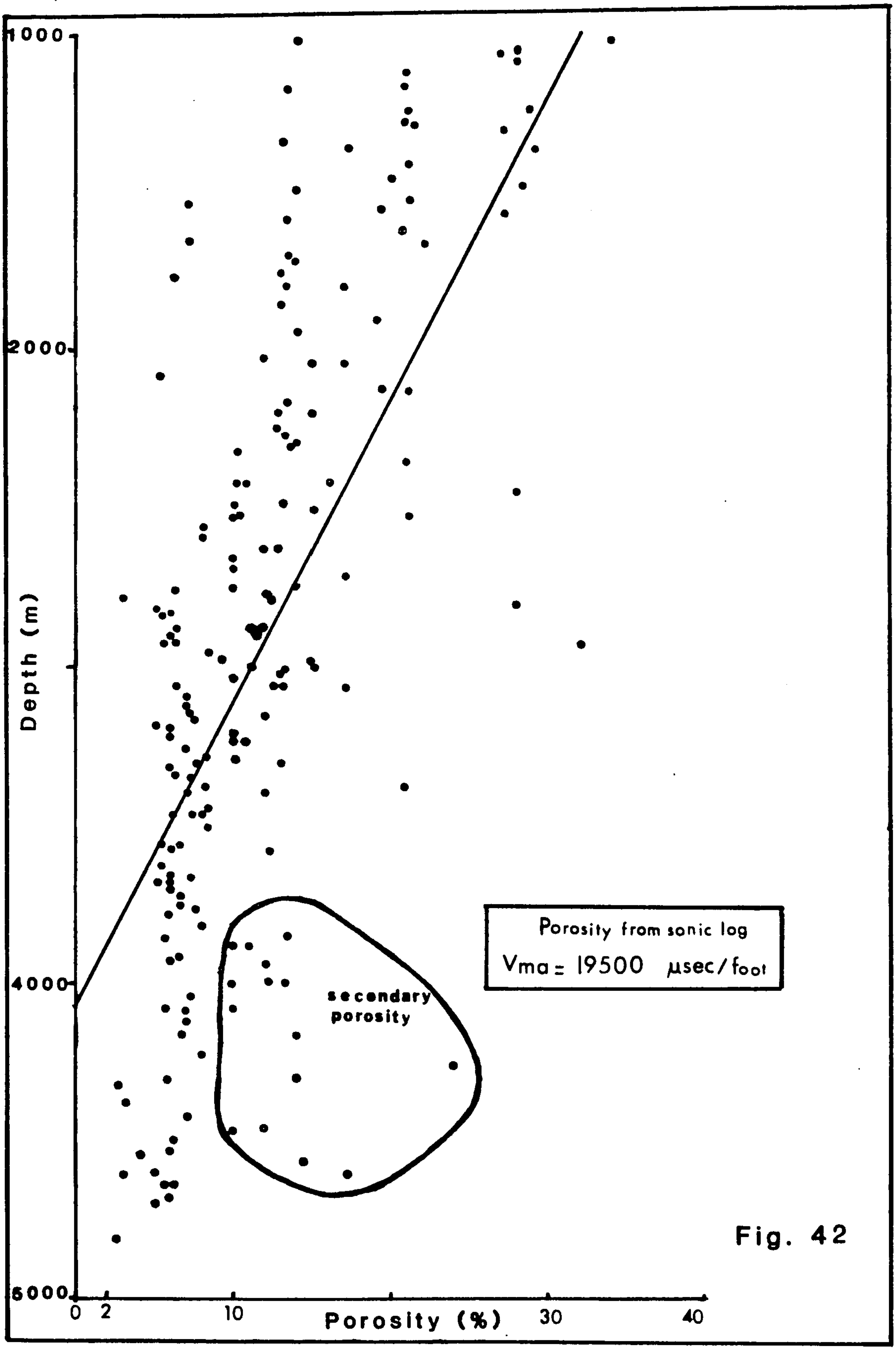

1000
2000
4000
6000
Depth (m)
0 2 10 30 40
Porosity (%)
Porosity from sonic log
Vma = 19500 µsec/foot
secondary porosity

Fig. 42

Well 1-CS-2-PR: (3075 - 3103m), produced gas and condensate at a flow rate of about 600,000 cfd.

Gas and oil have been produced in DSTs from other units such as the Rio Bonito Formation (overlying the Itarare Group) and from sandstones bodies from the Ponta Grossa Formation (Devonian).

Reservoir Seals and Traps. Reservoir seals and trap styles are not well understood in the Itarare Group. Certainly at this time is not easy to establish confidently, which rocks are seals and all the various types of traps present in the Itarare Group. However, observations from well logs suggest the following:

1 The best producing interval (2-CB-1-SP) is a sandstone beneath a 150m diabase intrusion. The diabase is fractured in the basal zone (about 13m). This fractured zone was isolated in a DST run in casing and produced gas. The central part of the diabase is not fractured and DST, also run in casing, in this zone indicated the diabase was tight in the interval tested. It seems that the unfractured zone of the diabase may be a local seal; however, brittle rocks such as diabases may be completelly fractured in other areas losing their ability to act as a seal unless fractures are naturally cemented.

2 In the 1-CS-2-PR well the reservoir rock is an extremely fractured sandstone with fractured diabase sills (1m). The producing zone is beneath a major diabase body (43m).

3 In the 2-RP-1-PR well the reservoir is beneath shale and anhydrite layers, which are traditionally good cap rocks.

4 Pebbly mudstones are present overlying most of the sandstones that produced small amount of gas in other intervals of the Itarare Group.

Of the possible cap rocks described above, pebbly mudstone is the most abundant in the Itarare Group. Pebbly mudstone bodies may be thick (more than 50m) and may cover an area of hundreds of square kilometers, such as in the Chapeu do Sol Member (Figs. 10 to 14). Shale in the Itarare Group is relatively common in Santa Catarina and Parana states, but is almost absent throughout the rest of the basin. Anhydrite was observed in only one well (2-RP-1-PR). Individual Diabases may be as thick as 266m in the 2-AN-1-PR well and are randomly distributed in the stratigraphic column of the Parana Basin. Diabase intrusions seem to be the cap rock in tar sands commonly found in the eastern outcrops of southeast Sao Paulo State (Zalan et al 1985, p. 229). However, because diabase may easily develop fractures in the subsurface, its potential to form seals is not consistent.

Trap style is certainly the least understood aspect in hydrocarbon exploration in the Parana Basin. This is because most of the wells drilled to date did not have enough seismic information due to the difficulties of seismic mapping in areas of thick basaltic terrain.

Relationships Between Reservoir and Source Rocks. The Devonian black shale from the Ponta Grossa Formation (Parana Group) and black shales from the Irati Formation (Permian) are probably the best source rocks in the Parana Basin (Goulart and Jardim, 1982, p. 71).

The Ponta Grossa Formation has an average content of organic carbon of about 0.5 percent. The organic matter is marine (type I) and continental (type III), according to Goulart and Jardim (1982, p. 56). The average content of organic carbon in the Irati Formation is about 1 percent (Goulart and Jardim 1982, p. 63). The organic matter is marine and continental as well.

The shales in the Ponta Grossa Formation, Parana Group (Fig. 43), underlie Itarare Group sandstones; whereas, the Irati Formation (Upper Permian) is separated from the Itarare Group by rocks from the Guata Group (Fig. 4). Therefore, the sandstones from the Itarare Group have a better physical relationship with the Devonian black shales of the Parana Group. Hydrocarbons discovered so far in the Itarare Group are more likely sourced from the Ponta Grossa Formation, than migrated downward from the Irati Formation.

Lopatin's Method. "The quantification of the amount and rate of basin subsidence is a vital part of basin analyisis" (Miall, 1984, p. 319). Most important for the oil and gas industry is the temperature history of buried sediments and how long these temperature were maintained. Thermal maturation of source rocks is a critical factor in controlling hydrocarbon generation. Thermal maturity can be evaluated by direct measuring in samples applying methods such as vitrinite reflectance and color alteration index (Miall, 1984, Chap. 7; Waples 1980).

However, in some basins such as the Parana Basin, the well density may be low, and maturity data is restrict to the present status

Fig. 43 Isolith map of potential source rocks in the Ponta Grossa Formation (Devonian black shale).
Wells such as the CB-1-SP, RP-1-PR, CA-2-PR, and CS-2-PR that have produced gas from the Itarare Group (Fig. 40), plots within the 200m isolith of potential source rock.

The Itarare Group is directly overlying the Ponta Grossa Formation.

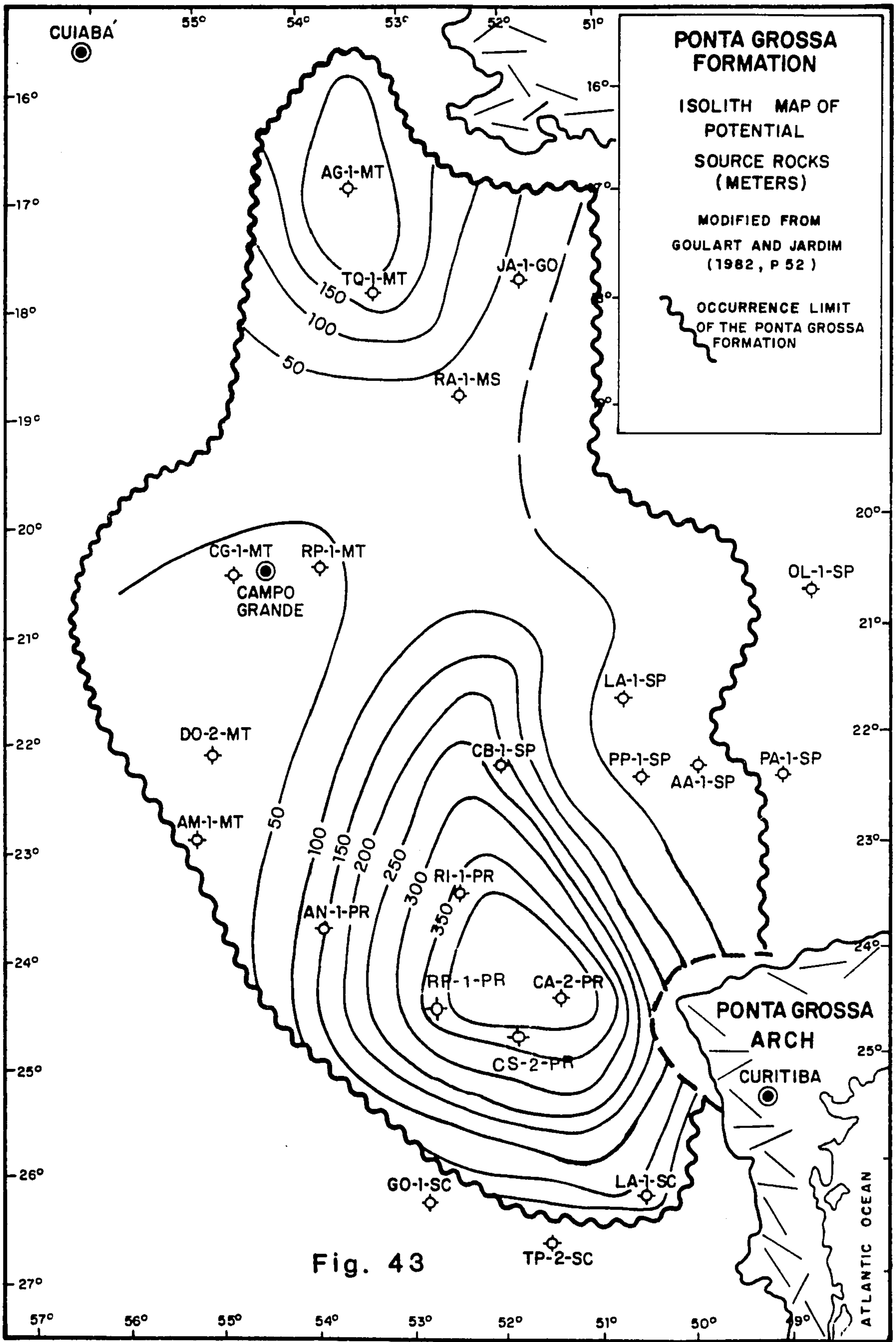


Fig. 43

Des. L. Caligaris Netto.

of the rock, whereas, it is important to know when maturation took place (Waples et al 1985, p. 2). Methods such as the "geohistory analysis" (Van Hinte, 1978) have been developed to calculate maturity for areas with low well density or where direct measurements are not available. The most popular of these methods was developed by Lopatin in the Soviet Union. The method is explained by Waples (1980).

Briefly, what the Lopatin's Method requires are the ages and present-day depths for the formations in the section and the present-day and past geothermal regimes (Waples, 1980, p. 2). The past geothermal regimes must be assumed, whereas the age and present geothermal gradient can be obtained from well data. The maturity is calculated in TTI (Time-temperature index) units, which can be compared to vitrinite reflectance or color alteration index (Waples, 1980, p. 921).

Threshold values of Lopatin's index TTI (Waples, 1980, p. 916) are:

15	Onset of oil generation
75	Peak of oil generation
160	End of oil generation
500	40 API oil preservation deadline
1,000	50 API oil preservation deadline
1,500	Wet gas preservation deadline
65,000	Dry gas preservation deadline.

The Lopatin's method is simple and can be calculate by hand, but it is time consuming and less precise than the Lopatin program (Waples, et al 1985), which can be used in an IBM PC or 100 percent compatible computer.

The first application of the Lopatin's Method to evaluate the maturity in the Parana Basin was done by Jardim et al (1981) when all calculations and graphs were made by hand. Their major conclusion (p. 9) were that the maturation of the Ponta Grossa Shale started during the Mesozoic.

The results of the Lopatin's Method applied to the Cuiaba Paulista well (2-CB-1-SP) is presented by using a Lopatin program on a PC computer (Waples, 1985). The Cuiaba Paulista well was chosen for its location deep in the basin and because it had the best gas production in the Parana Basin to date.

The present geothermal gradient for the Parana Basin is about 2.2°C/100m, calculated from well data (Jardim et al 1981, p. 7). For geothermal regimes in the past, it was adopted here the same assumptions made by Jardim et al (1981, p. 7), that is 2.2°C/100m for the Paleozoic, but during the Mesozoic when the Parana Basin was affected by great igneous activity associated to the Gondwana break-up, a higher gradient was assumed - 4.0°C/100m.

Figure 44 shows the isotherms calculated for 2-CB-1-SP, with the assumptions made above. Note how the basin was heated during the Mesozoic, between 100 and 140 million years ago (ma). The downdwarp in the isotherms between 295 and 253ma is the effect of the lower average surface temperature during the glacial periods in the Permo-Carboniferous.

Figure 45 shows the burial-history curves for the stratigraphic units in 2-CB-1-SP. The Itarare Group was deposited from about 295 to 253ma and since its deposition it has had the time-depth history as follow: To simplify let us take the top of the Itarare Group and follow it downward from left to right. Its top subsides from 0m at 253ma to about 1500m at 240ma. When the subsidence rate decreases

Fig. 44 Isotherms for the Parana Basin, using data from the 2-CB-1-SP well in the central part of the basin.

The pull up of the isotherms in the Mesozoic time, from about 170 to 70 million years ago, is due to the great igneous activity that affected the Parana Basin during the Gondwana break-up.

The pull down of the isotherms in the Paleozoic time about 295 to 253 million years ago is because of the surface low temperature during the glaciation periods (Permo-Carboniferous).

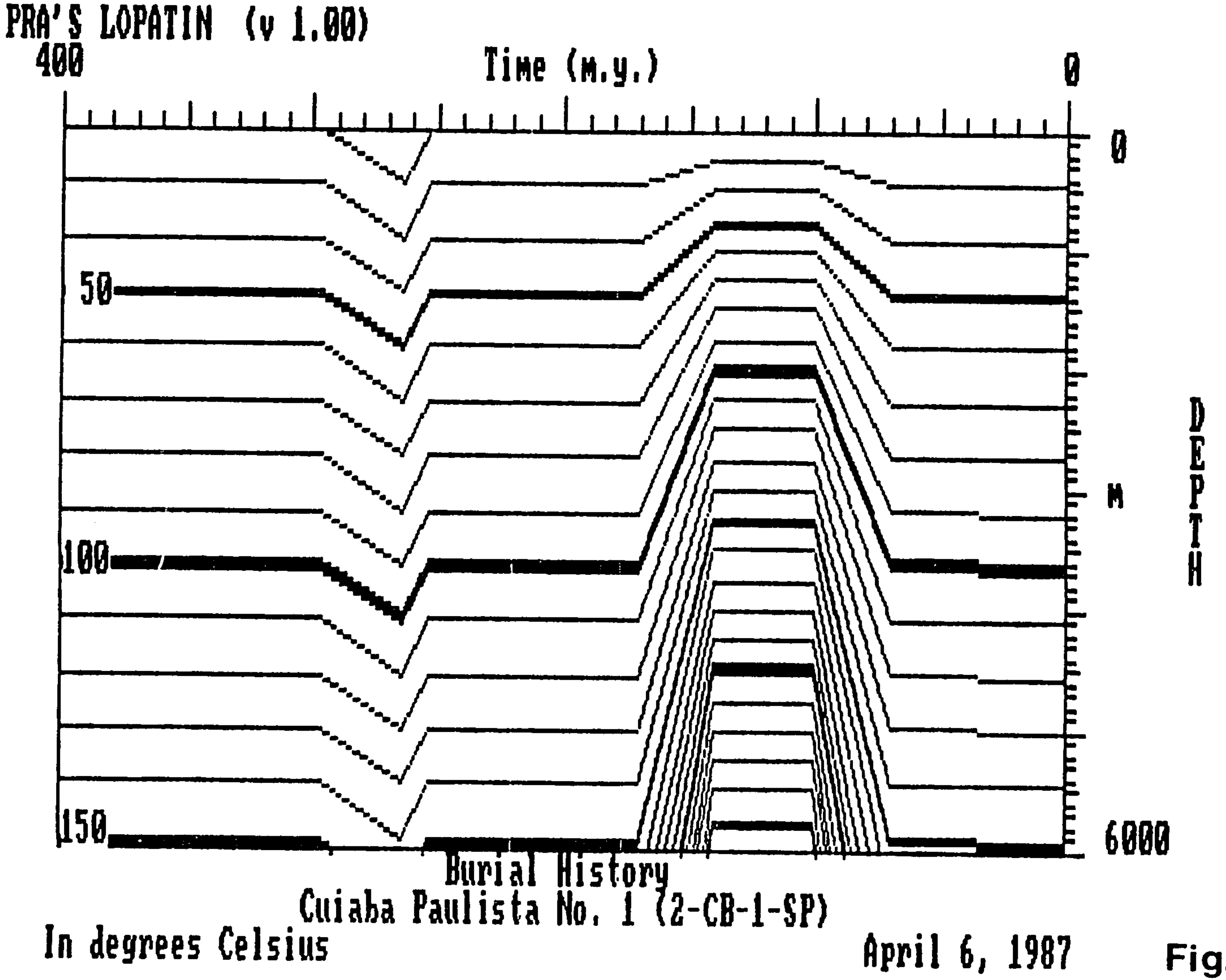

PRA'S LOPATIN (v 1.00)
400
Time (m.y.)
0
0
M
DEPTH
6000
50
100
150
Burial History
Cuiaba Paulista No. 1 (2-CB-1-SP)
In degrees Celsius
April 6, 1987

Fig. 44

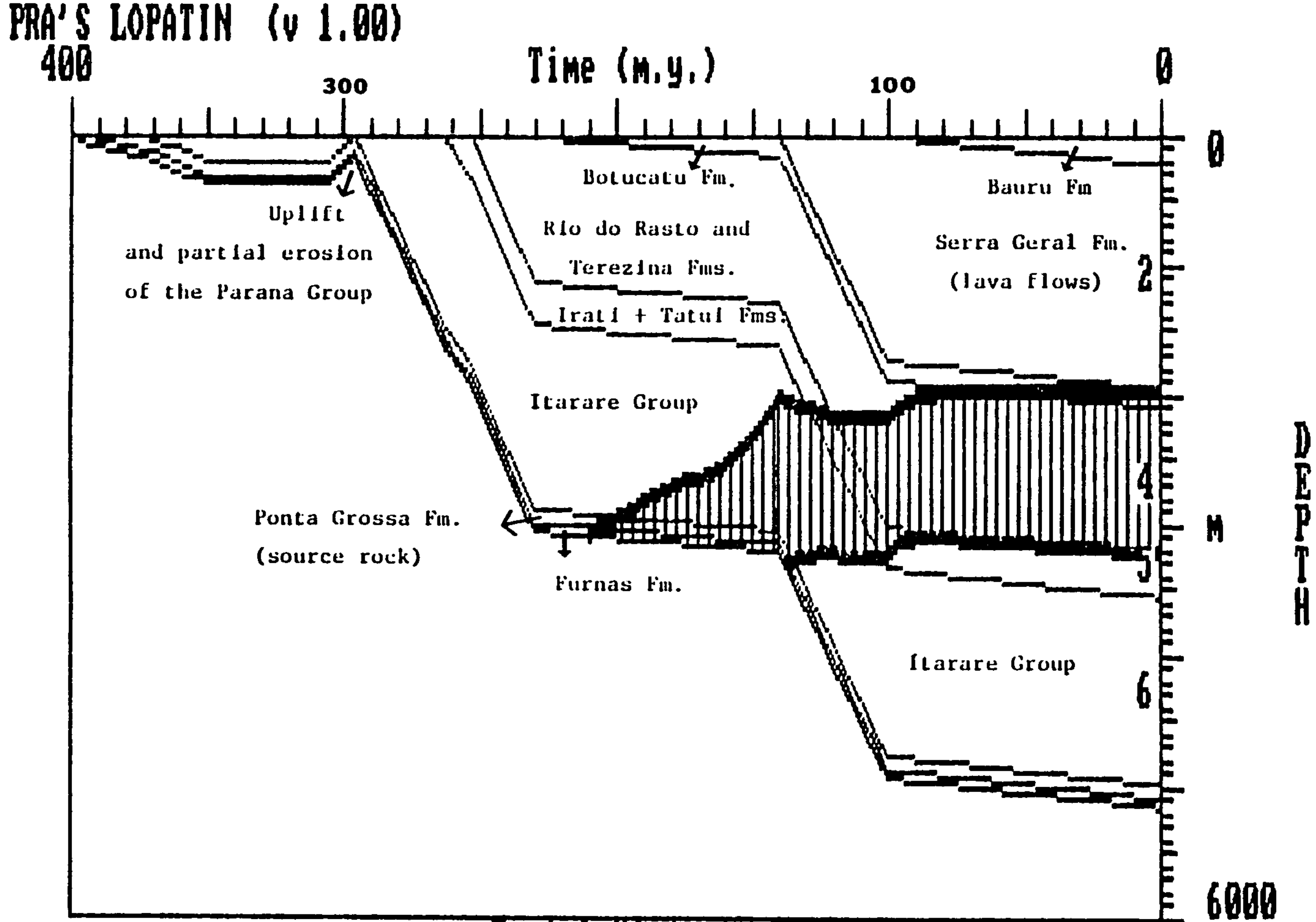
Fig. 45 Burial-history curves and progression of maturity through time for the Parana Basin in the 2-CB-1-SP well area.

Note that the Ponta Grossa Formation entered the oil-generation window (dashed area), about 200 million years ago (Jurassic time) remaining there untill about 140 million years ago (Cretaceous time).

The figure suggests that currently the Ponta Grossa Formation (5,000m deep) in the 2-CB-1-SP well is overmature.

Compare with figures 39 and 40.

Printed from Lopatin's Program (Waples, 1985).



Burial History
Cuiaba Paulista No. 1 (2-CB-1-SP)

Fig. 45

drastically from 240 to 140ma the top of the Itarare Group subsides only 200m from 1500 to 1700m. During this period of low subsidence rate, the great Triassic desert that deposited the eolian sandstones of the Botucatu Formation was formed. From 140 to about 100ma the top of the Itarare Group subsides from 1700, to about 3400m. This rapid subsidence was the result of about 1700m of lava extruded in the area of 2-CB-1-SP. After the igneous activity stopped, the subsidence rate declines again and at the present, the top of the Itarare Group is at 3586m in the CB-1 well.

The shaded area in Figure 45 represents the oil-generation window. Note that the Ponta Grossa Formation entered the oil-generation window about 210ma and remained there until about 135ma. Thus, according to Figure 45, the shales of the Ponta Grossa Formation in the area of the 2-CB-1-SP well (central part of the Parana Basin), have started to generate hydrocarbon in the Mesozoic time.

Appendex 4 has additional information from the computer and shows that the TTI values calculated for the base of the Itarare Group in 2-CB-1-SP (19,042) are beyond the wet gas preservation deadline, but before the dry gas preservation deadline (> 65,000). The 2-CB-1-SP well produced dry gas (3MM cfd) from the interval 4600-4625m, which is an agreement with the results found by the Lopatin's method. In addition, Figure 45 shows that the shales from the Ponta Grossa Formation in the 2-CB-1-SP well are presently overmature. Unfortunately direct measurement, such as vitrinite reflectance, is not available to check this observation.

The major conclusion from the Lopatin's method is that the Ponta Grossa Formation started hydrocarbon generation during the

Mesozoic and in some cases it is currently still within the oil-generation window, suggesting that hydrocarbon is still being generated; whereas, deep in the central part of the Parana Basin, the source rock is overmature as suggested by Figure 45.

CONCLUSIONS AND RECOMENDATIONS

Historically, the study of the stratigraphy of most basins started in their outcrop, where only a portion of the total section of the basin can be seen. Here units are not only generally thin but some may be totally absent. Today it is widely recognized that the best place to define the stratigraphy of a basin is in its deepest part where unconformities are less likely and sedimentation was most continuous. Based on this procedure, well logs and cores from wells drilled in the central part of the Parana Basin were analysed and a new stratigraphic nomenclature proposed for the Itarare Group. This new nomenclature facilitates subsurface exploration in the basin because only in the subsurface can regional stratigraphic relations and the full stratigraphic section be seen. The relationships between these new stratigraphic units proposed for the subsurface and the outcrop is relatively easy in southern parts of the Parana Basin, but it is still complex and unclear in the rest of the basin. Additional studies such as carefull correlation of shallow drilling and paleontology are necessary to improve the correlation between the subsurface and the outcrop belt.

Well logs suggest that the Itarare Group has three major depositional cycles all of each can be identified on gamma ray and spontaneous potential logs (Fig. 2). The lower depositional cycle corresponds to the Lagoa Azul Formation, the middle cycle is the Campo Mourao Formation and the upper cycle corresponds to the Taciba Formation. The identification of these depositional cycles in the Itarare Group is certainly the fundamental starting point for future studies.

The upper depositional cycle seems to be present in much of the outcrop. In the southern parts of the basin, it corresponds mostly to what Schneider et al (1974) have called as Rio do Sul Formation. In Sao Paulo State the upper depositional cycle seems to correspond to units that outcrop along parts of the 'Castelinho' and Bandeirantes highways, which traverse in the northeastern part of the basin.

The depositional cycles in the Itarare Group seems to be response to both climate and sea level changes (Table 2). There seems to have been three major ice advances into the Parana Basin during the Permo-Carboniferous. "Major ice advances" are defined here as those capable of depositing extensive, thick pebbly mudstones (minimum of 50m thick) and being traceable for tens of kilometers in well logs.

The first major ice advance into the Parana Basin in Permo-Carboniferous time deposited terrestrial tillites late in the lower depositional cycle. The second major ice advance occurred during a minor marine transgression and produced interbedded terrestrial and marine deposits late in the middle depositional cycle. The third and last major ice advance into the Parana Basin was contemporaneous with the Permian transgression, which was responsible for a relative deep water basin in the southern parts of the Parana Basin, where turbidites and fossiliferous varved dark-gray to black shale with dropstones were deposited, the Rio do Sul Member. In the northern part of the basin, however, water depths were shallower and marine glaciers deposited tillites and possibly even subaquous outwash.

The major ice advances identified in the subsurface, some of which are up to 150m thick, may represent as many as three to five separate tillites in the outcrop. Careful outcrop mapping and shallow drilling will be required to relate outcrop units of tills to the larger units of the subsurface.

In summary, log correlation shows that outcrop belt, such as in Sao Paulo State, represents one major glacier advance of the upper depositional cycle, where a glacier deposited tillites, and glacigenic debris flows in a shallow sea in association with deltaic sandstones, turbidites, and storm deposits. This complex environment is probably the reason for the complicated estratigraphy and for the discrepancy in the number of tillites and glacial advances reported by several authors for the Parana Basin as mentioned by Gravenor and Rocha-Campos (1983).

The figure 36 shows the ice pattern movement into the Parana Basin, that was first proposed by Crowell and Frakes (1975). The Santa Catarina Lobe and the Mato Grosso Lobe are new additions to their map and are based on thickness and percentage maps of the pebbly mudstones in the Itarare Group.

The reservoir rocks in the Itarare Group are interbedded with the pebbly mudstones described above and are composed essentially of sandstones.

There are basically two types of sandstones in the Itarare Group, one type is clay-rich with no porosity and the other type has little or no clay. This last type of sandstone has porosity ranging from about 35 percent in shallow wells, to less than 5 percent in deep wells. The porosity is mostly secondary and predominantly intergranular due to the dissolution of early carbonate cement (siderite is the earliest identifiable cement). Dissolution of feldspars and lithics have contributed to form minor secondary porosity.

The development of secondary porosity in the Itarare Group is probably contemporaneous or later, to the Gondwana break-up when the Parana Basin was affected by one of the great periods of igneous activity in the globe - the lavas and intrusives of the Serra Geral Formation. Because of this, thermomaturation of organic matter was probably accelerated in deepest parts of the basin and may even have occurred in its shallower parts near the outcrop. Organic acids and carbon dioxide released from the maturation of shales and perhaps CO_2 from volcanic and intrusive rocks were responsible for the corrosive solutions that have percolated through sandstones leaching carbonates, feldspars, and other unstable constituents.

After the development of the secondary porosity, cementation took place. The most abundant cements are anhydrite and Fe-dolomite, followed by quartz overgrowths and chlorite, which occurs only below about 3800m. Quartz cement is the only one that appears to have major effects on reservoirs, mainly in the Cuiaba Paulista Member, where silica cementation is locally intense obliterating almost completely the porosity. Chlorite is a problem for well estimulation, requiring especial fluid treatment to inhibit the precipitation of iron-hydroxide.

The best potential seals in the Itarare Group are the extensive and massive pebbly mudstones, such as in the Chapeu do Sol Member (Figs. 10 and 25). However, it is possible that unfractured diabase may also be a seal in some wells such as in 2-CB-1-SP in Sao Paulo State, and in 1-CS-2-PR in Parana State.

Fortunately each depositional cycle ot the Itarare Group has reservoirs and seals (Table 2). However, the best possibilities for hydrocarbon accumulation in the Itarare Group, are in the middle and upper cycles, where the reservoir qualities are better than in the lower one. The sandstones present within the "shaly" sections, for instance in the Tarabai Member in 3-CB-3-SP (Fig. 13), provide still another possibility.

Structure and traps, although important in hydrocarbon accumulation, were not discussed in details for it is beyond the scope of this work. Very little is known about this subject in the Parana Basin, however, some suggestions emerge from the stratigraphic analysis.

Seismic research is the main tool to map subsurface structure, however, in the Parana Basin seismic research is affected not only by the lava flows in the surface, but also by the sills and dikes that mask the lateral continuity of the reflectors. Moreover, Paleozoic rocks tend to have low reflection coefficients due to small difference in acoustic impedance between sandstones and compacted shales. In spite of this, major reflectors such as the Devonian unconformity, the top of the basement and the base of the Serra Geral Formation, among others, can be recognized by recent seismic research due to new technological advances in acquiring and processing data (Silva and Vianna, 1982). Future seismic study should be aimed at identification of the depositional cycles described here, on the seismic lines. In other words, future researches should study the seismic stratigraphy of the Itarare Group.

This approach may provide data to contour structure maps at the level of the depositional cycles. Such maps will improve the chances of drilling a structural closure near the reservoir rocks of the Itarare Group and thus diminish exploratory risk. Certainly this would be a great improvement for the exploration in a frontier basin such as the Parana Basin.

Future studies in the Itarare Group should emphasize paleontology for a better support on the lithostratigraphic and environmental analysis done in this work. Especial attention must be given to dating the Campo Mourao Formation in Santa Catarina and Parana states (Fig. 7). According to paleontological information in composite logs, the Campo Mourao Formation is dated as late Stephanian to Artinskian in wells drilled in Santa Catarina and Parana states. However, basin-wide log correlation (Figs. 10 to 14) suggests that the Campo Mourao Formation might be younger than actually proposed. A review on paleontological data of the Itarare Group would certainly improve the new stratigraphic column proposed in Figure 7.

Recently there has been good studies in marine sedimentation in cold seas such as Pelletier (1986) who studied the sediments of the Hudson Bay. Drewry (1986) presents an update work on glacial processes; chapters 10 to 14 emphasizes glacial sedimentation in continental and marine environments.

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APPENDIX 3

(Appendecis 1 and 2 are folded in back pocket)

Petrographic point count result

TACIBA FORMATION - Chapeu do Sol Member

SAMPLE	DEPTH	CORE #	Qm	Qp	Fk	Fp	RF	MTX	n
CB-1/1	3615	4	19	3	0	2	13	163	200
TB-1	2830	5	18	3	1	2	32	144	200
TB-2	2843	5	17	3	2	1	44	133	200
AL-1	2700	16	2	0	0	0	1	197	200
AL-9	2734	19	24	3	2	3	6	162	200
AL-16	2764	22	21	4	4	5	15	151	200
AA-2	1993	7	10	1	1	5	13	170	200
AA-27	2004	7	25	3	1	4	9	158	200
AVERAGE			17.0	2.5	1.4	2.8	16.6	159.8	
AVG/2			8.5	1.3	0.7	1.4	8.3	79.9	
STD			7.1	1.2	1.2	1.7	13.4	17.9	

TACIBA FORMATION - Rio Ivai Member.

SAMPLE	DEPTH	CORE #	Qm	Qp	Fk	Fp	RF	MTX	POR	CMT	n	VLC	SS	SLT	SHALE	GNT	MTM	UND	n
RP-1	3074	8	98	9	16	37	8	0	25	7	200	2	3	3	36	1	49	1	94
RP-2	3079	9	110	11	17	22	8	2	18	12	200	1	5	3	5	1	29	0	44
RP-4	3082	9	94	11	11	20	38	0	15	11	200	10	15	14	20	4	35	2	100
RP-7	3087	9	112	11	13	26	6	1	17	14	200								
CB-1/4	3785	5	104	14	12	6	12	6	3	43	200	9	10	9	5	1	34	0	68
CB-1/5	3786	5	86	18	8	10	51	0	0	27	200	11	26	8	0	14	40	1	100
TB-3	2997	7	81	31	9	8	35	0	6	30	200	11	21	5	6	7	47	3	100
TB-5	2999	7	95	25	6	8	32	0	20	14	200	14	31	3	7	0	42	3	100
TB-6	3002	7	127	13	9	10	7	0	30	4	200	4	20	7	7	0	58	4	100
TB-7	3004	7	102	24	9	3	30	0	19	13	200	10	17	17	20	1	28	0	93
CS-1/2	2713	28	120	7	14	33	7	8	9	2	200								
AVERAGE			102.6	15.8	11.3	16.6	21.3	1.5	14.7	16.1									
AVG/2			51.3	7.9	5.6	8.3	10.6	0.8	7.4	8.0									
STD			13.3	7.3	3.3	11.1	15.4	2.7	8.9	11.8									

LAGOA AZUL FORMATION - Cuiaba Paulista Member.

SAMPLE	DEPTH	CORE #	Qm	Qp	Fk	Fp	RF	MTX	POR	CMT	n
AA-19	2757	10	21	2	0	0	5	172	0	0	200
AA-21	2781	11	24	1	0	1	6	168	0	0	200
AA-23	2789	13	33	4	6	0	8	149	0	0	200
AA-26	2803	13	45	7	4	3	6	135	0	0	200
CB-4/2	4466	4	112	26	16	10	7	6	17	6	200
CB-4/4	4468	4	143	13	9	4	4	6	15	6	200
LA-4	3822	11	106	10	8	14	3	48	2	9	200
LA-6	3881	13	87	8	9	11	9	67	7	2	200
PN-9	1483	13	40	5	4	2	18	131	0	0	200
TI-1	4470	1	141	9	7	8	7	16	5	7	200
TI-3	4473	1	137	11	8	10	3	17	1	13	200
PA-2	1873	14	21	1	0	1	1	176	0	0	200
AVERAGE			75.8	8.1	5.9	5.3	6.4	90.9	3.9	3.6	
AVG/2			37.9	4.0	3.0	2.7	3.2	45.5	2.0	1.8	
STD			48.0	6.6	4.5	4.7	4.1	67.4	5.8	4.3	

CAMPO MOURAO FORMATION

SAMPLE	DEPTH	CORE #	Qm	Qp	Fk	Fp	RF	MTX	POR	CMT	n	VLC	SS	SLT	SHALE	GNT	MTM	UND	n
PN-5	775	10	116	6	15	16	0	0	47	0	200								
RO-6	3167	4	74	29	14	9	50	0	5	19	200	10	21	6	1	15	45	2	100
RO-7	3165	4	73	12	6	12	33	64	0	0	200	8	4	3	0	1	27	1	44
RI-1	3285	15	113	9	9	30	2	0	26	11	200								
LA-2	2664	10	35	8	1	4	51	95	0	6	200	5	10	4	3	18	25	1	66
AL-23	3009	28	115	7	23	17	3	0	29	6	200								
CS-2/2	3086	5	99	4	1	5	0	65	4	22	200								
CS-2/3	3105	7	114	3	0	32	2	0	0	49	200								
CS-2/5	3113	11	118	3	7	26	6	31	1	8	200								
AA-4	2291	8	108	6	9	11	24	10	28	4	200	20	19	7	11	4	37	2	100
AA-5	2292	8	108	9	17	12	21	7	22	4	200	12	32	10	15	6	25	0	100
AA-6	2293	8	99	10	17	11	20	13	21	9	200	11	28	14	7	4	36	0	100
AA-7	2294	8	107	14	9	11	21	18	16	4	200	8	21	14	9	3	44	1	100
AA-8	2295	8	122	6	8	6	24	13	19	2	200	12	25	15	17	0	31	0	100
AA-9	2296	8	90	8	13	5	51	12	14	7	200	18	28	11	5	6	31	1	100
AA-10	2297	8	69	7	8	9	70	14	15	8	200	10	32	9	7	7	35	0	100
AA-11	2298	8	117	11	6	9	21	9	13	14	200	16	28	19	7	0	30	0	100
AA-12	2299	8	120	6	11	9	8	7	29	10	200	5	11	10	23	2	21	1	100
AA-13	2303	8	76	12	8	14	21	69	0	0	200								
AVERAGE			98.57	8.9	9.6	13.1	22.5	22.5	15.2	9.6									
AVG/2			49.3	4.5	4.8	6.5	11.3	11.2	7.6	4.8									
STD			22.7	5.6	5.8	7.9	19.8	27.9	12.8	11.0									

LAGOA AZUL FORMATION - Tarabai Member.

SAMPLE	DEPTH	CORE #	Qm	Qp	Fk	Fp	RF	MTX	POR	CMT	n	VLC	SS	SLT	SHALE	GNT	MTM	UND	n
CB-1/7	4478	7	109	36	1	4	18	0	20	12	200	6	15	6	2	2	34	1	66
CB-1/8	4708	9	131	7	13	19	2	2	7	19	200								
CB-3/14	4483	8	151	11	10	5	0	1	11	11	200								
CB-3/17	4484	8	135	6	16	9	1	0	20	13	200								
CB-3/22	4460	5	143	14	0	2	0	0	1	40	200								
CB-3/29	4463	5	162	12	0	5	4	2	5	10	200								
CB-3/36	4472	7	131	20	0	7	6	0	17	19	200								
CB-3/37	4477	7	141	8	0	12	2	1	34	2	200								
CB-3/38	4478	8	146	7	0	14	1	0	25	7	200								
CB-3/39	4479	8	159	14	0	15	2	2	7	1	200								
CB-3/40	4465	6	121	6	12	23	1	22	1	14	200								
CB-3/54	4543	10	141	5	5	8	5	1	32	3	200								
CB-3/55	4547	10	137	12	8	7	0	11	9	16	200								
TB-9	3709	9	114	3	10	24	4	2	0	43	200								
AVERAGE			137.2	11.5	5.4	11.0	3.3	3.1	13.5	15.0									
AVG/2			68.6	5.8	2.7	5.5	1.6	1.6	6.8	7.5									
STD			14.9	8.1	5.7	6.8	4.5	5.9	10.9	12.2									

Symbols:

Qm - Monocrystalline quartz

Qp - Polycrystalline quartz

Fk - Potassium feldspar

Fp - Plagioclase

Rf - Rock fragment

MTX - Matrix

POR - Porosity

CMT - Cement

n - total number of point counts

VLC - Volcanic rock fragments

SS - Sandstone fragments

SLT - Siltstone fragments

GNT - Granite fragments

MTM - Metamorphic rock fragments

UND - Unidentified rock fragment

APPENDIX 4

Lopatin's Method Result

2-CB-1-SP well

Platte River Associates, Inc.: LOPATIN (v 1.00)
Burial History
Cuiaba Paulista No. 1 (2-CB-1-SP)

January 1, 1980 20:11

****

Formation summary:

Layer:	Formation	Top Bottom m	Temperature C	TTI
1 :	Bauru Formation	0	20.0	0.0
		216	24.8	0.3
2 :	Serra Geral Fm.	216	24.8	0.3
		1939	62.7	9.5
3 :	Botucatu Fm.	1939	62.7	9.5
		2094	66.1	13.6
4 :	R. Rasto + Ter.	2094	66.1	13.6
		3220	90.8	187.0
5 :	Irati + Tatui	3220	90.8	187.0
		3547	98.0	422.6
6 :	Itarare' Group	3547	98.0	422.6
		4973	129.4	17430.9
10 :	Ponta Grossa Fm	4973	129.4	17431.2
		5078	131.7	23076.6
11 :	Furnas Fm.	5078	131.7	23076.6
		5141	133.1	27315.0

Platte River Associates, Inc.: LOPATIN (v 1.00)
Burial History
Cuiaba Paulista No. 1 (2-CB-1-SP)

January 1, 1980 20:11

****

Calculation interval: 4.0 m.y.

Top of oil window (at TTI= 10): 1961 m.
Bottom of oil window (at TTI=180): 3200 m

Platte River Associates, Inc.: LOPATIN (v 1.00)
Burial History
Cuiaba Paulista No. 1 (2-CB-1-SP)

January 1, 1980 20:11
Location: Sao Paulo State, Brazil
Basin: Bacia do Parana'
Geologist: A. Franca

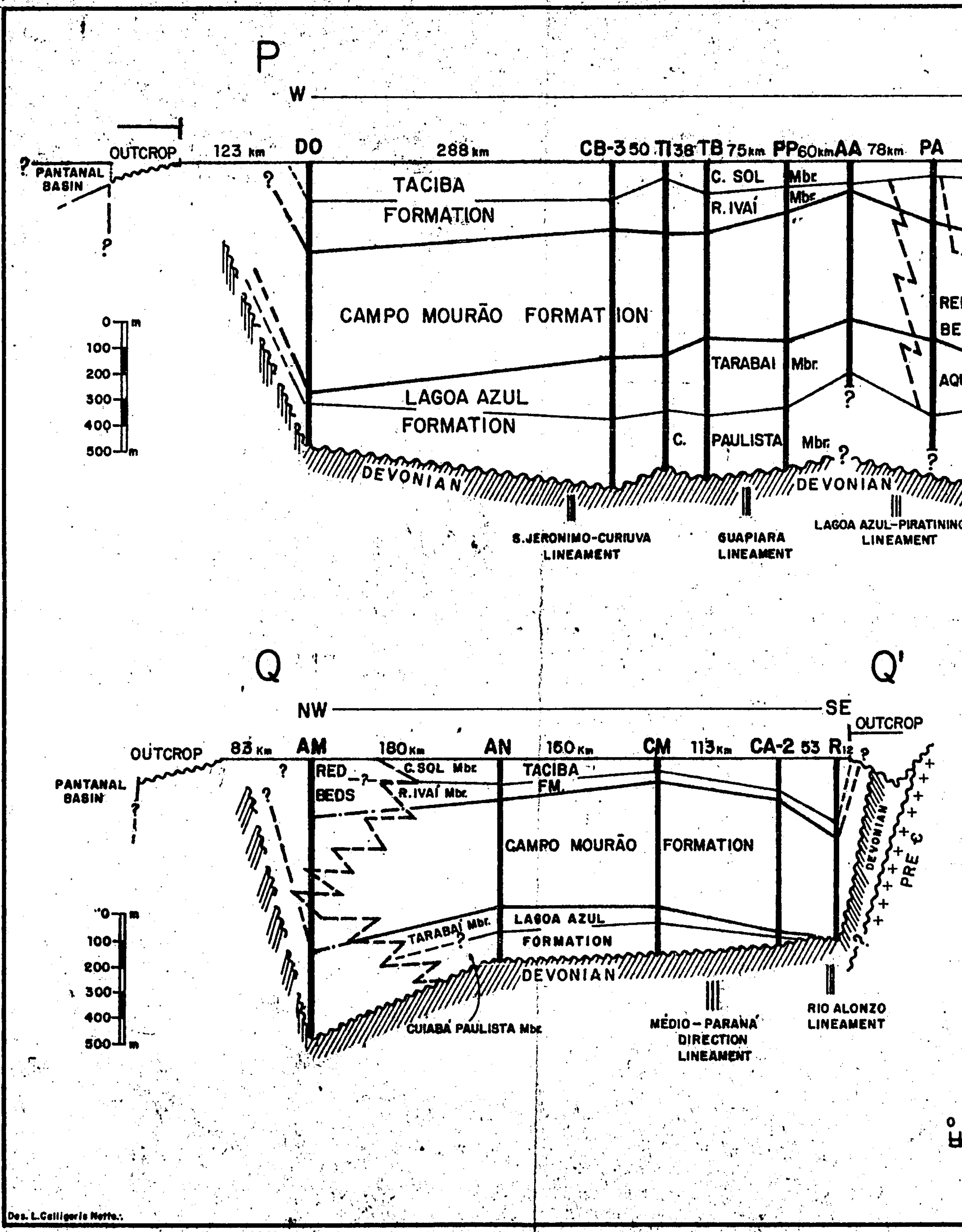
****

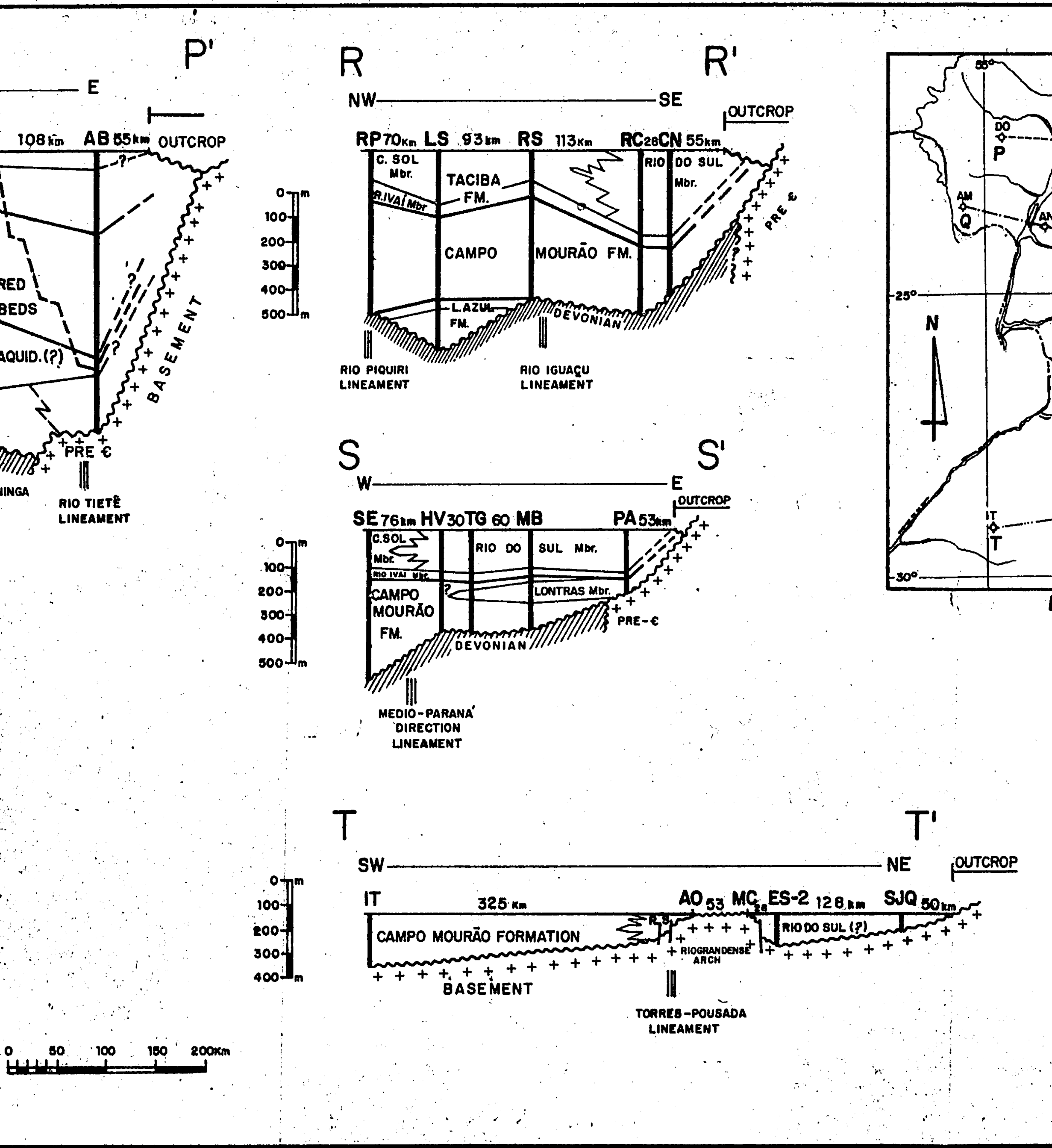
Rock layer parameters:

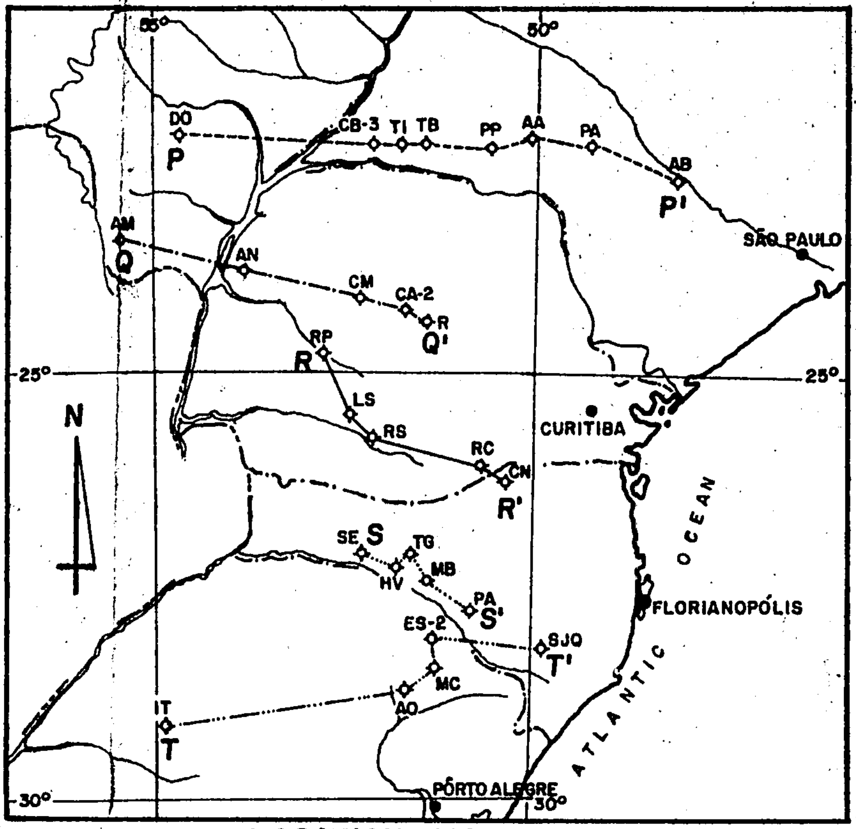
Layer:	Formation	Time at top	Time at bottom	Thickness m	Ts C
1 :	Bauru Formation	0.0	100.0	216	20.0
2 :	Serra Geral Fm.	100.0	140.0	1723	20.0
3 :	Botucatu Fm.	140.0	230.0	155	20.0
4 :	R. Rasto + Ter.	230.0	253.0	1126	20.0
5 :	Irati + Tatui	253.0	263.0	327	20.0
6 :	Itarare' Group	263.0	296.0	1426	10.0
7 :	Erosion	296.0	306.0	-200	20.0
8 :	Hiatus	306.0	350.0	0	20.0
9 :	Deposition	350.0	374.0	200	20.0
10 :	Ponta Grossa Fm	374.0	394.0	105	20.0
11 :	Furnas Fm.	394.0	400.0	63	20.0

Geothermal Gradients:

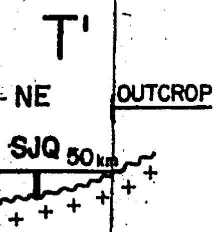
# :	Time	Leg 1	
1 :	0.0	2.20	(C/100 m)
2 :	70.0	2.21	(C/100 m)
3 :	100.0	4.00	(C/100 m)
4 :	140.0	4.00	(C/100 m)
5 :	170.0	2.20	(C/100 m)


P
W
OUTCROP
123 km
DO
288 km
CB-3 50 TI 38 TB 75 km PP 60 km AA 78 km PA
PANTANAL BASIN
TACIBA FORMATION
C. SOL Mbr.
R. IVAÍ Mbr.
CAMPO MOURÃO FORMATION
TARABAI Mbr.
LAGOA AZUL FORMATION
C. PAULISTA Mbr.
DEVONIAN
S.JERONIMO-CURIUVA LINEAMENT
GUAPIARA LINEAMENT
LAGOA AZUL-PIRATININGA LINEAMENT
Q
Q'
NW
SE
OUTCROP
83 Km AM 180 Km AN 160 Km CM 113 Km CA-2 53 R12
PANTANAL BASIN
RED BEDS
C.SOL Mbr.
R.IVAÍ Mbr.
TACIBA FM.
CAMPO MOURÃO FORMATION
TARABAÍ Mbr.
LAGOA AZUL FORMATION
DEVONIAN
CUIABÁ PAULISTA Mbr.
MÉDIO-PARANÁ DIRECTION LINEAMENT
RIO ALONZO LINEAMENT
PRE Є
0 m
100
200
300
400
500 m
Des. L.Calligeris Netto.


P'
E
108 km
AB 55 km
OUTCROP
RED
BEDS
AQUID.(?)
BASEMENT
PRE Є
RIO TIETÊ
LINEAMENT
R
R'
NW
SE
OUTCROP
RP 70 Km
LS
93 km
RS
113 Km
RC 28 CN 55 km
C. SOL
Mbr.
R.IVAÍ Mbr
TACIBA
FM.
CAMPO
MOURÃO FM.
RIO
DO SUL
Mbr.
L.AZUL
FM.
DEVONIAN
PRE Є
RIO PIQUIRI
LINEAMENT
RIO IGUAÇU
LINEAMENT
0 m
100
200
300
400
500 m
S
S'
W
E
OUTCROP
SE 76 km
HV 30
TG 60
MB
PA 53 km
C.SOL
Mbr.
RIO IVAI Mbr.
RIO DO SUL Mbr.
LONTRAS Mbr.
CAMPO
MOURÃO
FM.
DEVONIAN
PRE-Є
MEDIO-PARANÁ
DIRECTION
LINEAMENT
0 m
100
200
300
400
500 m
T
T'
SW
NE
OUTCROP
IT
325 Km
AO 53
MC 28
ES-2
128 km
SJQ 50 km
CAMPO MOURÃO FORMATION
R.S.
RIO DO SUL (?)
RIOGRANDENSE
ARCH
BASEMENT
TORRES-POUSADA
LINEAMENT
0 m
100
200
300
400 m
0
50
100
150
200Km
DO
P
AM
Q
IT
T
N
25°
30°



LOCATION MAP



MAIN LITHOLOGIES

CHAPÉU DO SOL MEMBER: PEBBLY MUDSTONE

RIO IVAÍ MEMBER: SANDSTONE; SILTSTONE

RIO DO SUL MEMBER: SHALE, SANDSTONE

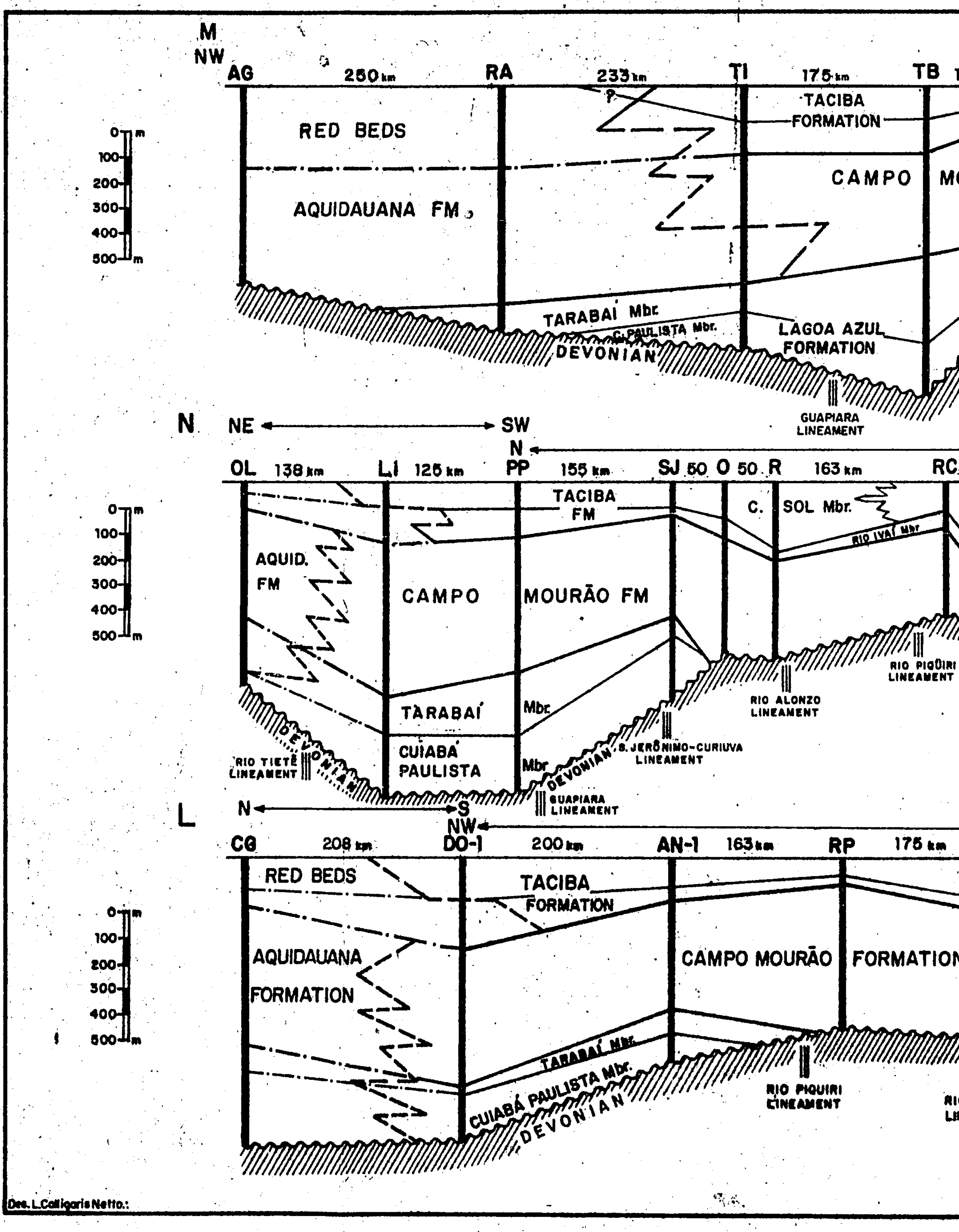
CAMPO MOURÃO FORMATION: SANDSTONE, SILTSTONE PEBBLY MUDSTONE; SHALE.

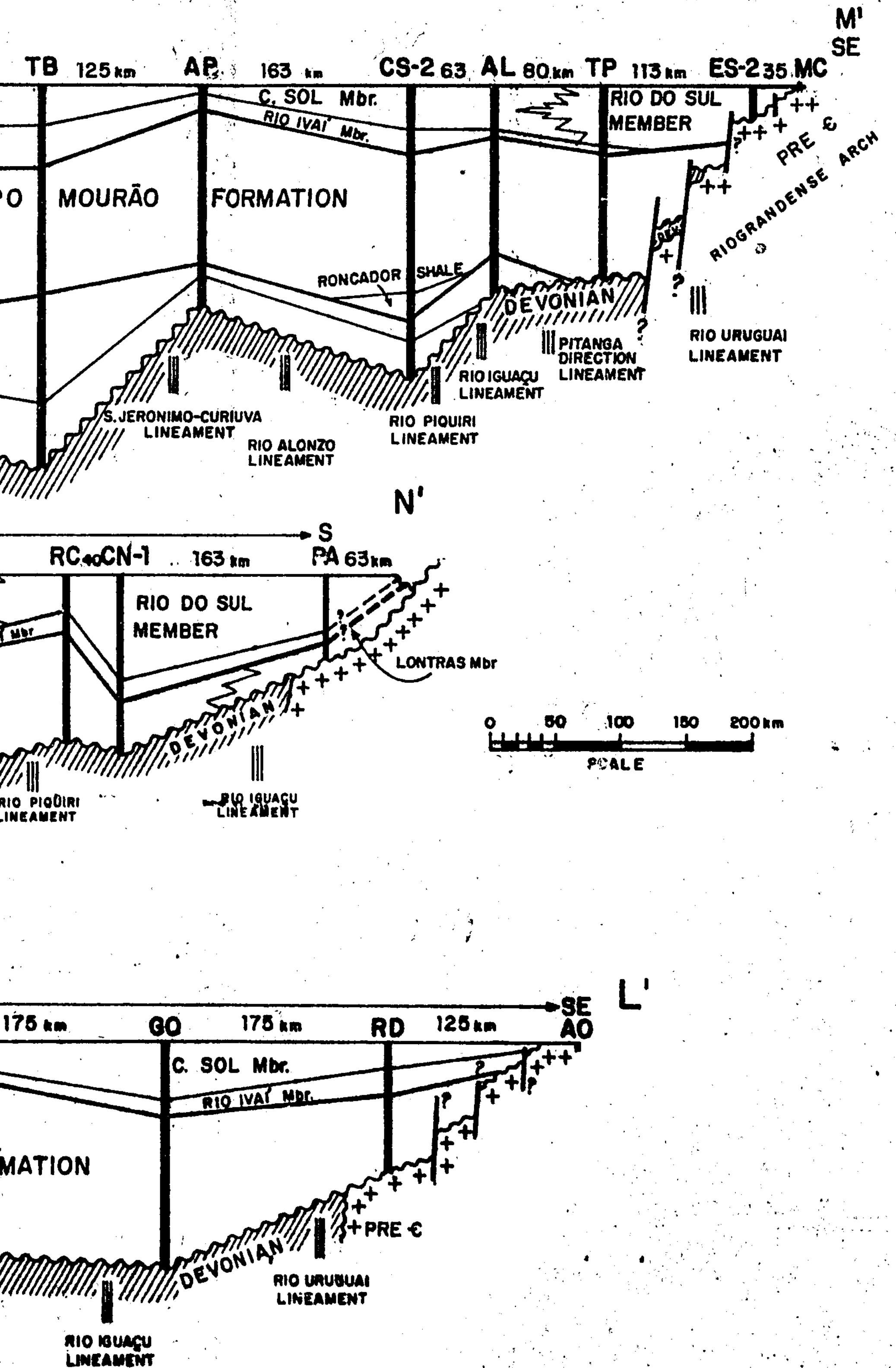
LONTRAS MEMBER: BLACK SHALE AND SANDSTONE

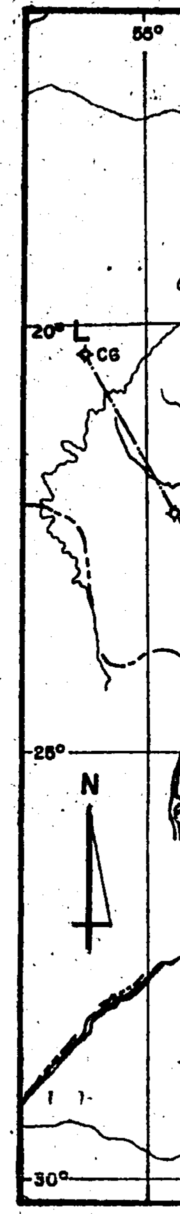
TARABAI MEMBER: SILTSTONE, PEBBLY MUDSTONE, SANDSTONE, SHALE

CUIABÁ PAULISTA MEMBER: SANDSTONE

Appendex 1

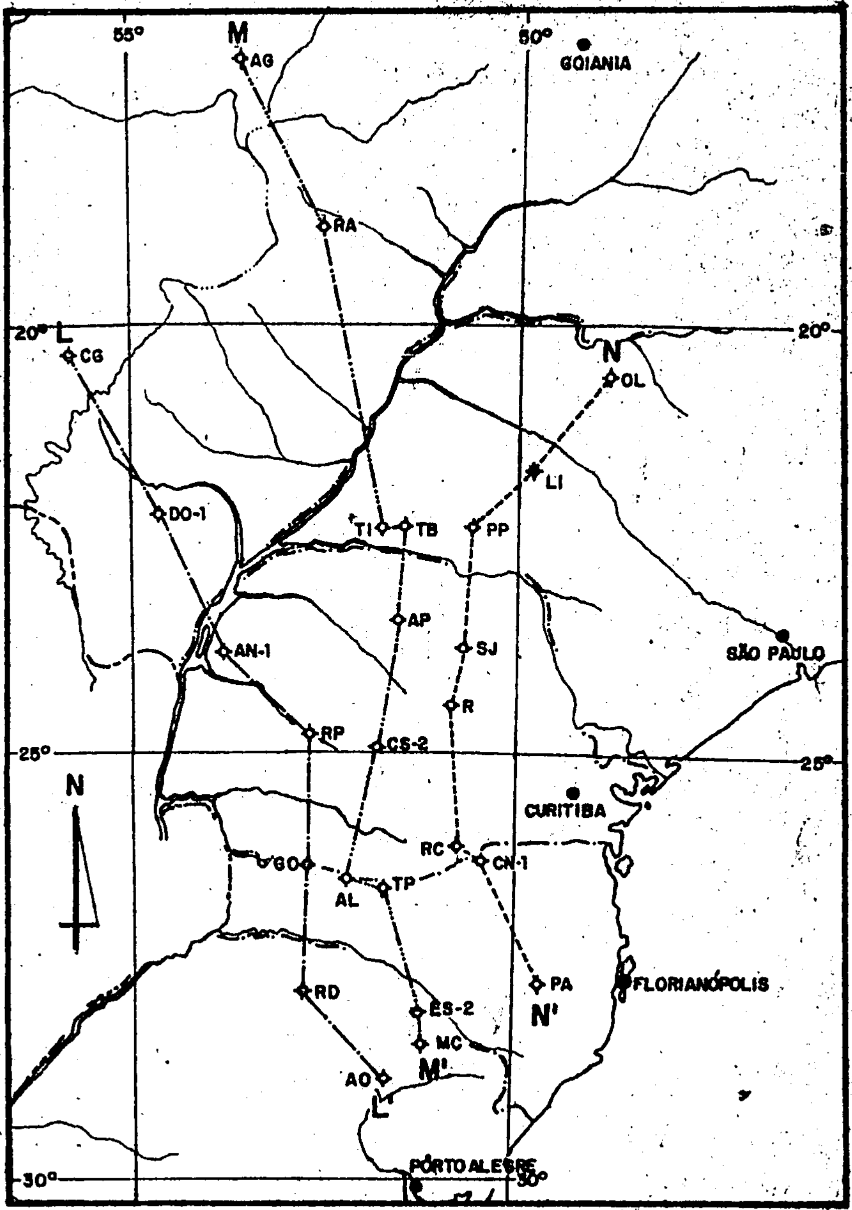

M
NW
AG
250 km
RA
233 km
TI
175 km
TB
RED BEDS
AQUIDAUANA FM
TACIBA FORMATION
CAMPO
TARABAI Mbr.
C. PAULISTA Mbr.
DEVONIAN
LAGOA AZUL FORMATION
GUAPIARA LINEAMENT
0 m
100
200
300
400
500 m
N
NE
SW
OL
138 km
LI
125 km
PP
155 km
SJ
50
O
50
R
163 km
TACIBA FM
C.
SOL Mbr.
RIO IVAÍ Mbr
AQUID. FM
CAMPO
MOURÃO FM
TARABAÍ
Mbr.
CUIABÁ PAULISTA
Mbr
DEVONIAN
RIO TIETÊ LINEAMENT
GUAPIARA LINEAMENT
S. JERÔNIMO-CURIUVA LINEAMENT
RIO ALONZO LINEAMENT
RIO PIQÜIRI LINEAMENT
L
N
S
NW
CG
208 km
DO-1
200 km
AN-1
163 km
RP
175 km
RED BEDS
TACIBA FORMATION
AQUIDAUANA FORMATION
CAMPO MOURÃO
FORMATION
TARABAÍ Mbr.
CUIABÁ PAULISTA Mbr.
DEVONIAN
RIO PIQUIRI LINEAMENT
Des. L. Calligaris Netto.:





CHAPÉU DO S
RIO IVAI ME
RIO DO SUL
CAMPO MOU
LONTRAS ME
TARABAI ME
RONCADOR
CUIABÁ PAU
AQUIDAUANA

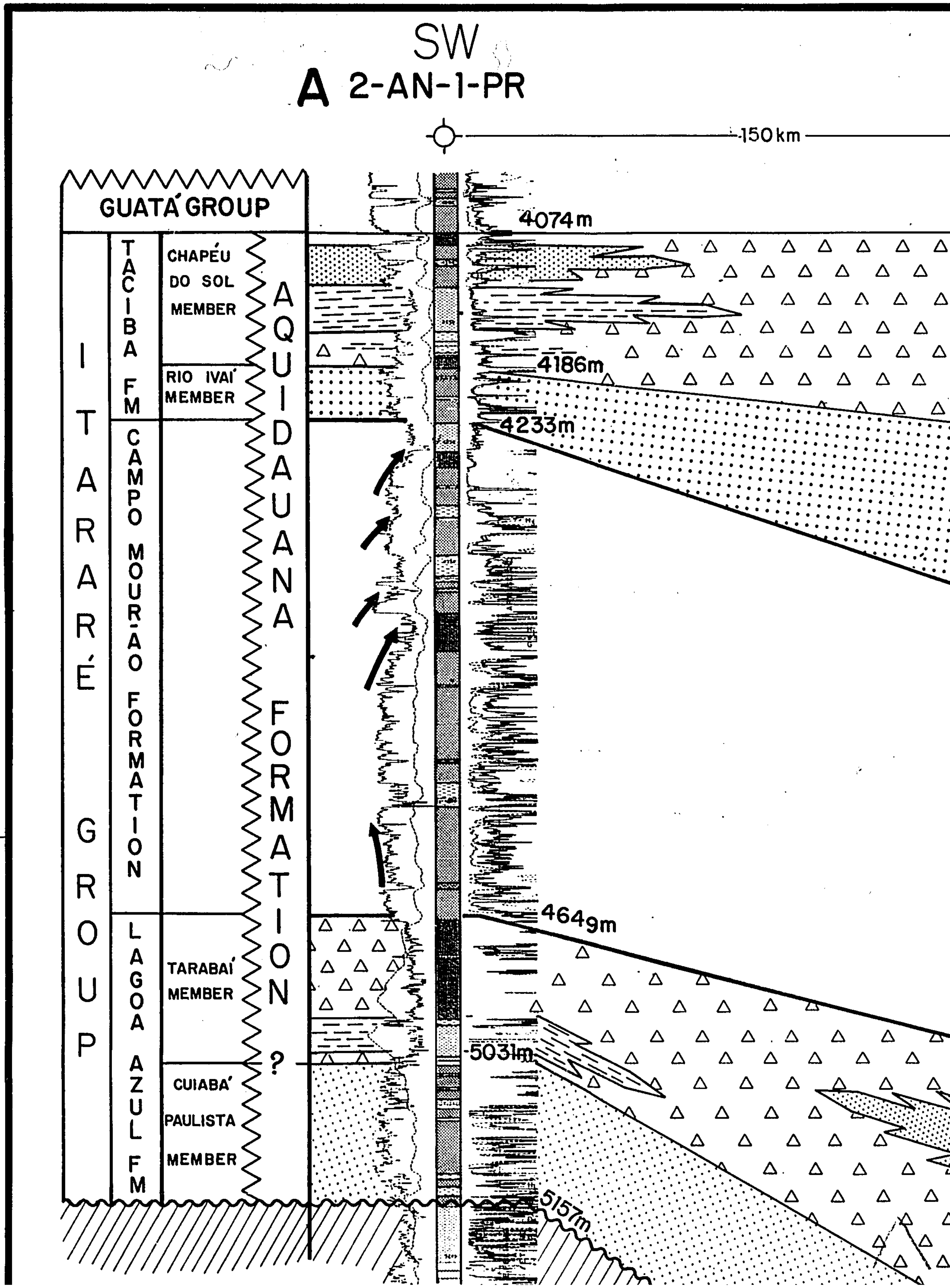
Appendex 2

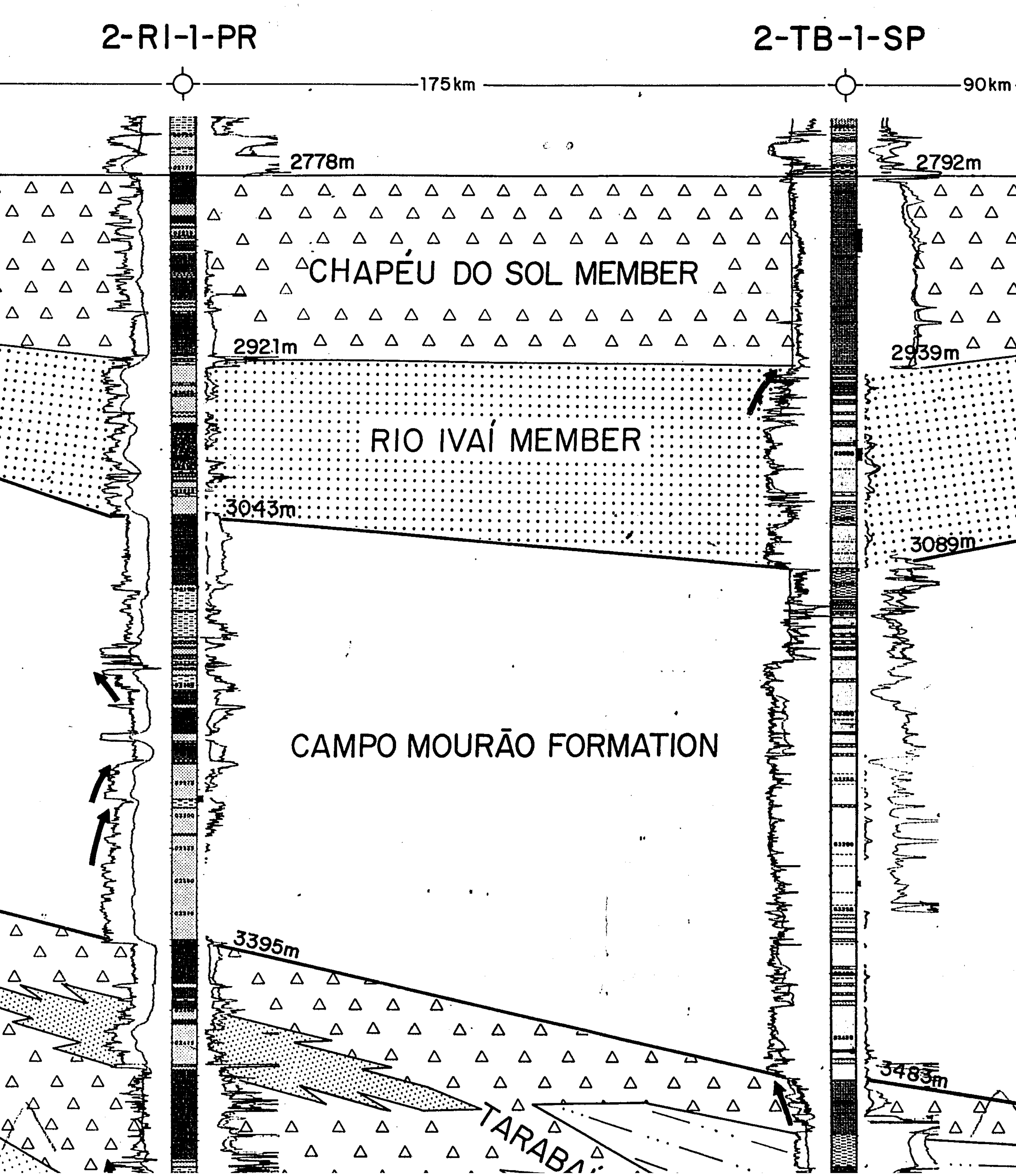


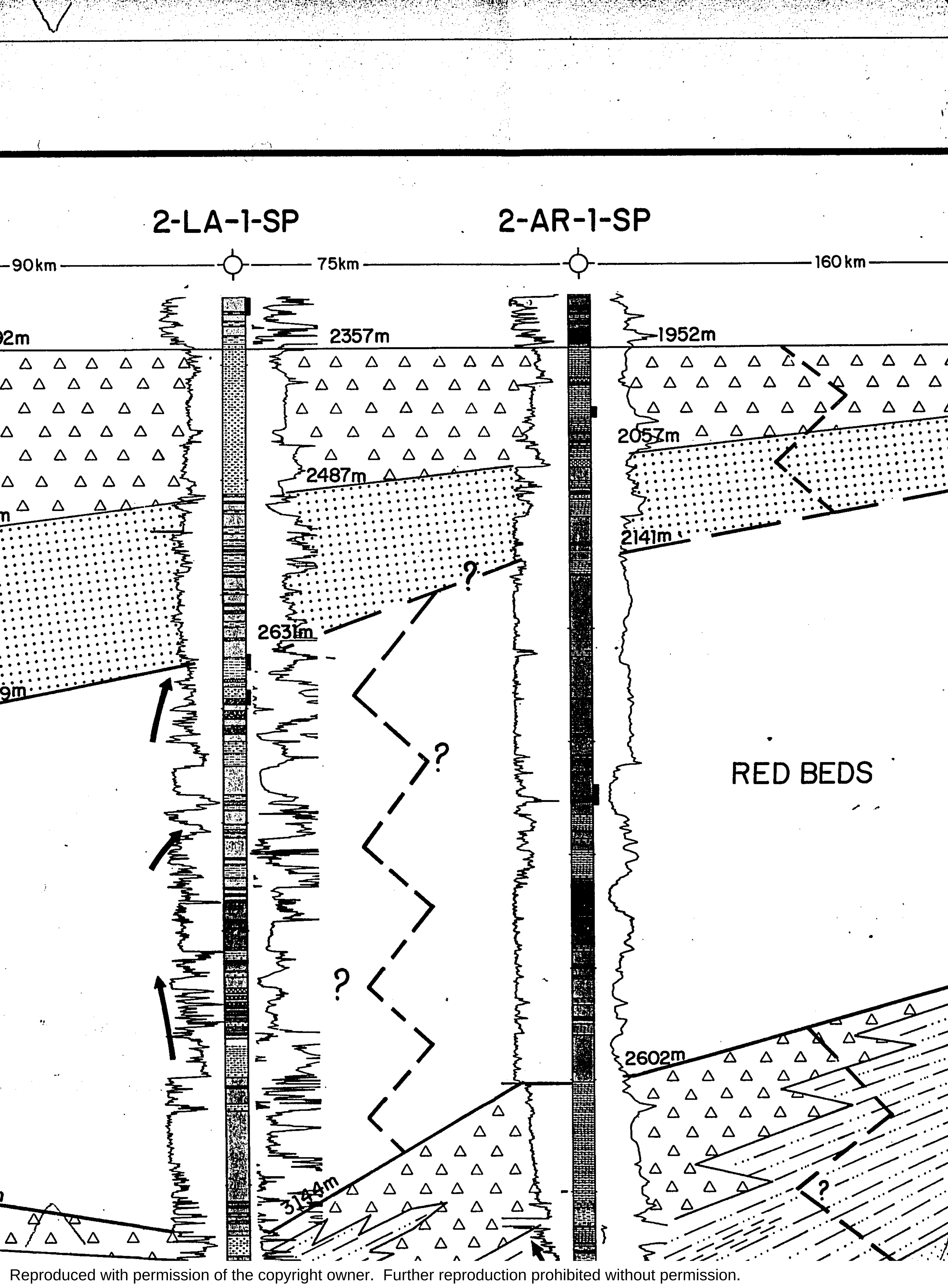
LOCATION MAP

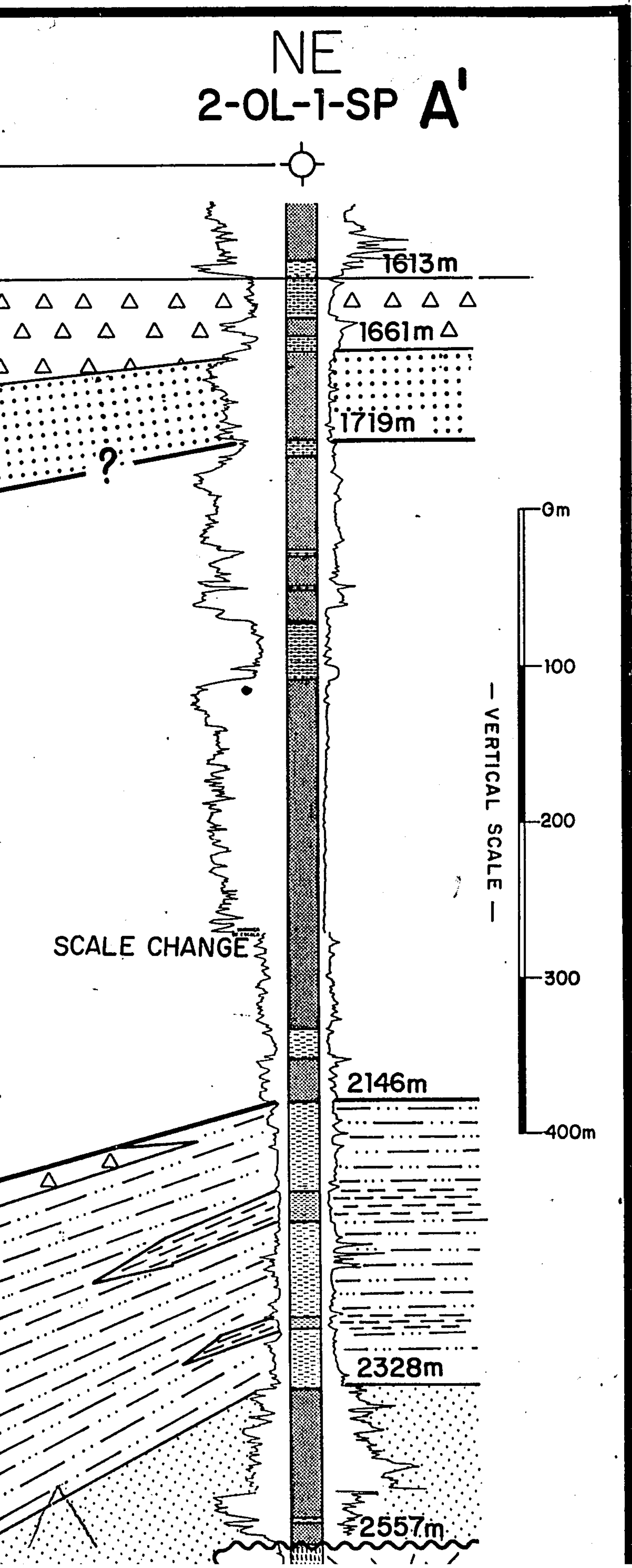
MAIN LITHOLOGIES

CHAPÉU DO SOL MEMBER: PEBBLY MUDSTONE.
RIO IVAÍ MEMBER: SANDSTONE; SILTSTONE.
RIO DO SUL MEMBER: SHALE, SANDSTONE.
CAMPO MOURÃO FORMATION: SANDSTONE, PEBBLY MUDSTONE, SILTSTONE, SHALE.
LONTRAS MEMBER: BLACK SHALE, SANDSTONE.
TARABAÍ MEMBER: SILTSTONE, PEBBLY MUDSTONE, SANDSTONE SHALE.
RONCADOR SHALE: BLACK TO BROWNISH SHALE WITH HIGH GAMMA RAY VALUES.
CUIABÁ PAULISTA MEMBER: SANDSTONE.
AQÜIDAUANA FORMATION: RED SANDESTONE, SILTSTONE, AND PEBBLY MUDSTONE.


SW
A 2-AN-1-PR
150 km
GUATÁ GROUP
ITARARÉ GROUP
TACIBA FM
CHAPÉU DO SOL MEMBER
RIO IVAÍ MEMBER
CAMPO MOURÃO FORMATION
LAGOA AZUL FM
TARABAÍ MEMBER
CUIABÁ PAULISTA MEMBER
AQUIDAUANA FORMATION
?
4074m
4186m
4233m
4649m
5031m
5157m


2-RI-1-PR
2-TB-1-SP
175km
90km
2778m
2792m
CHAPÉU DO SOL MEMBER
2921m
2939m
RIO IVAÍ MEMBER
3043m
3089m
CAMPO MOURÃO FORMATION
3395m
3483m


2-LA-1-SP
2-AR-1-SP
90km
75km
160km
2357m
1952m
2487m
2057m
2141m
2631m
RED BEDS
2602m
3144m

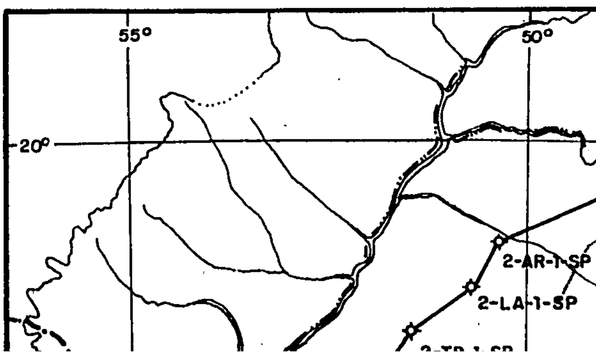


STRATIGRAPHIC CROSS S

DATUM: TOP OF ITARARÉ

DIABASE EXCLUDE

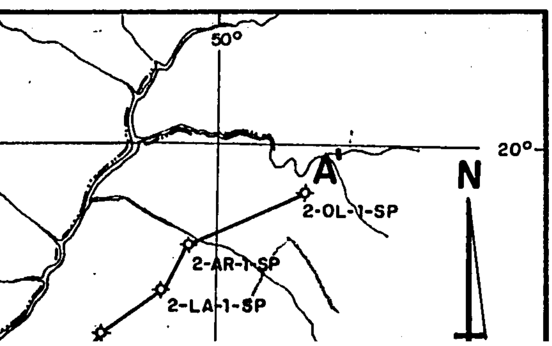
LOCATION MA

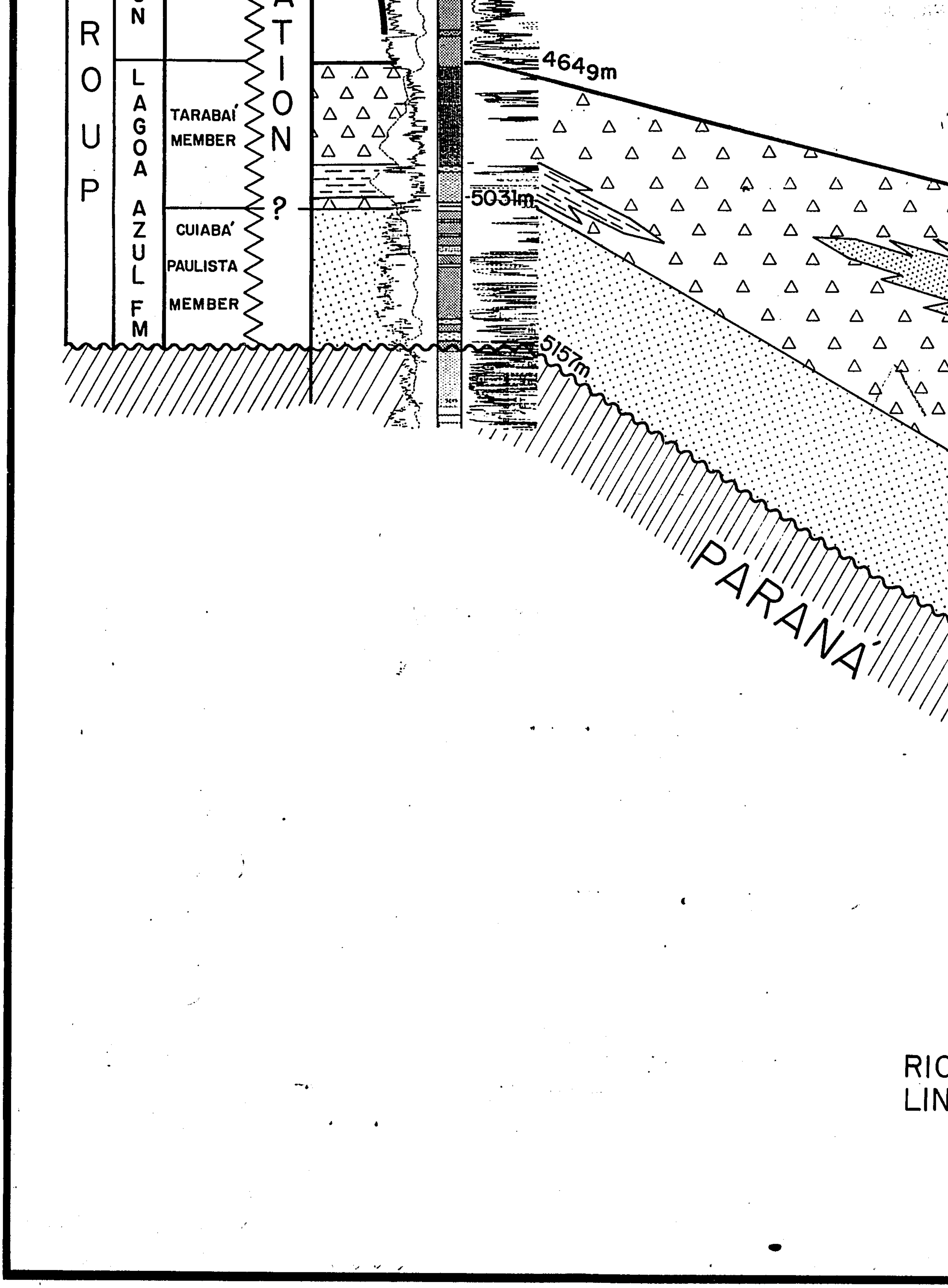


HIC CROSS SECTION A-A'
P OF ITARARÉ GROUP
ASE EXCLUDED

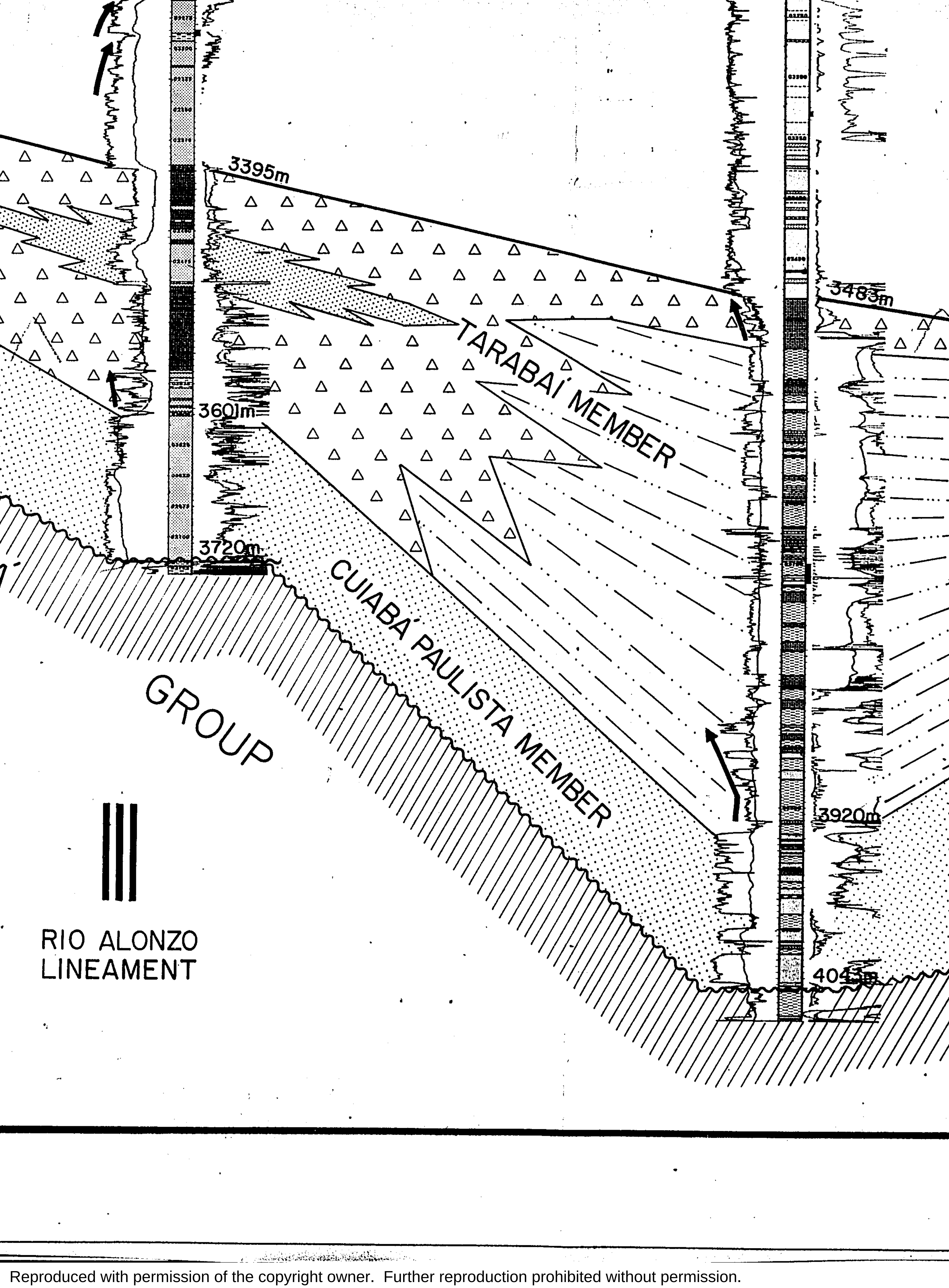
Fig. 10

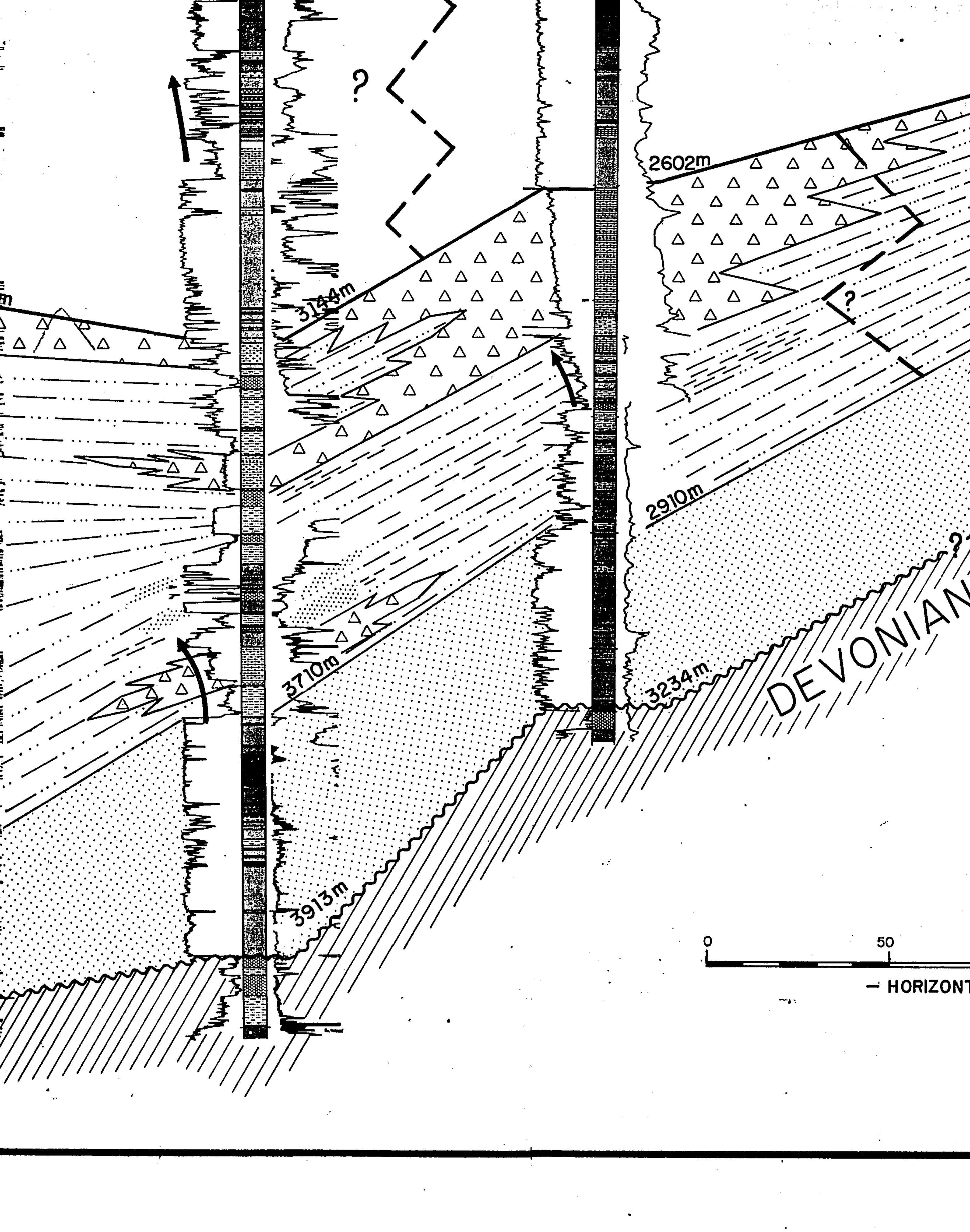
CATION MAP

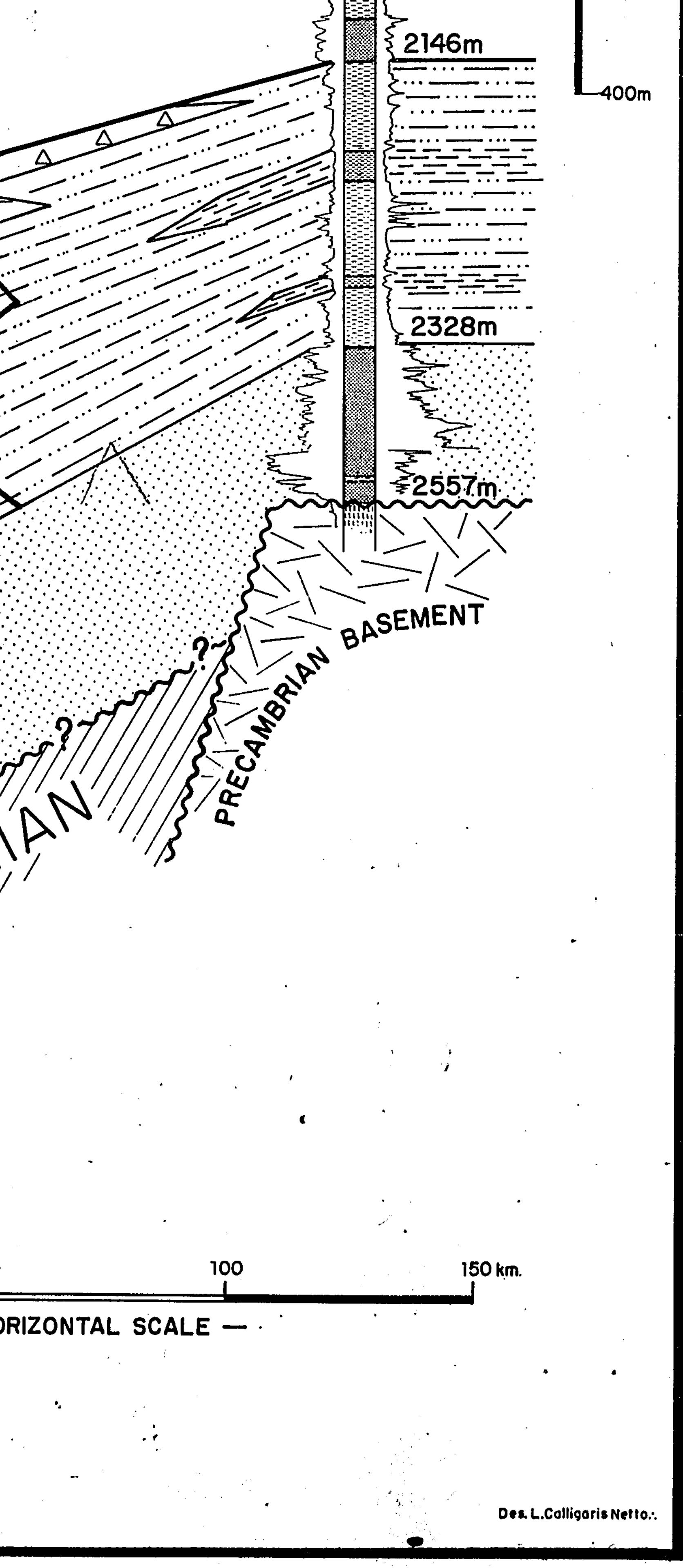


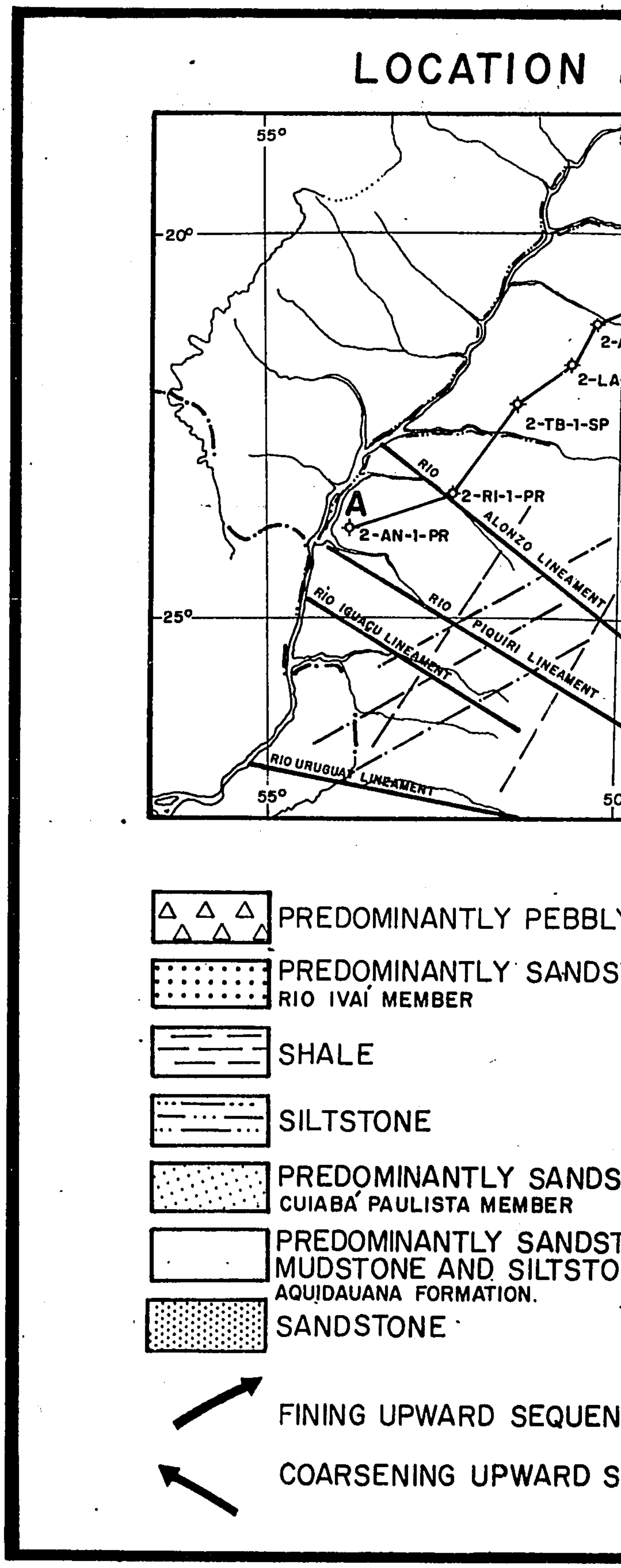


R
O
U
P
N
L
A
G
O
A
A
Z
U
L
F
M
TARABAÍ
MEMBER
CUIABÁ
PAULISTA
MEMBER
A
T
I
O
N
?
4649m
5031m
5157m
PARANÁ
RIO
LIN

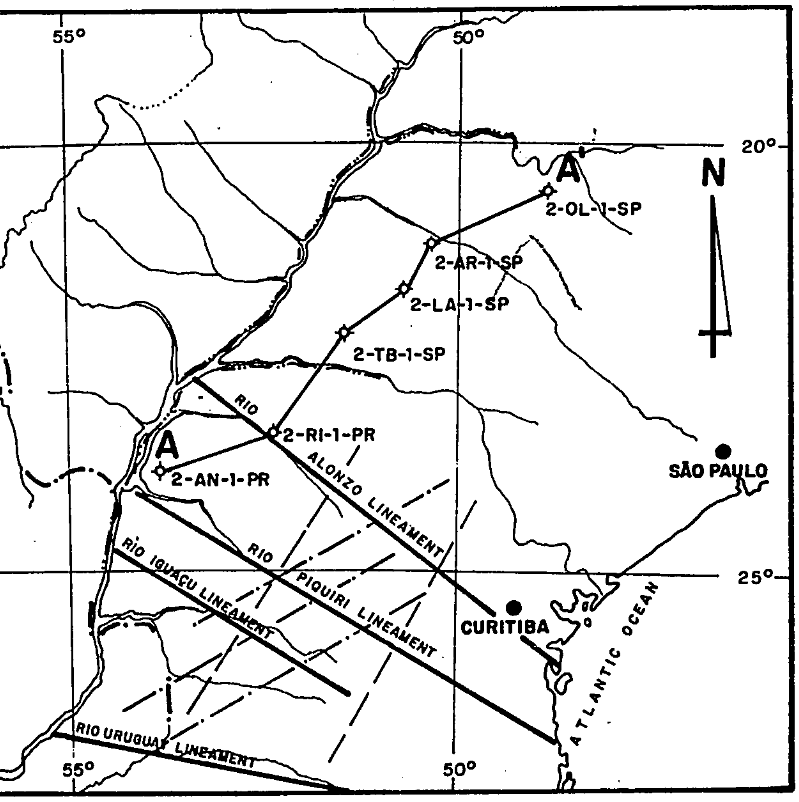

3395m
3483m
TARABAÍ MEMBER
3601m
3720m
CUIABÁ PAULISTA MEMBER
GROUP
3920m
4043m
RIO ALONZO
LINEAMENT


2602m
3144m
2910m
3710m
3234m
3913m
DEVONIAN
?
0
50
HORIZONT


2146m
400m
2328m
2557m
PRECAMBRIAN BASEMENT
IAN
100
150 km.
ORIZONTAL SCALE —
Des. L.Calligaris Netto.


LOCATION
55°
20°
25°
55°
2-TB-1-SP
2-RI-1-PR
2-AN-1-PR
A
RIO ALONZO LINEAMENT
RIO PIQUIRI LINEAMENT
RIO IGUAÇU LINEAMENT
RIO URUGUAY LINEAMENT
PREDOMINANTLY PEBBL
PREDOMINANTLY SANDS
RIO IVAÍ MEMBER
SHALE
SILTSTONE
PREDOMINANTLY SANDS
CUIABÁ PAULISTA MEMBER
PREDOMINANTLY SANDST
MUDSTONE AND SILTSTO
AQUIDAUANA FORMATION.
SANDSTONE
FINING UPWARD SEQUEN
COARSENING UPWARD S

LOCATION MAP



PREDOMINANTLY PEBBLY MUDSTONE

PREDOMINANTLY SANDSTONE
RIO IVAÍ MEMBER

SHALE

SILTSTONE

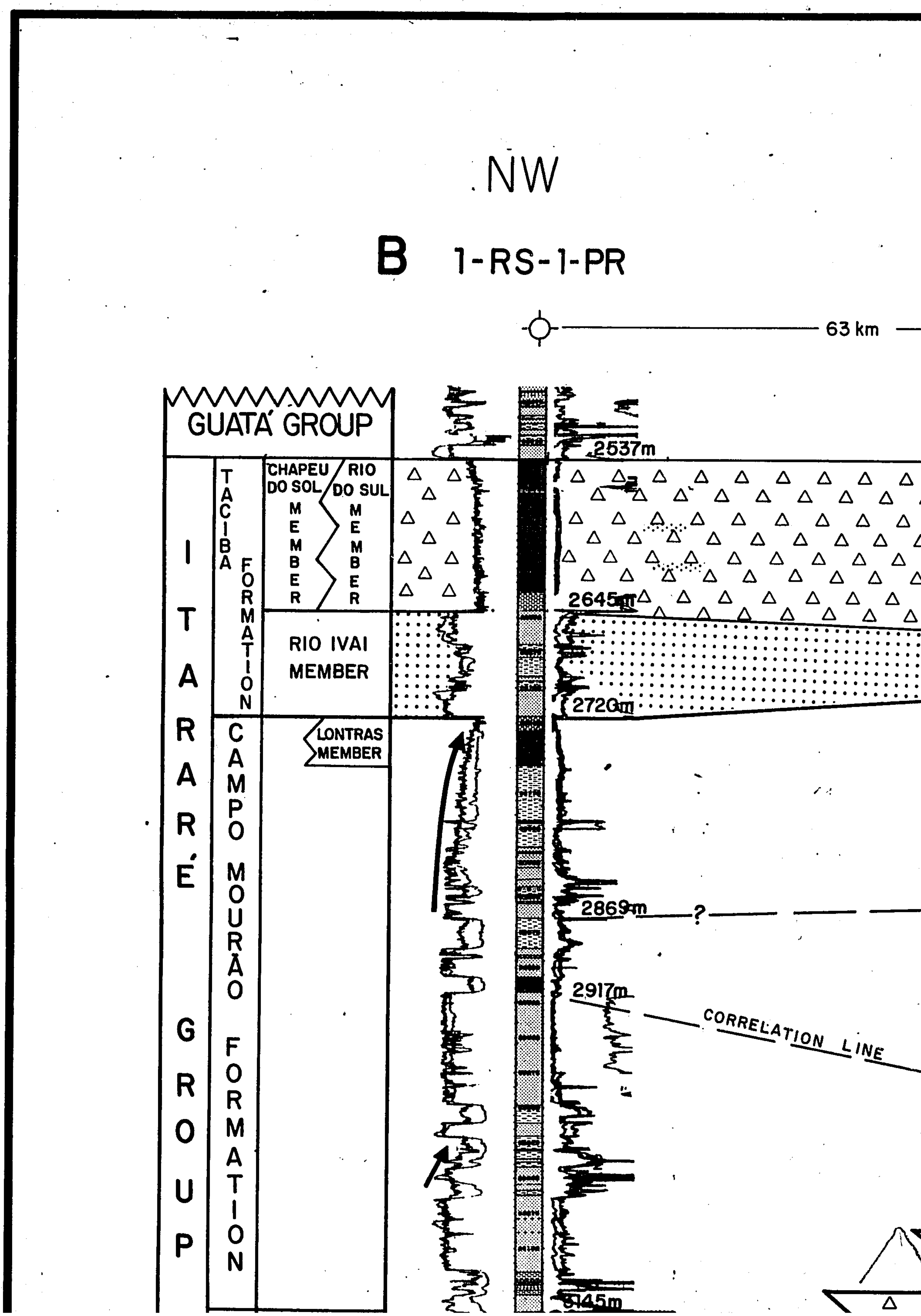
PREDOMINANTLY SANDSTONE
CUIABÁ PAULISTA MEMBER

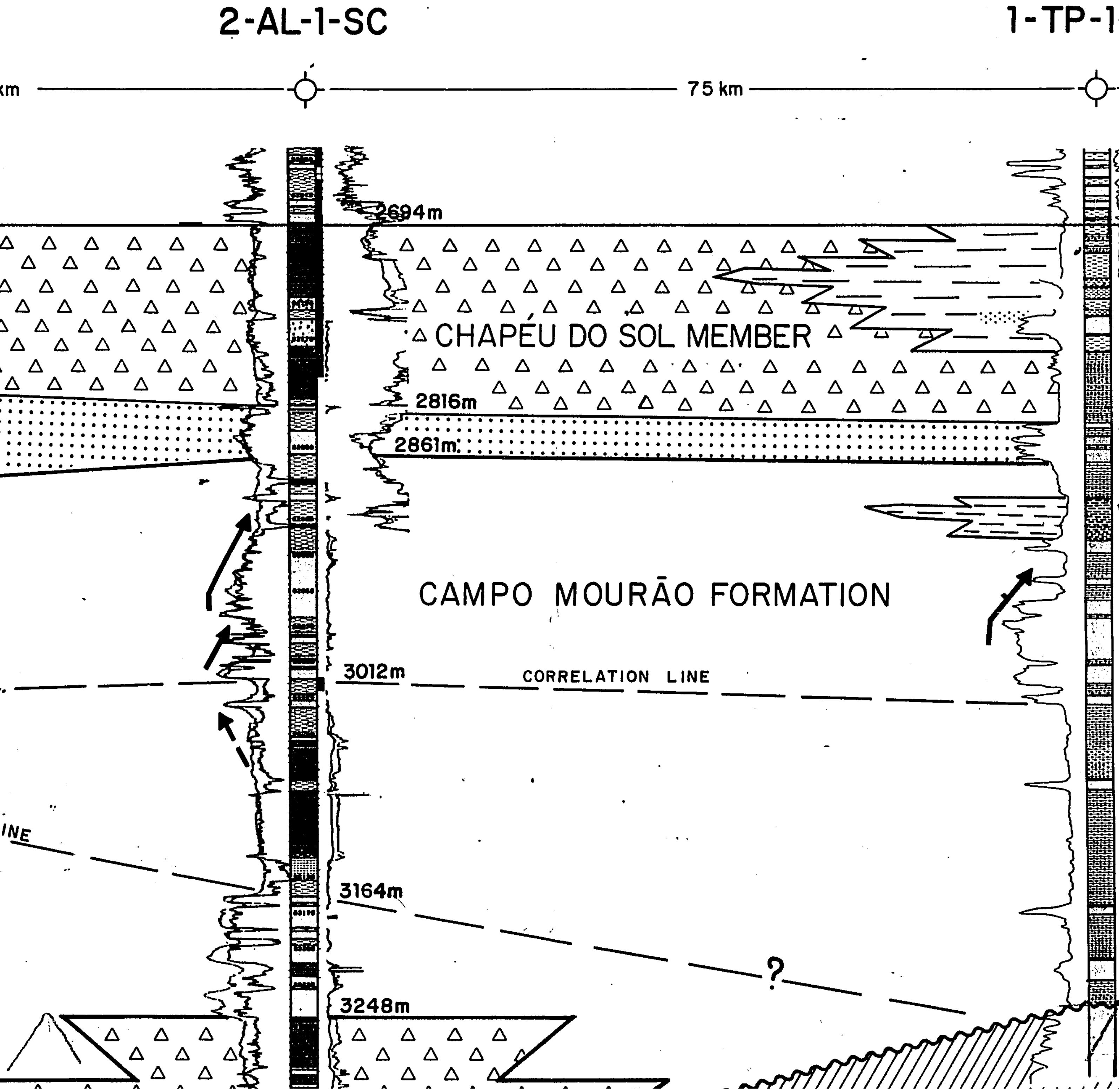
PREDOMINANTLY SANDSTONE, ALSO PEBBLY MUDSTONE AND SILTSTONE. CAMPO MOURÃO AND AQUIDAUANA FORMATION.

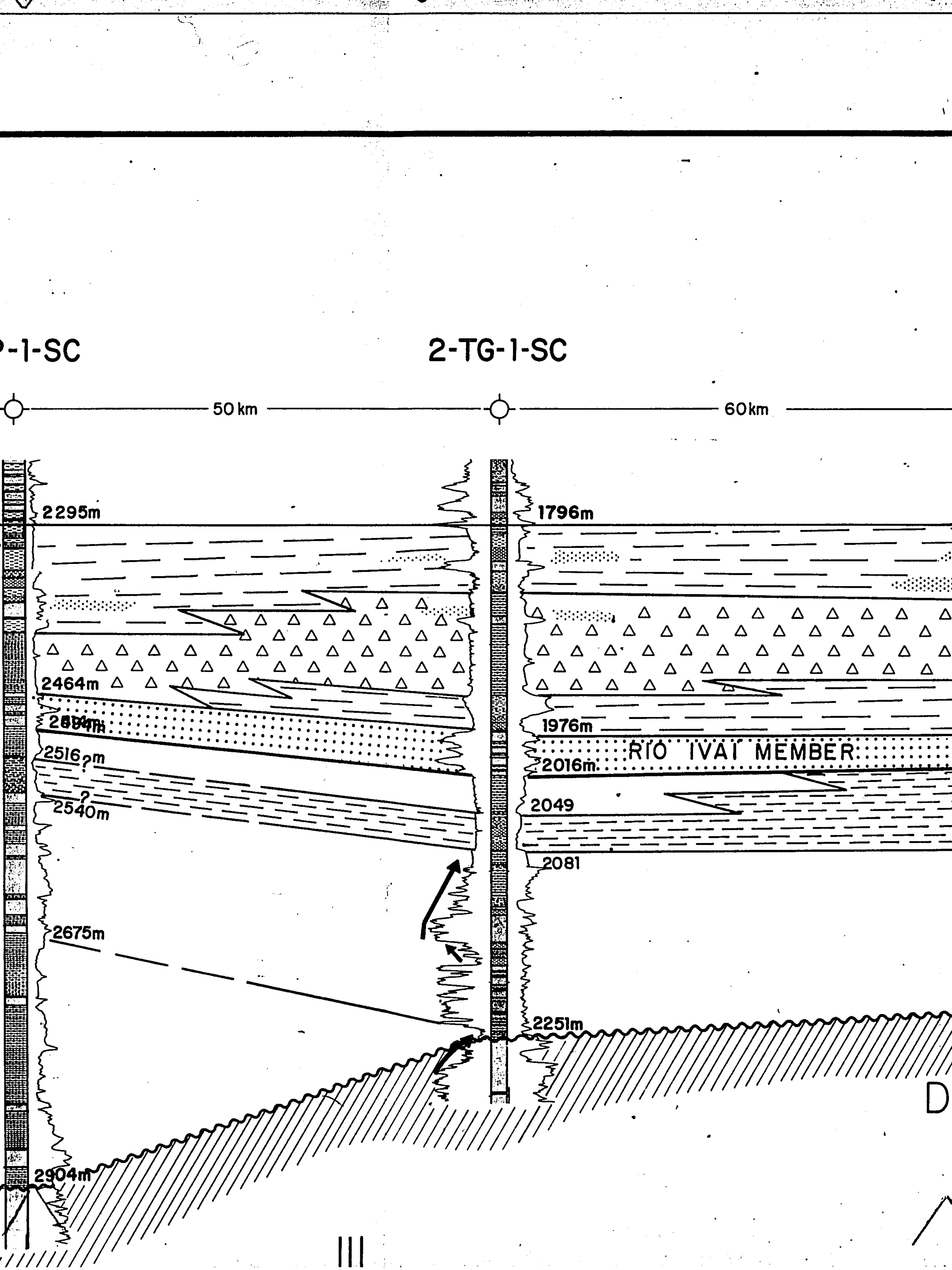
SANDSTONE

FINING UPWARD SEQUENCE

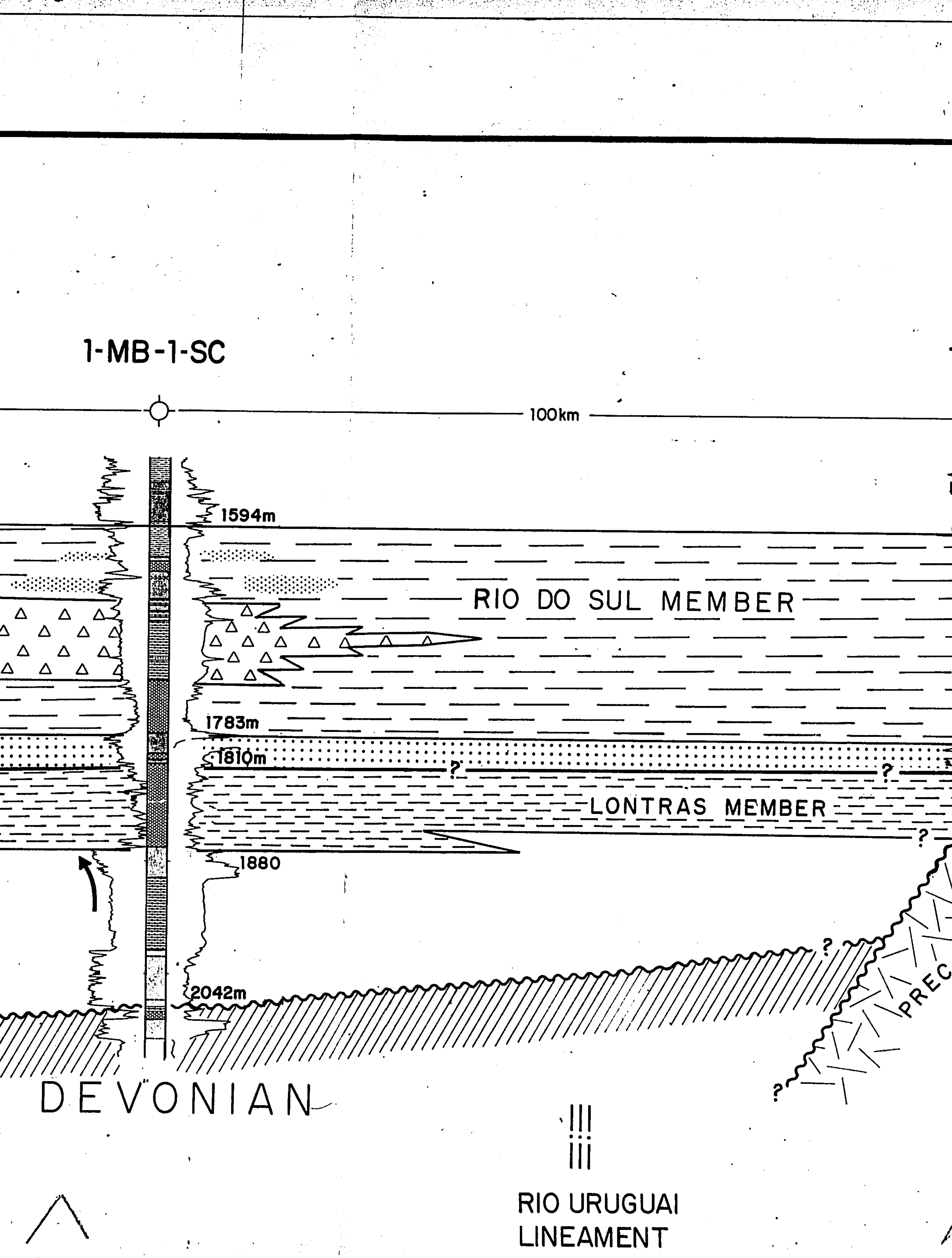
COARSENING UPWARD SEQUENCE

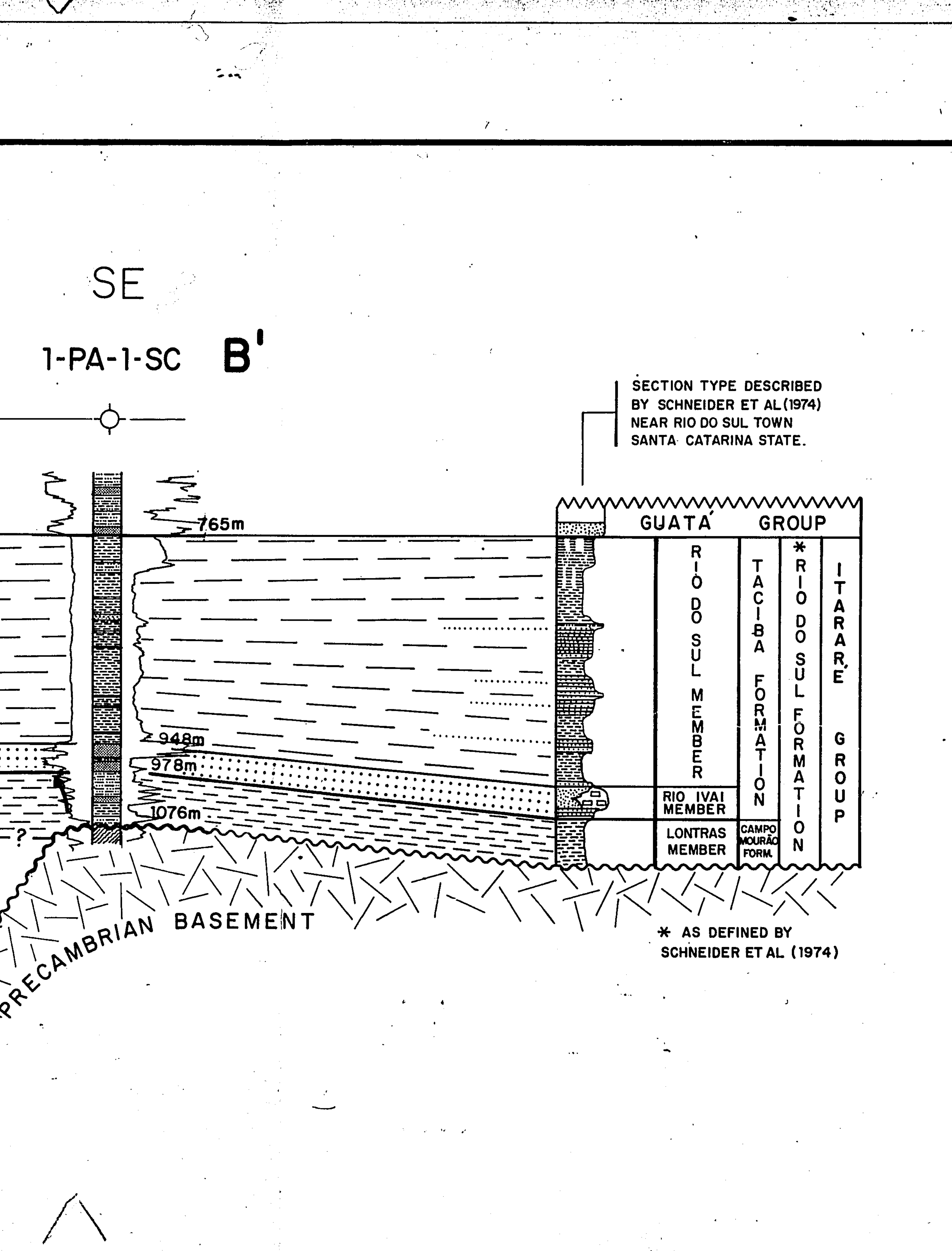

NW
B 1-RS-1-PR
63 km
GUATÁ GROUP
ITARARÉ GROUP
TACIBA FORMATION
CHAPEU DO SOL MEMBER
RIO DO SUL MEMBER
RIO IVAI MEMBER
CAMPO MOURÃO FORMATION
LONTRAS MEMBER
2537m
2645m
2720m
2869m
?
2917m
CORRELATION LINE
3145m

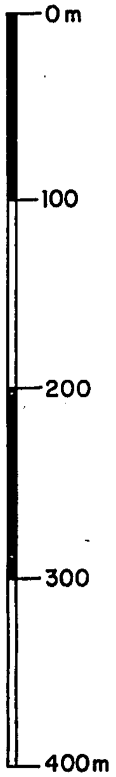

2-AL-1-SC
1-TP-1
75 km
2694m
CHAPÉU DO SOL MEMBER
2816m
2861m
CAMPO MOURÃO FORMATION
3012m
CORRELATION LINE
3164m
?
3248m



2-TG-1-SC
50 km
60 km
2295m
2464m
2516m
2540m
2675m
2904m
1796m
1976m
RIO IVAI MEMBER
2016m
2049
2081
2251m
III


1-MB-1-SC
100km
1594m
RIO DO SUL MEMBER
1783m
1810m
?
LONTRAS MEMBER
1880
2042m
DEVONIAN
PREC
RIO URUGUAI
LINEAMENT


SE
1-PA-1-SC B'
SECTION TYPE DESCRIBED BY SCHNEIDER ET AL (1974) NEAR RIO DO SUL TOWN SANTA CATARINA STATE.
765m
948m
978m
1076m
?
GUATÁ GROUP
RIO DO SUL MEMBER
RIO IVAI MEMBER
LONTRAS MEMBER
TACIBA FORMATION
CAMPO MOURÃO FORM.
* RIO DO SUL FORMATION
ITARARÉ GROUP
PRECAMBRIAN BASEMENT
* AS DEFINED BY SCHNEIDER ET AL (1974)



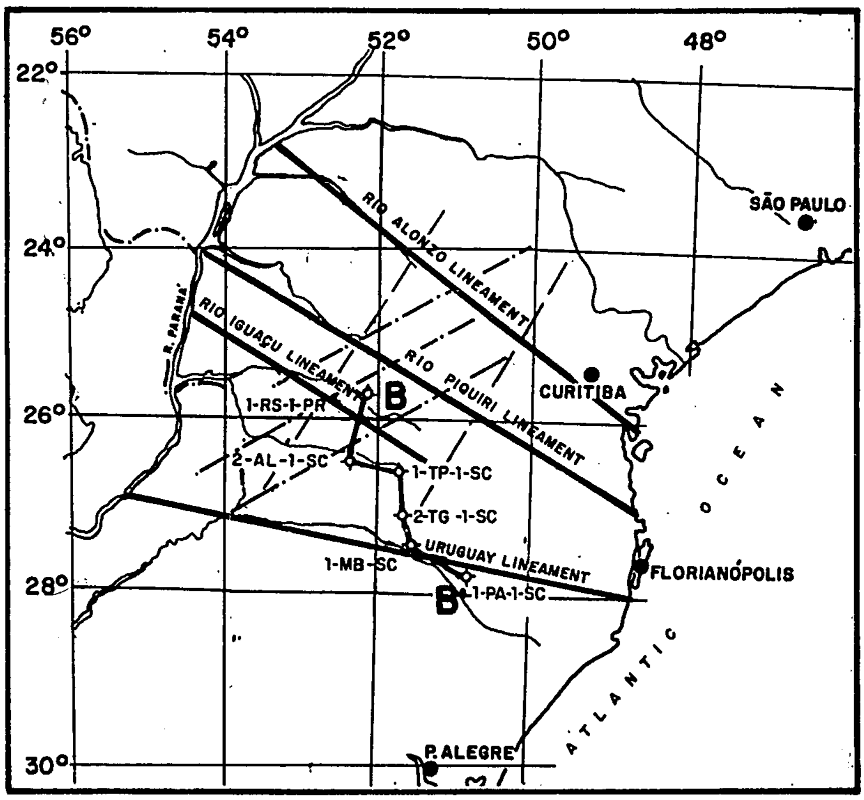
STRATIGRAPHIC CROSS SECTION B-B'

DATUM: TOP OF ITARARÉ GROUP

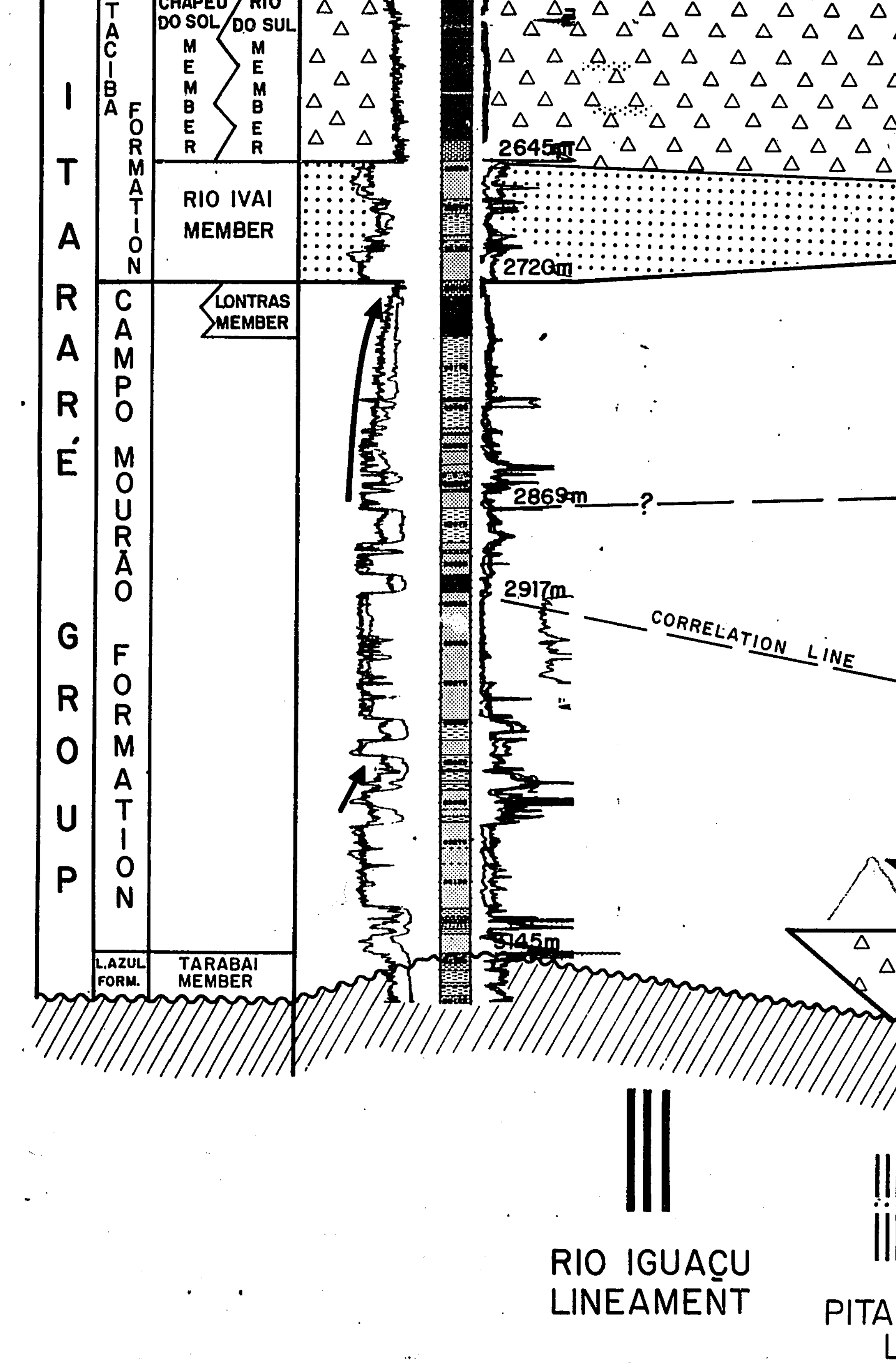
DIABASE EXCLUDED

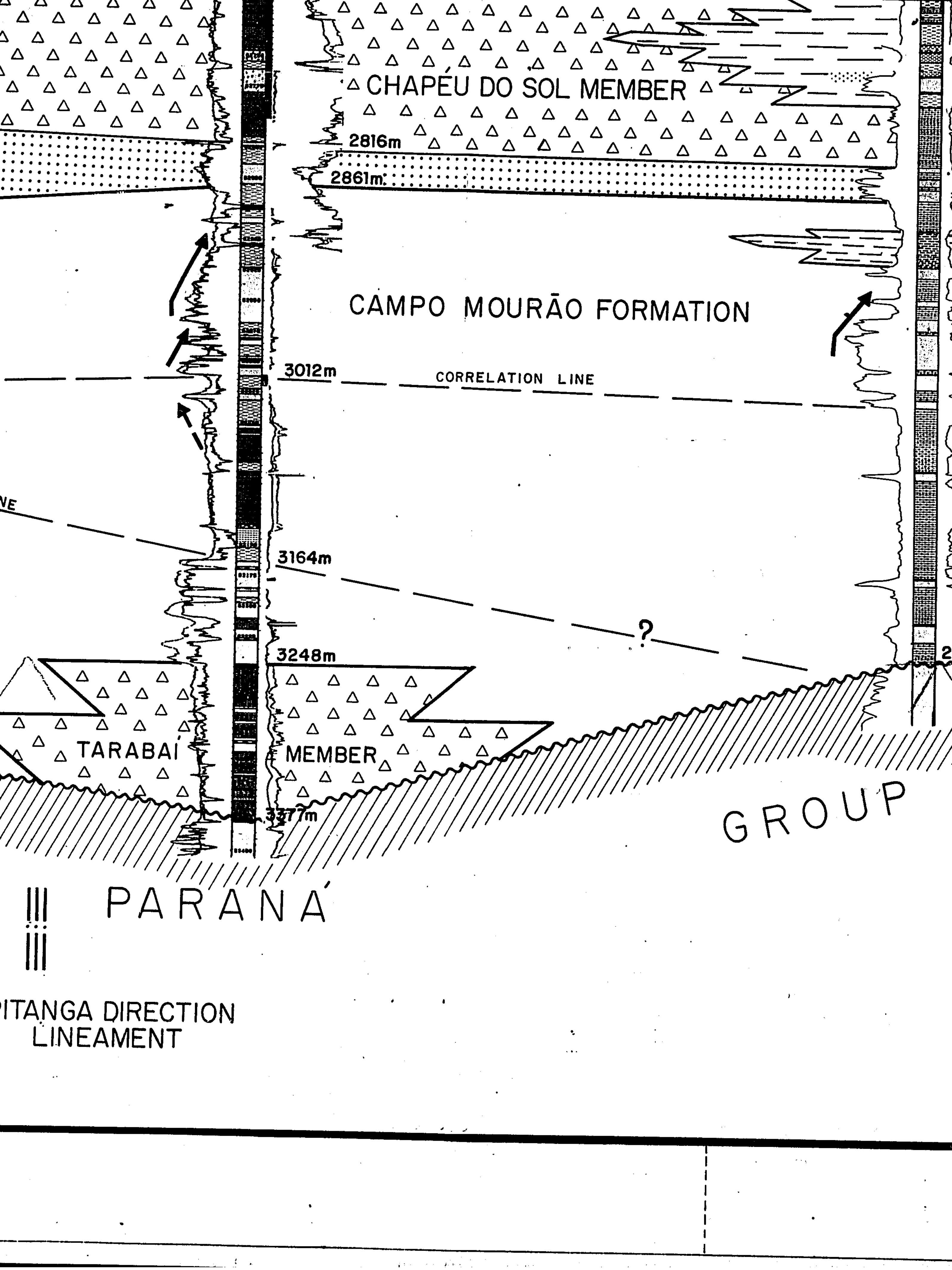
Fig. 11

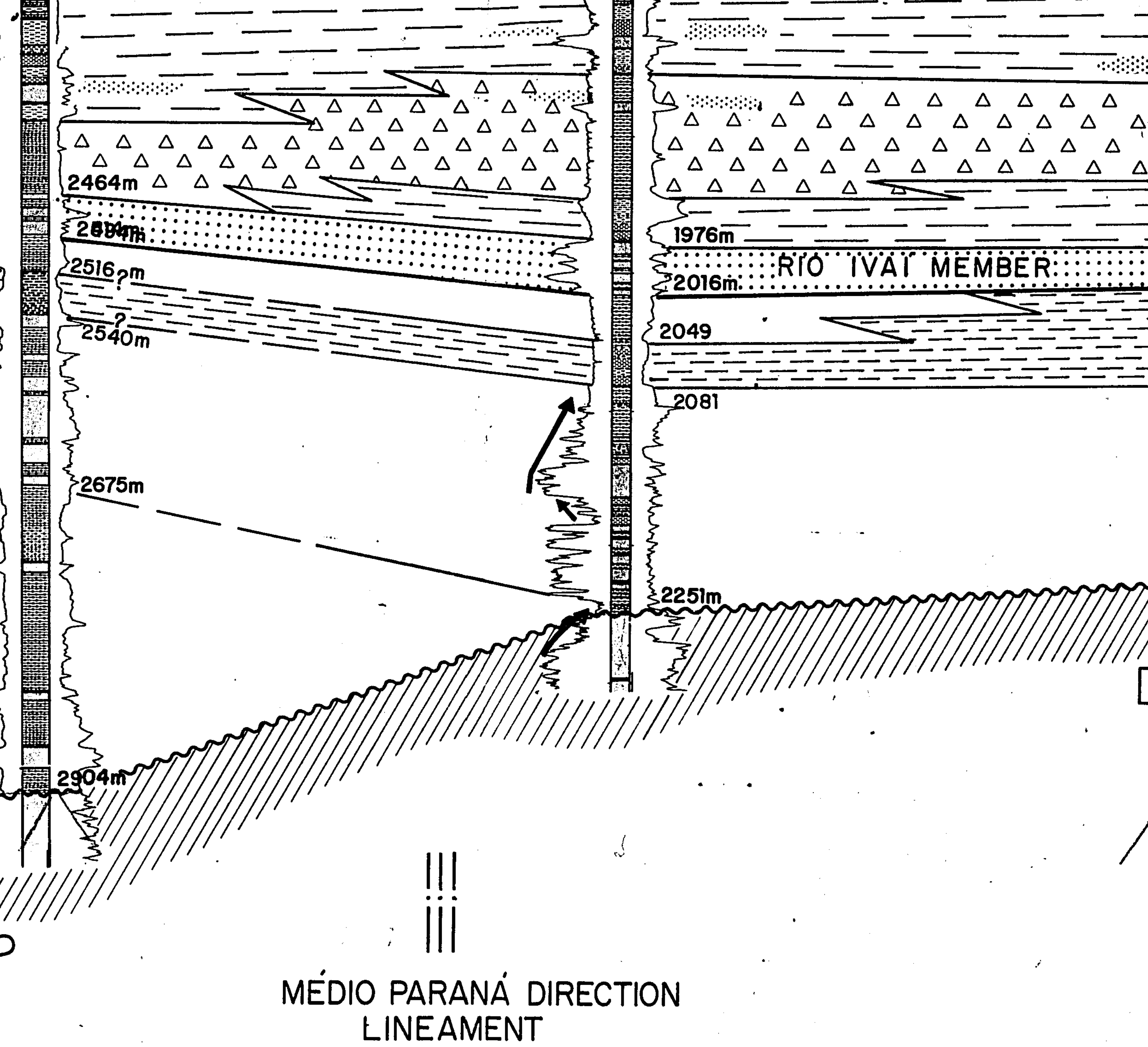
LOCATION MAP

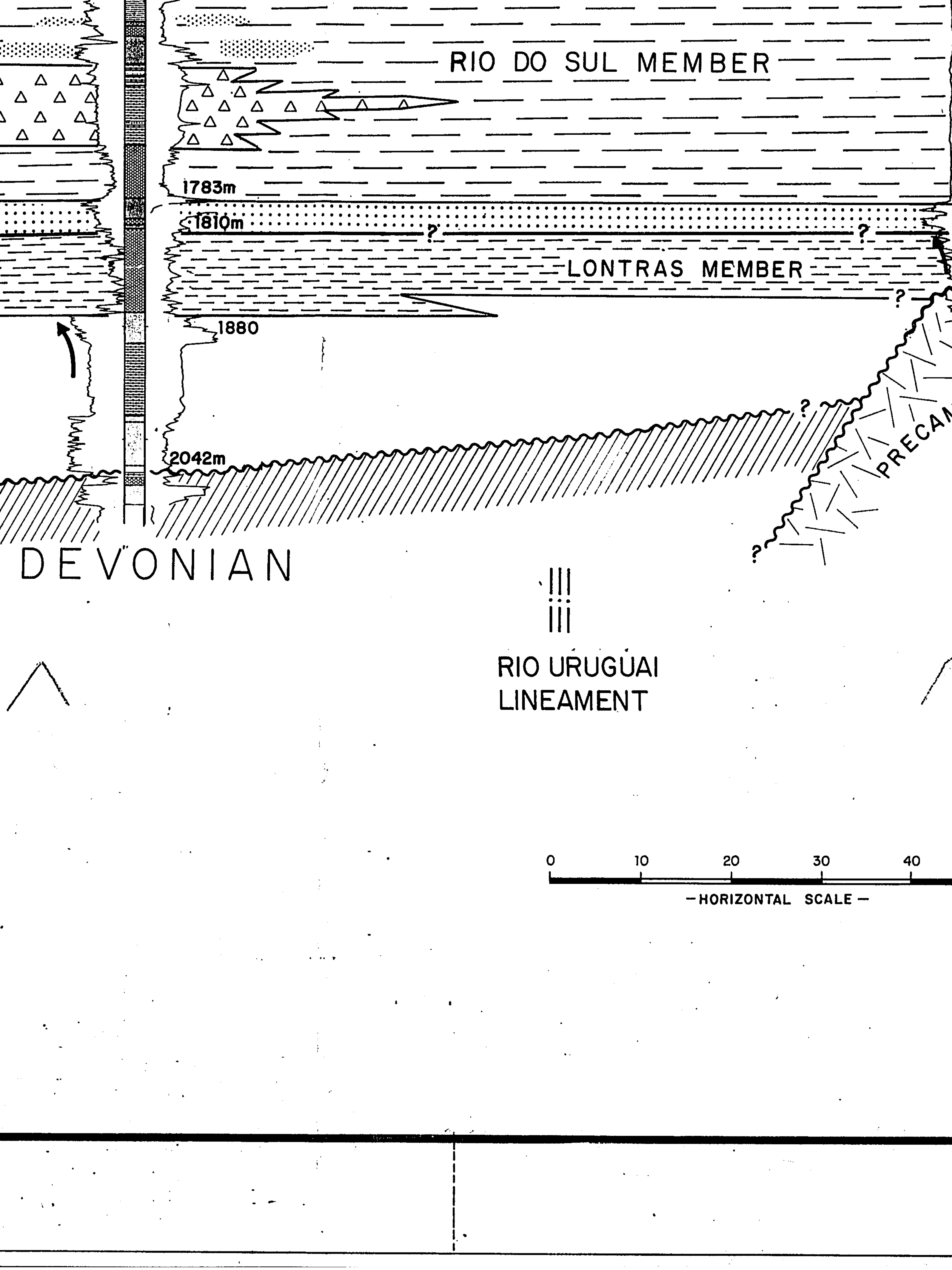


PREDOMINANTLY PEBBLY MUDSTONE

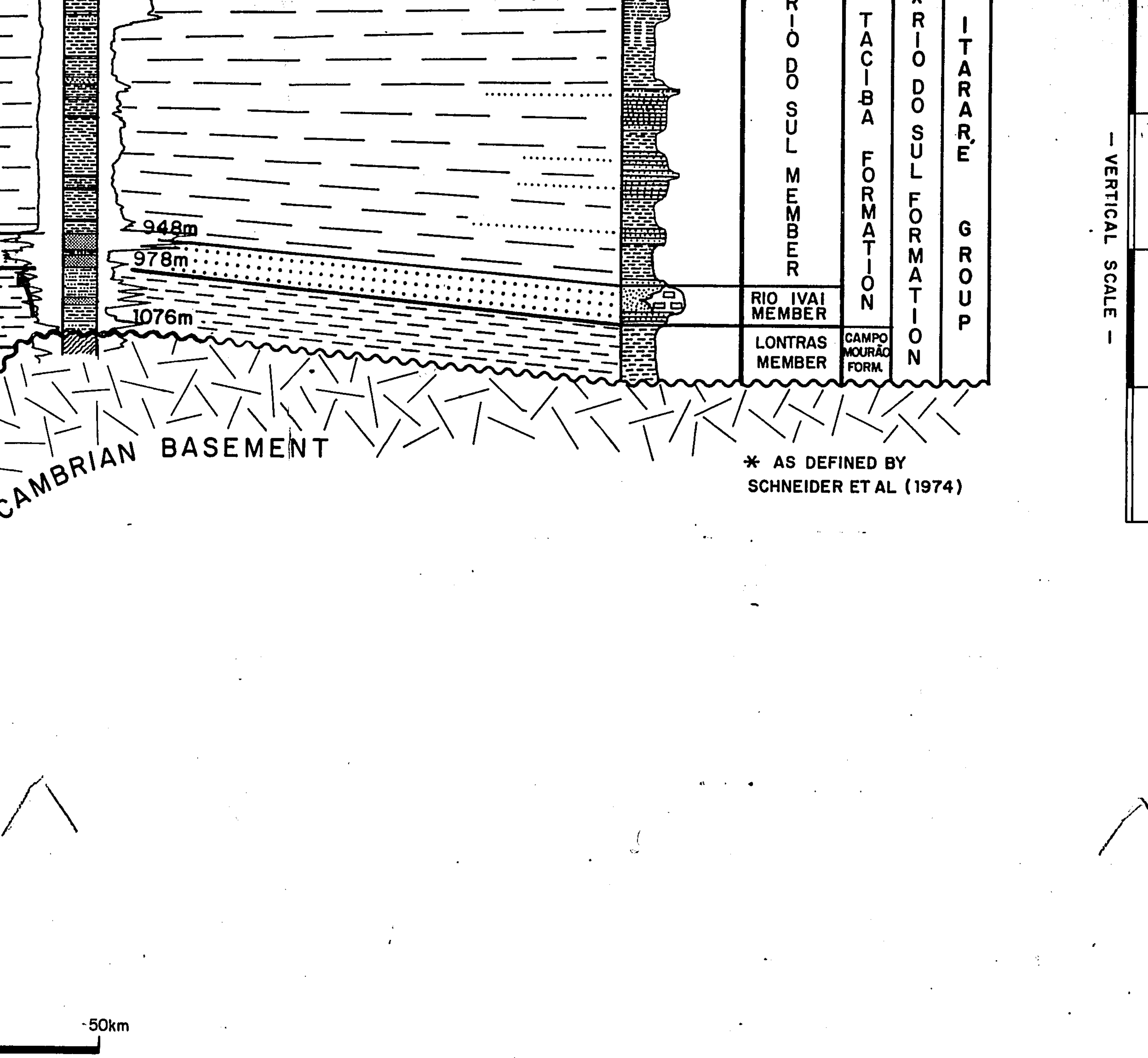

ITARARÉ GROUP
TACIBA FORMATION
CHAPÉU DO SOL MEMBER
RIO DO SUL MEMBER
RIO IVAI MEMBER
CAMPO MOURÃO FORMATION
LONTRAS MEMBER
L.AZUL FORM.
TARABAI MEMBER
2645m
2720m
2869m
?
2917m
CORRELATION LINE
3145m
RIO IGUAÇU LINEAMENT
PITA
L


CHAPÉU DO SOL MEMBER
2816m
2861m
CAMPO MOURÃO FORMATION
3012m
CORRELATION LINE
NE
3164m
?
3248m
TARABAI
MEMBER
3377m
GROUP
PARANÁ
ITANGA DIRECTION
LINEAMENT

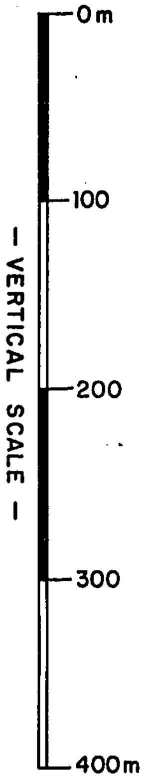

2464m
2516 m
2540m
2675m
2904m
1976m
RIO IVAI MEMBER
2016m
2049
2081
2251m
MÉDIO PARANÁ DIRECTION
LINEAMENT



RIO DO SUL MEMBER
1783m
1810m
LONTRAS MEMBER
1880
2042m
DEVONIAN
PRECAM
RIO URUGUAI
LINEAMENT
0
10
20
30
40
— HORIZONTAL SCALE —

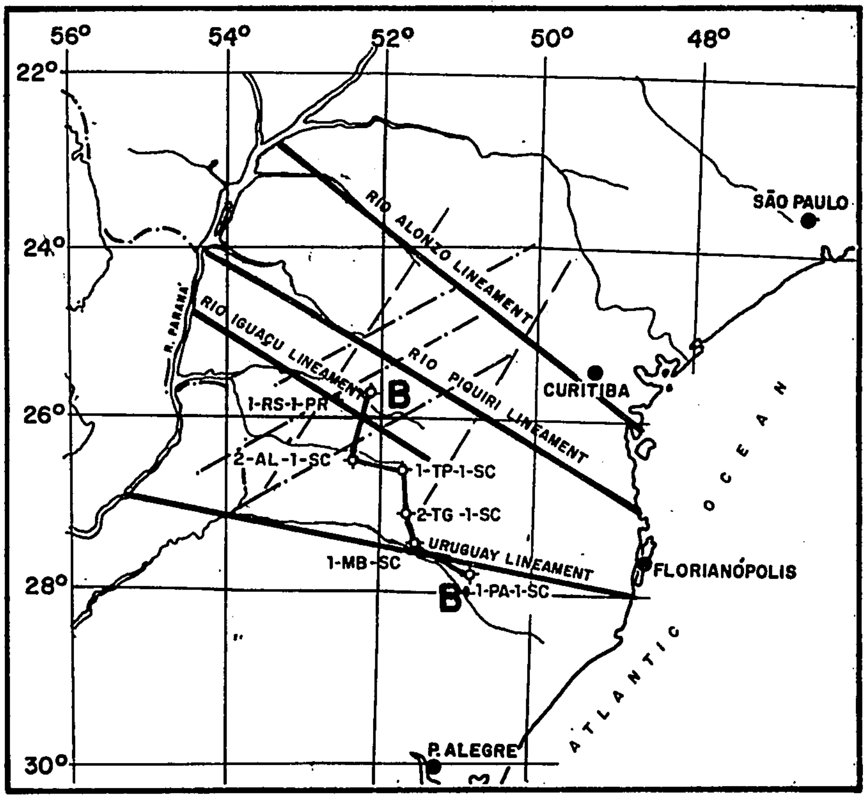

948m
978m
1076m
RIO DO SUL MEMBER
RIO IVAI MEMBER
LONTRAS MEMBER
TACIBA FORMATION
CAMPO MOURÃO FORM.
*RIO DO SUL FORMATION
ITARARÉ GROUP
— VERTICAL SCALE —
CAMBRIAN BASEMENT
* AS DEFINED BY
SCHNEIDER ET AL (1974)
50km

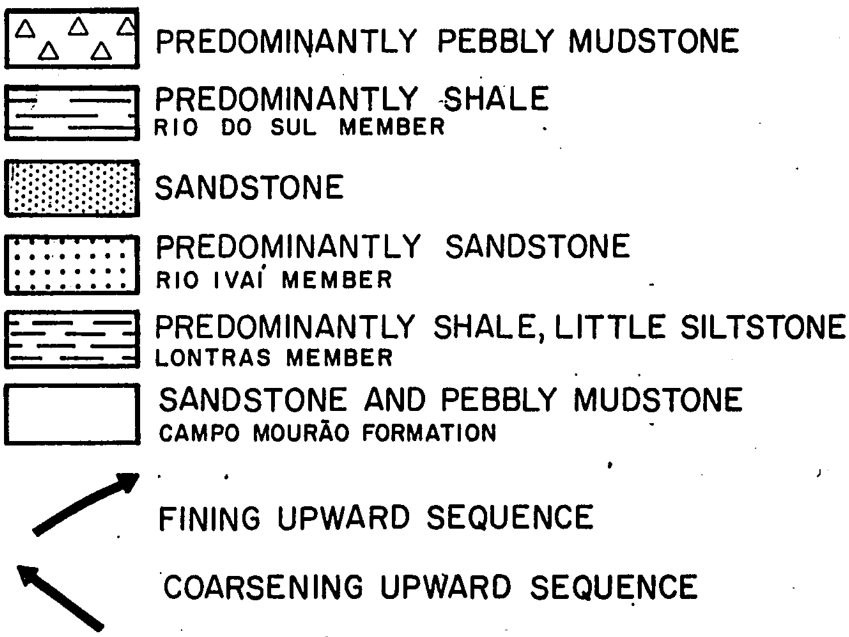
Des. L

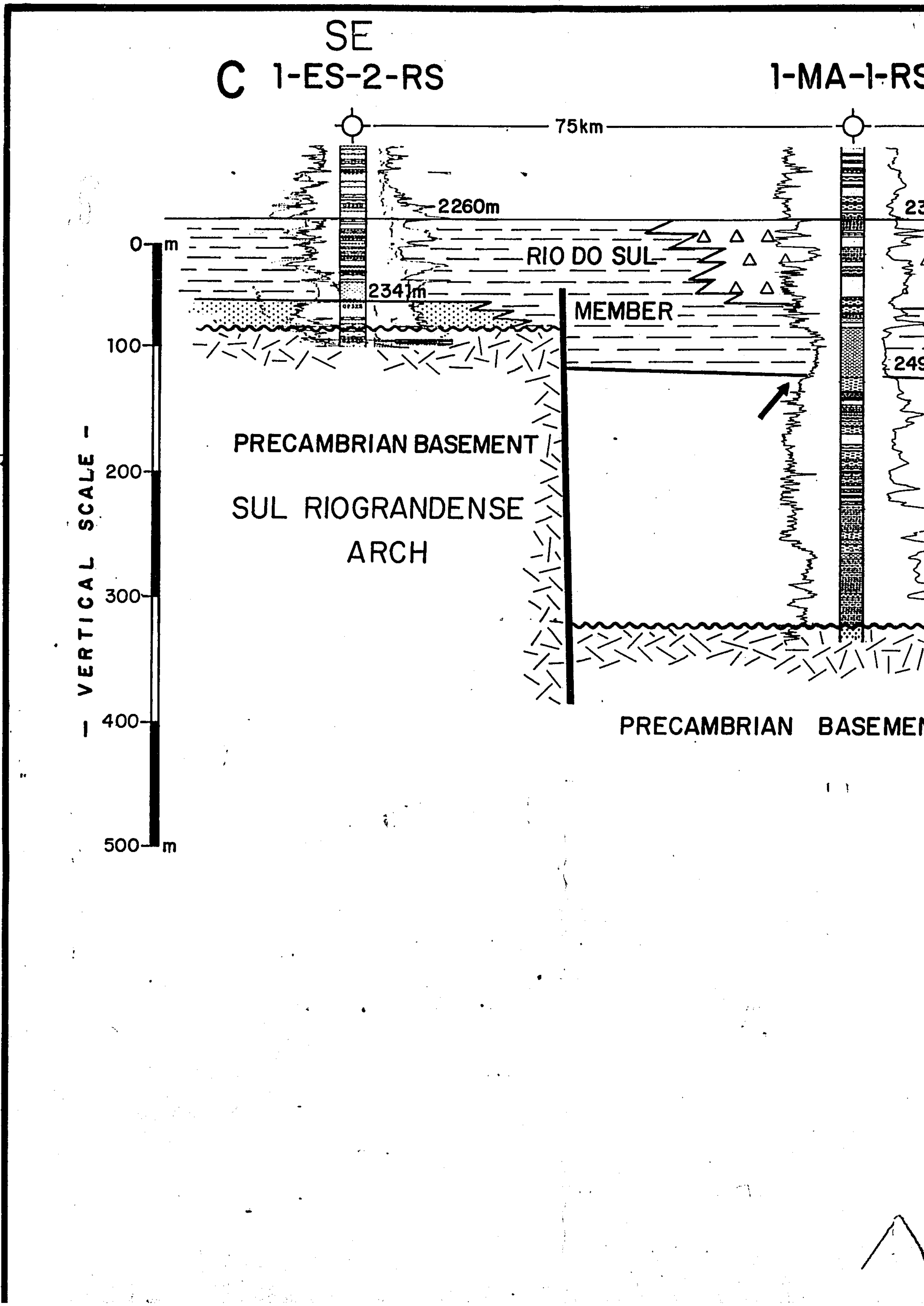


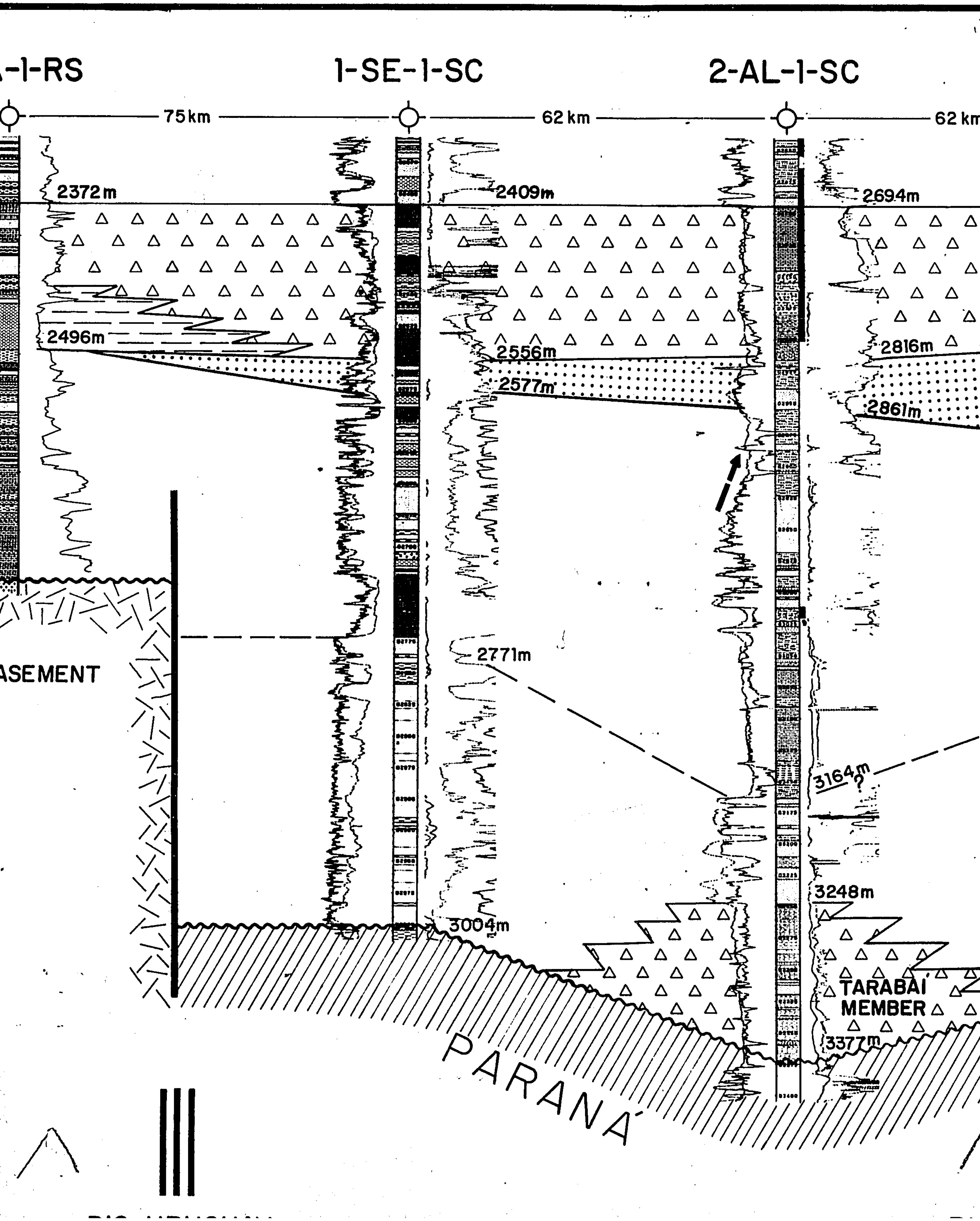
Des. L.Colligaris Netto. /87

LOCATION MAP

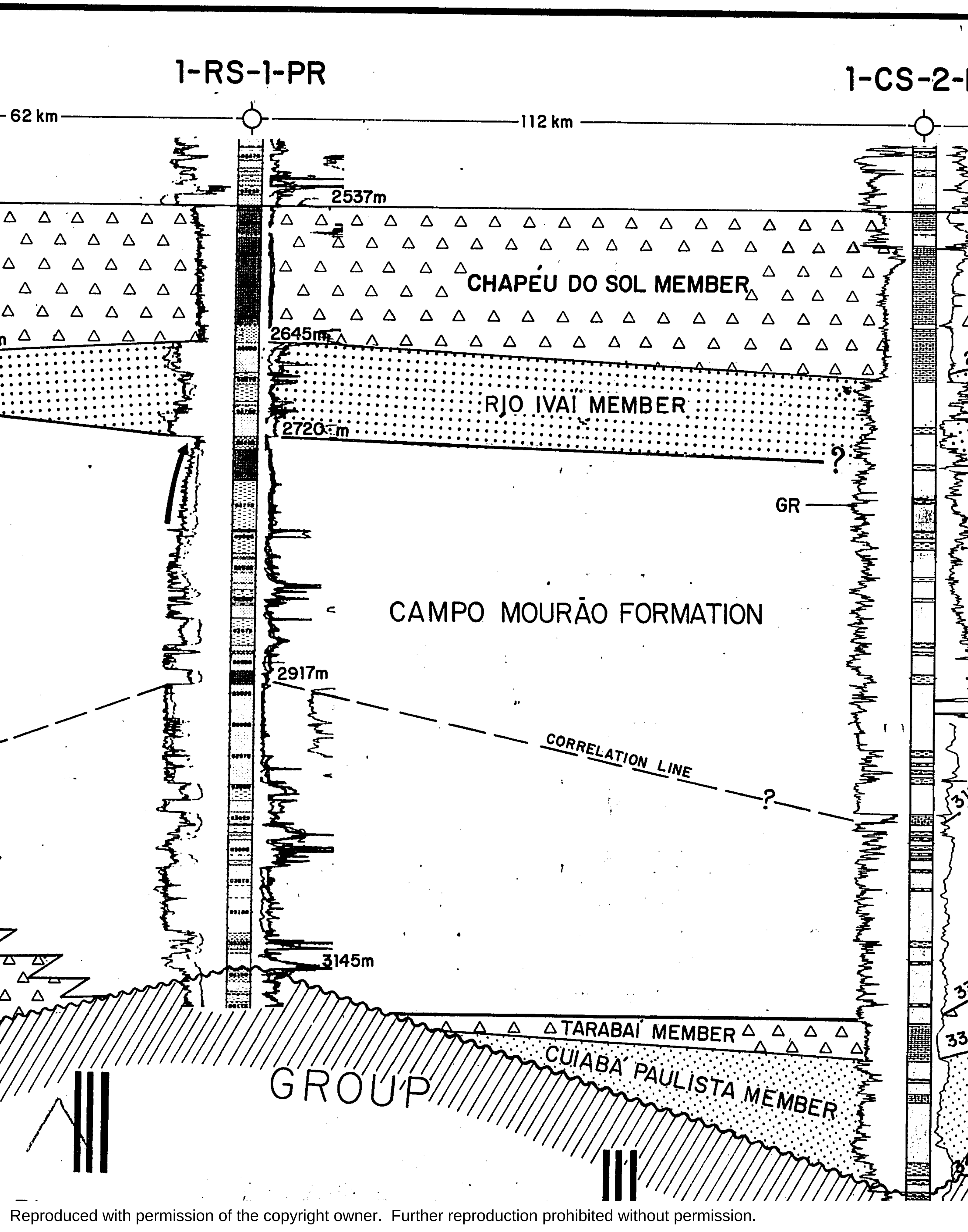


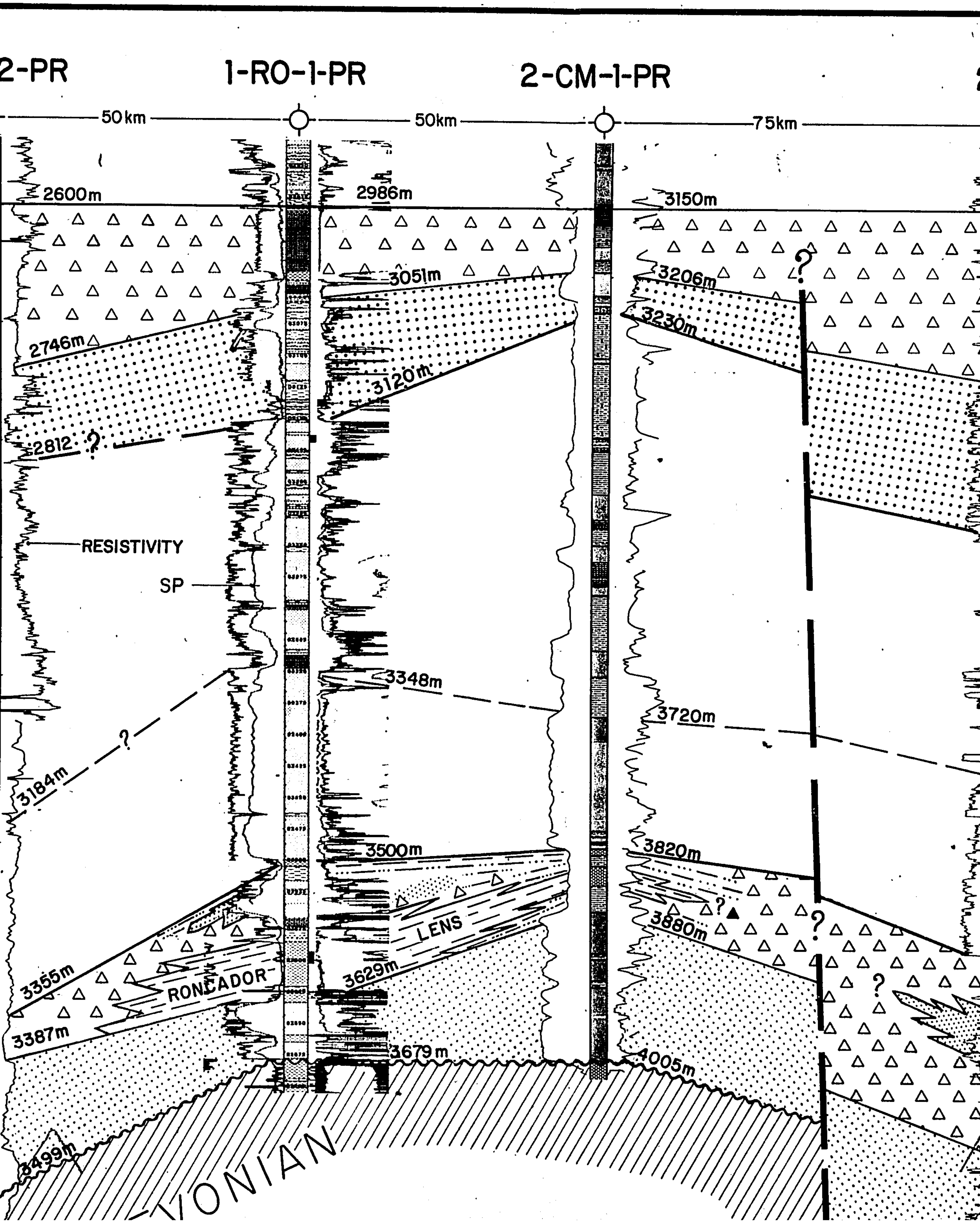


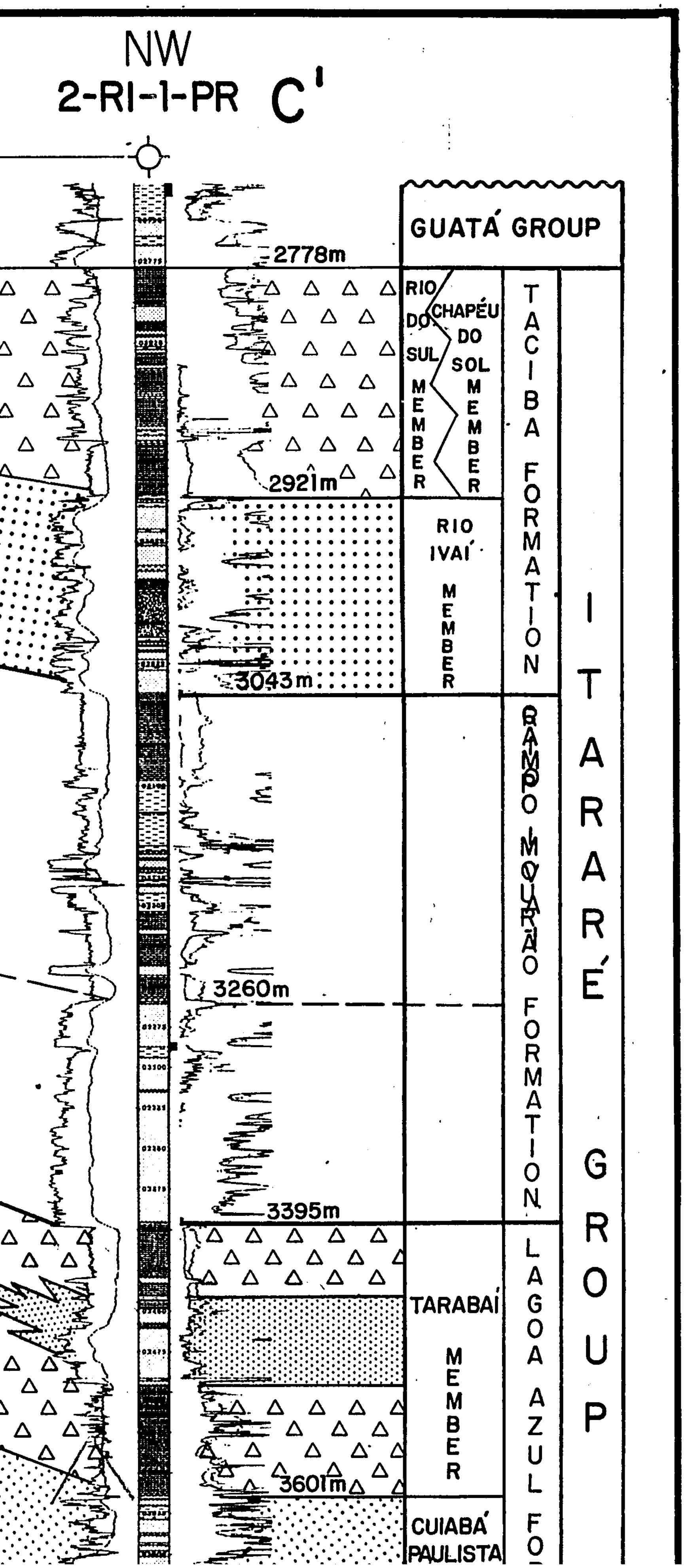

SE
C 1-ES-2-RS
1-MA-1-RS
75km
2260m
2341m
RIO DO SUL
MEMBER
PRECAMBRIAN BASEMENT
SUL RIOGRANDENSE
ARCH
PRECAMBRIAN BASEMEN
- VERTICAL SCALE -
0 m
100
200
300
400
500 m



-1-RS
1-SE-1-SC
2-AL-1-SC
75km
62 km
62 km
2372m
2409m
2694m
2496m
2556m
2577m
2816m
2861m
2771m
3164m
?
3248m
3004m
3377m
ASEMENT
TARABAI
MEMBER
PARANA


1-RS-1-PR
1-CS-2-
62 km
112 km
2537m
CHAPEU DO SOL MEMBER
2645m
RIO IVAI MEMBER
2720 m
GR
CAMPO MOURÃO FORMATION
2917m
CORRELATION LINE
3145m
TARABAI MEMBER
CUIABA PAULISTA MEMBER
GROUP
?


2-PR
1-RO-1-PR
2-CM-1-PR
50km
50km
75km
2600m
2986m
3150m
3051m
3206m
3230m
2746m
3120m
2812
?
?
RESISTIVITY
SP
3348m
3720m
?
3184m
3500m
3820m
LENS
?
3880m
?
3355m
RONCADOR
3629m
?
3387m
3679m
4005m
3499m
VONIAN

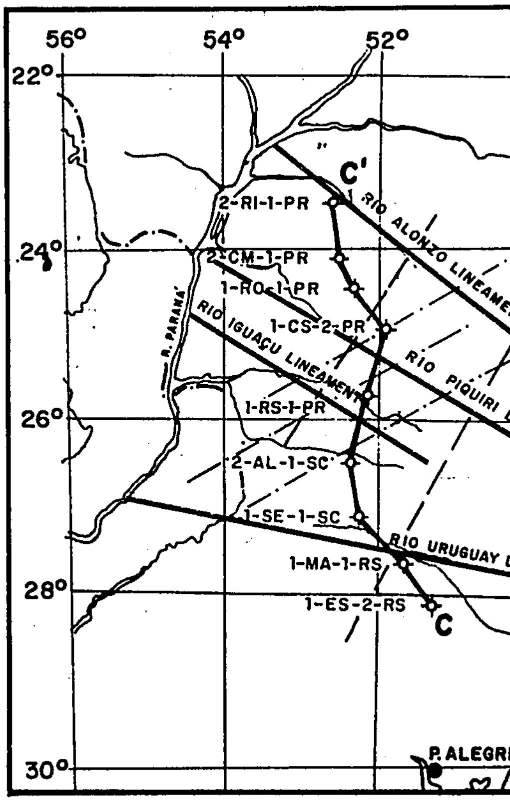


STRATIGRAPHIC CROS

DATUM: TOP OF ITAR

DIABASE EXCL

LOCATION



PREDOMINANTLY PEBB

PREDOMINANTLY SAND

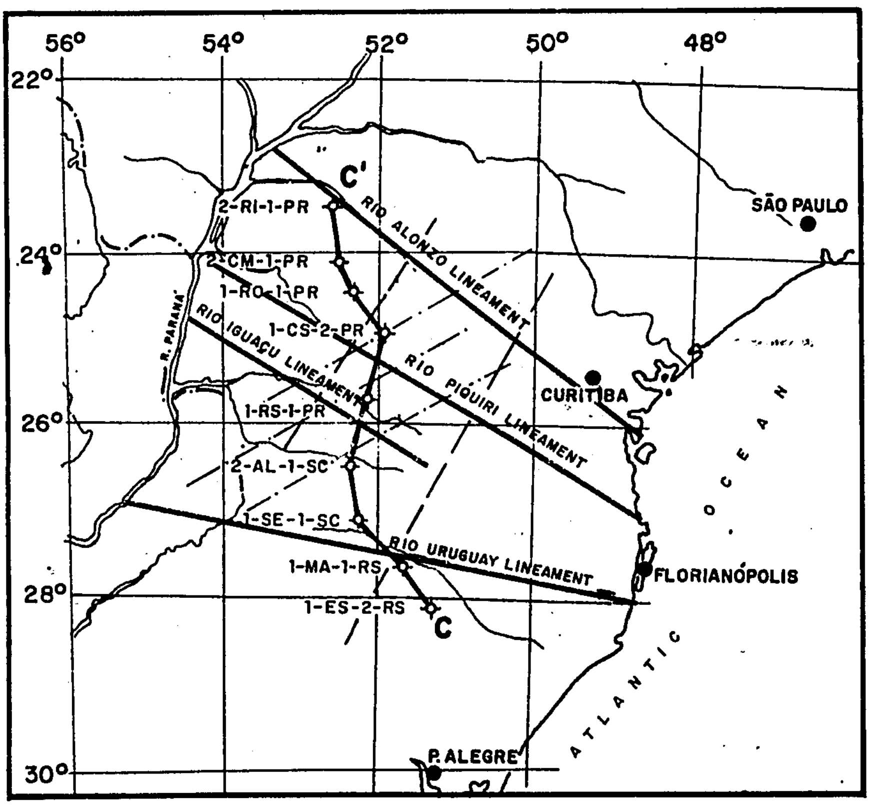
STRATIGRAPHIC CROSS SECTION C-C'

DATUM: TOP OF ITARARÉ GROUP

DIABASE EXCLUDED

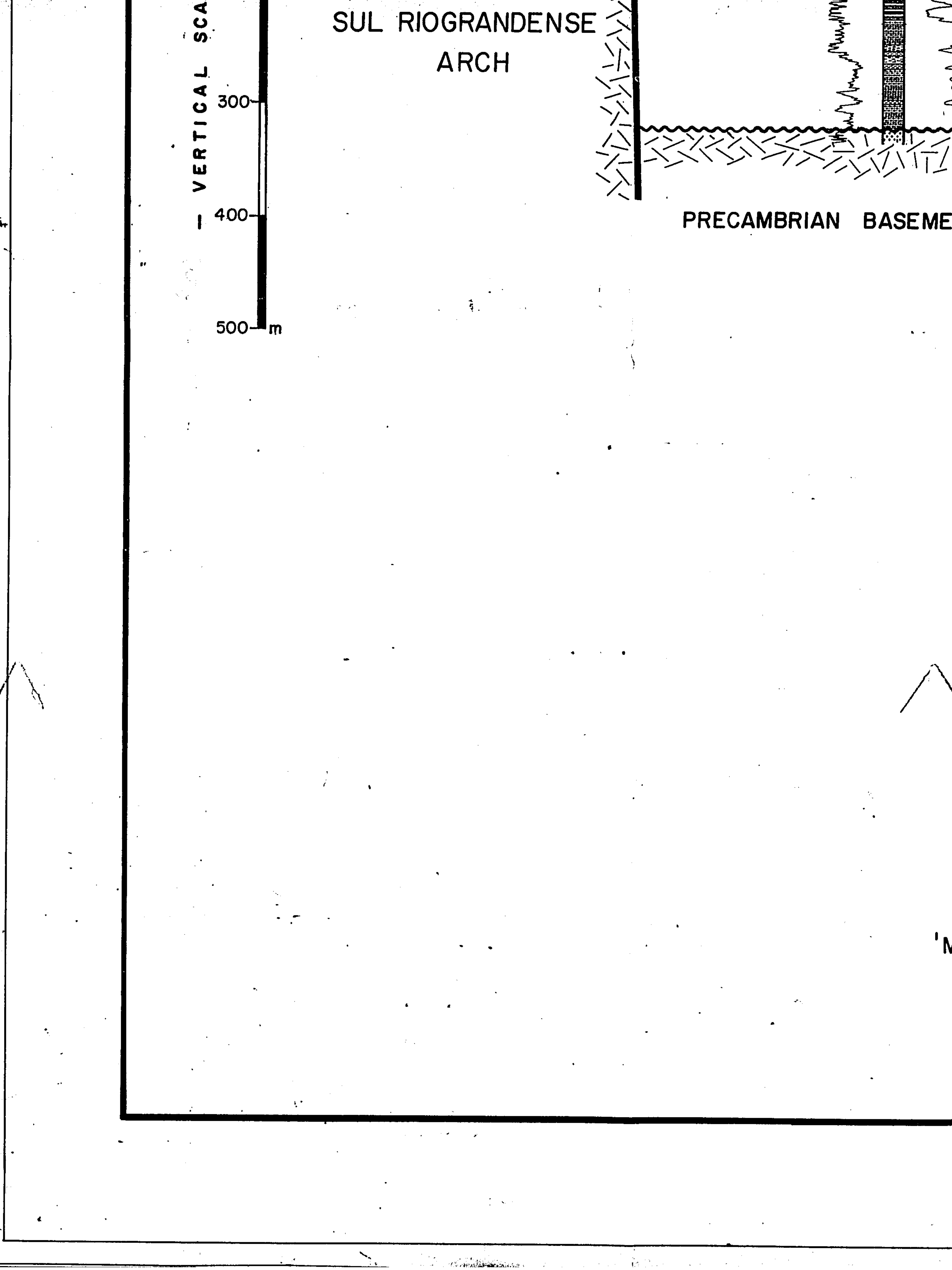
Fig. 12

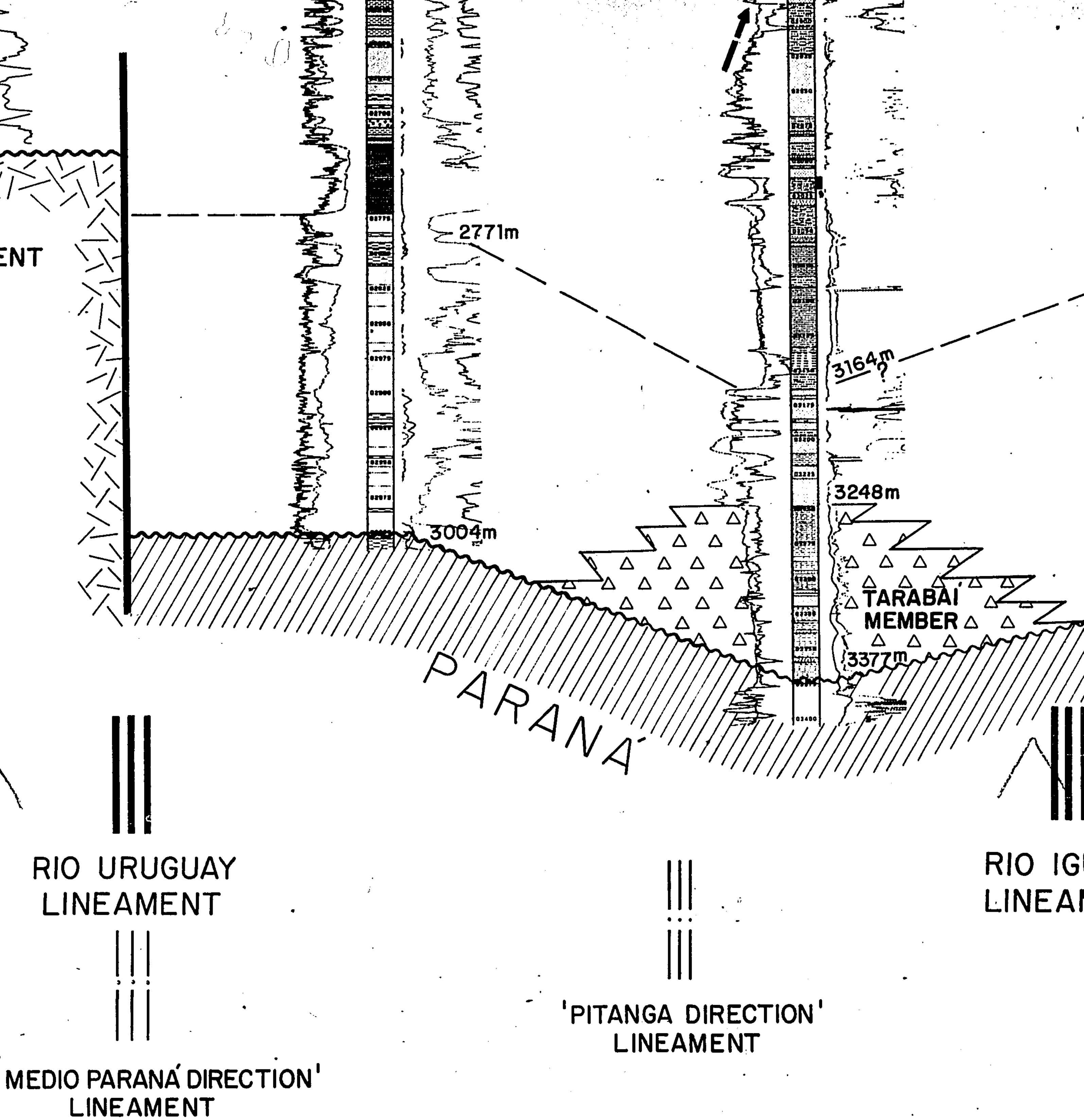
LOCATION MAP

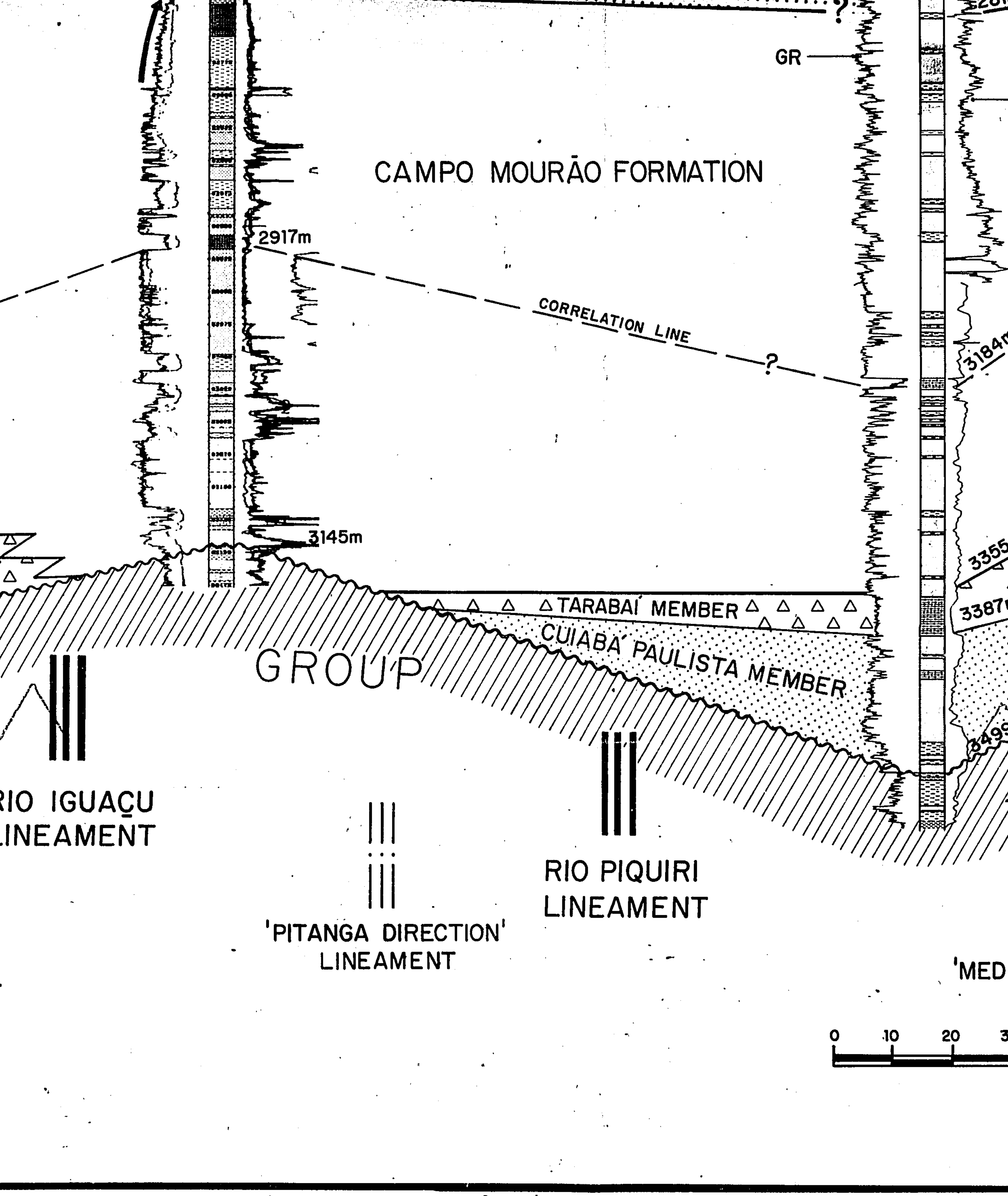


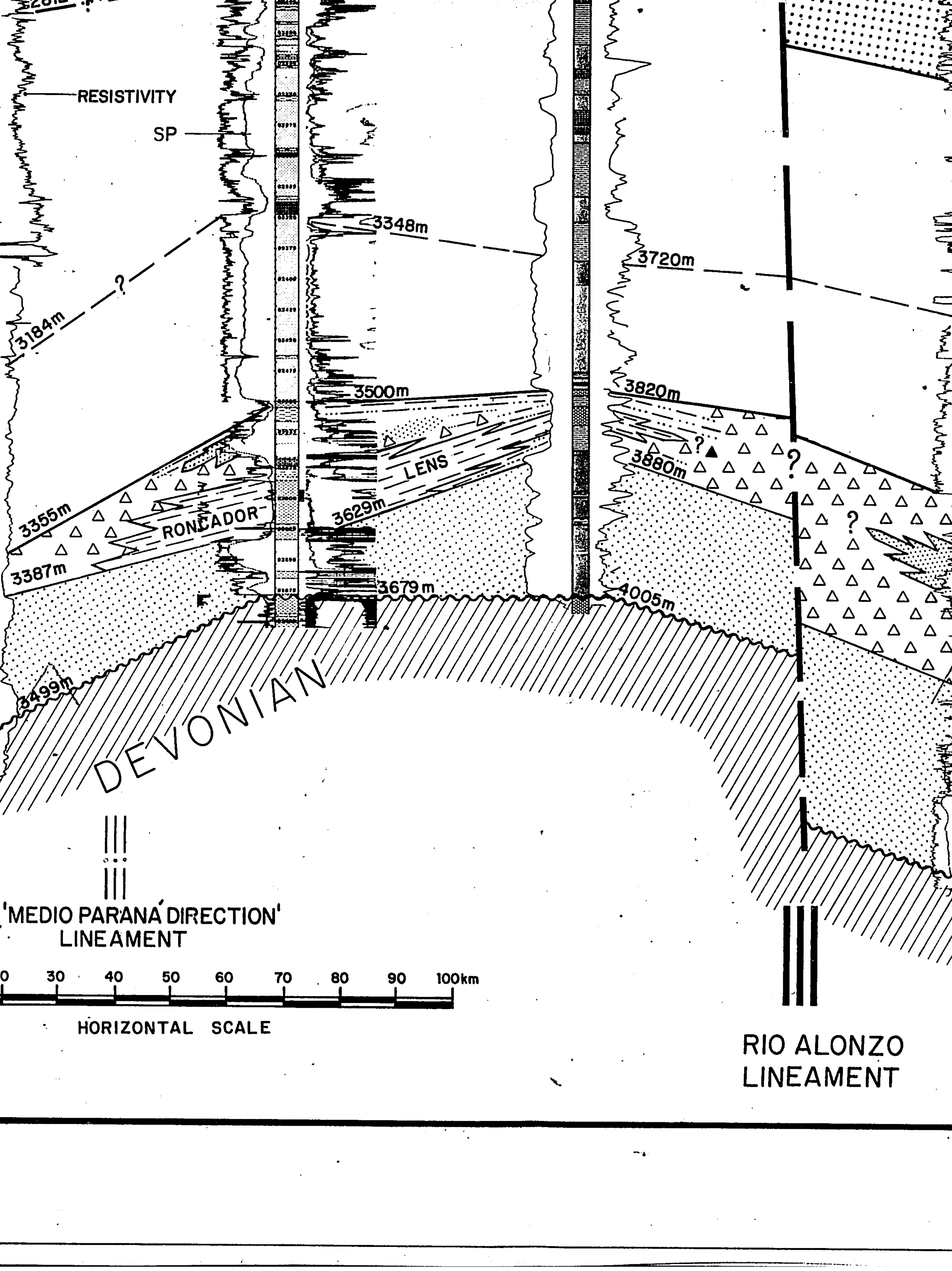
△ △ △ PREDOMINANTLY PEBBLY MUDSTONE

PREDOMINANTLY SANDSTONE

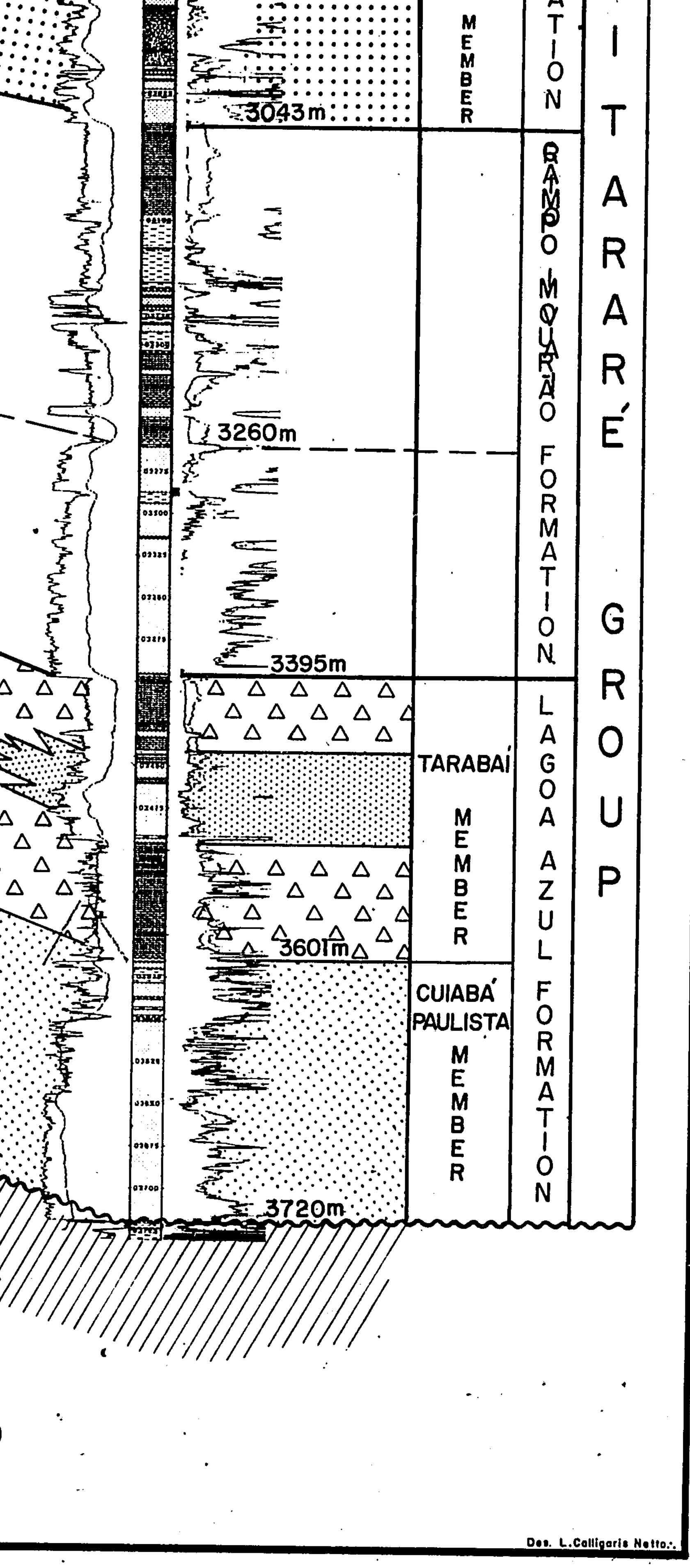

SUL RIOGRANDENSE
ARCH
VERTICAL SCA
300
400
500 m
PRECAMBRIAN BASEME

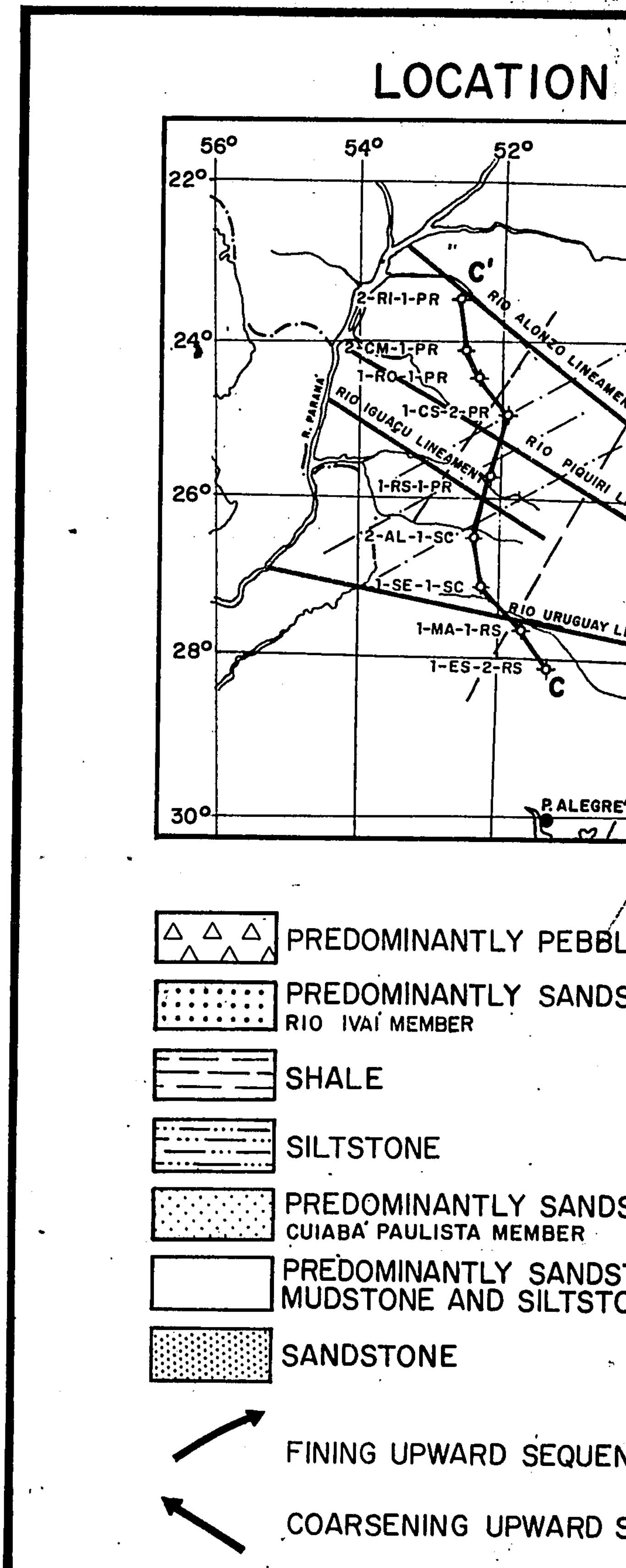

2771m
3004m
3164m
?
3248m
TARABAI MEMBER
3377m
PARANA
RIO URUGUAY LINEAMENT
'MEDIO PARANÁ DIRECTION' LINEAMENT
'PITANGA DIRECTION' LINEAMENT


GR
CAMPO MOURÃO FORMATION
2917m
CORRELATION LINE
?
3184m
3145m
3355
TARABAÍ MEMBER
3387
CUIABÁ PAULISTA MEMBER
GROUP
3499
RIO IGUAÇU
LINEAMENT
'PITANGA DIRECTION'
LINEAMENT
RIO PIQUIRI
LINEAMENT
'MED
0
10
20

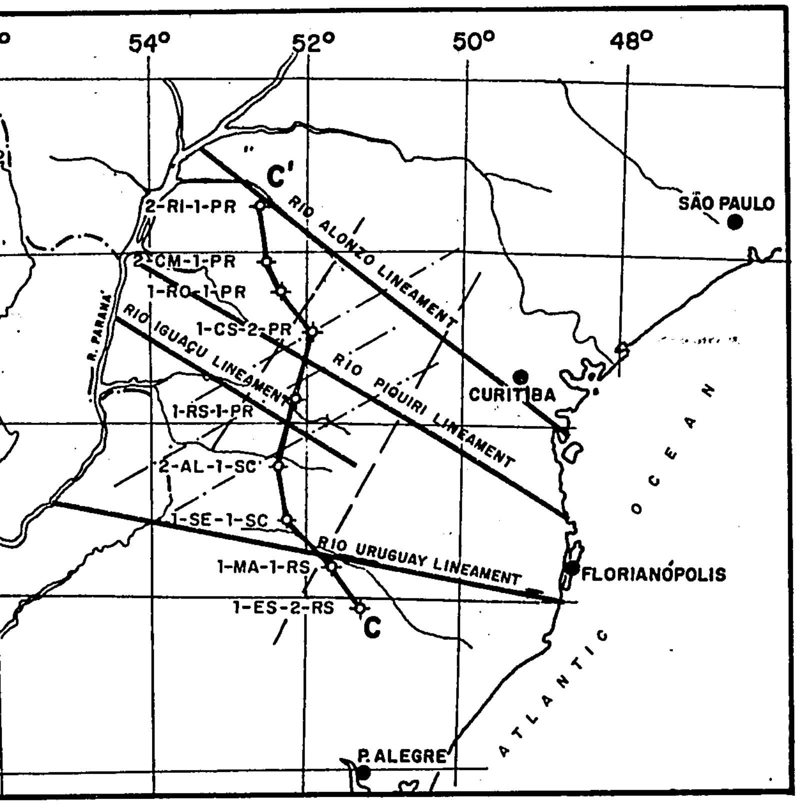


RESISTIVITY
SP
3348m
3720m
3184m
3500m
3820m
3880m
LENS
3355m
RONCADOR
3629m
3387m
3679m
4005m
3499m
DEVONIAN
'MEDIO PARANÁ DIRECTION' LINEAMENT
0 30 40 50 60 70 80 90 100km
HORIZONTAL SCALE
RIO ALONZO LINEAMENT


MEMBER
ITARARÉ GROUP
3043m
CAMPO MOURÃO FORMATION
3260m
3395m
TARABAÍ MEMBER
LAGOA AZUL FORMATION
3601m
CUIABÁ PAULISTA MEMBER
3720m
Des. L.Calligaris Netto.


LOCATION
56°
54°
52°
22°
24°
26°
28°
30°
C'
2-RI-1-PR
2-CM-1-PR
1-RO-1-PR
1-CS-2-PR
1-RS-1-PR
2-AL-1-SC
1-SE-1-SC
1-MA-1-RS
1-ES-2-RS
C
R. PARANÁ
RIO IGUAÇU LINEAMENT
RIO ALONZO LINEAMEN
RIO PIQUIRI L
RIO URUGUAY LI
P. ALEGRE
PREDOMINANTLY PEBBL
PREDOMINANTLY SANDS
RIO IVAÍ MEMBER
SHALE
SILTSTONE
PREDOMINANTLY SANDS
CUIABÁ PAULISTA MEMBER
PREDOMINANTLY SANDST
MUDSTONE AND SILTSTO
SANDSTONE
FINING UPWARD SEQUEN
COARSENING UPWARD S

LOCATION MAP



PREDOMINANTLY PEBBLY MUDSTONE

PREDOMINANTLY SANDSTONE
RIO IVAÍ MEMBER

SHALE

SILTSTONE

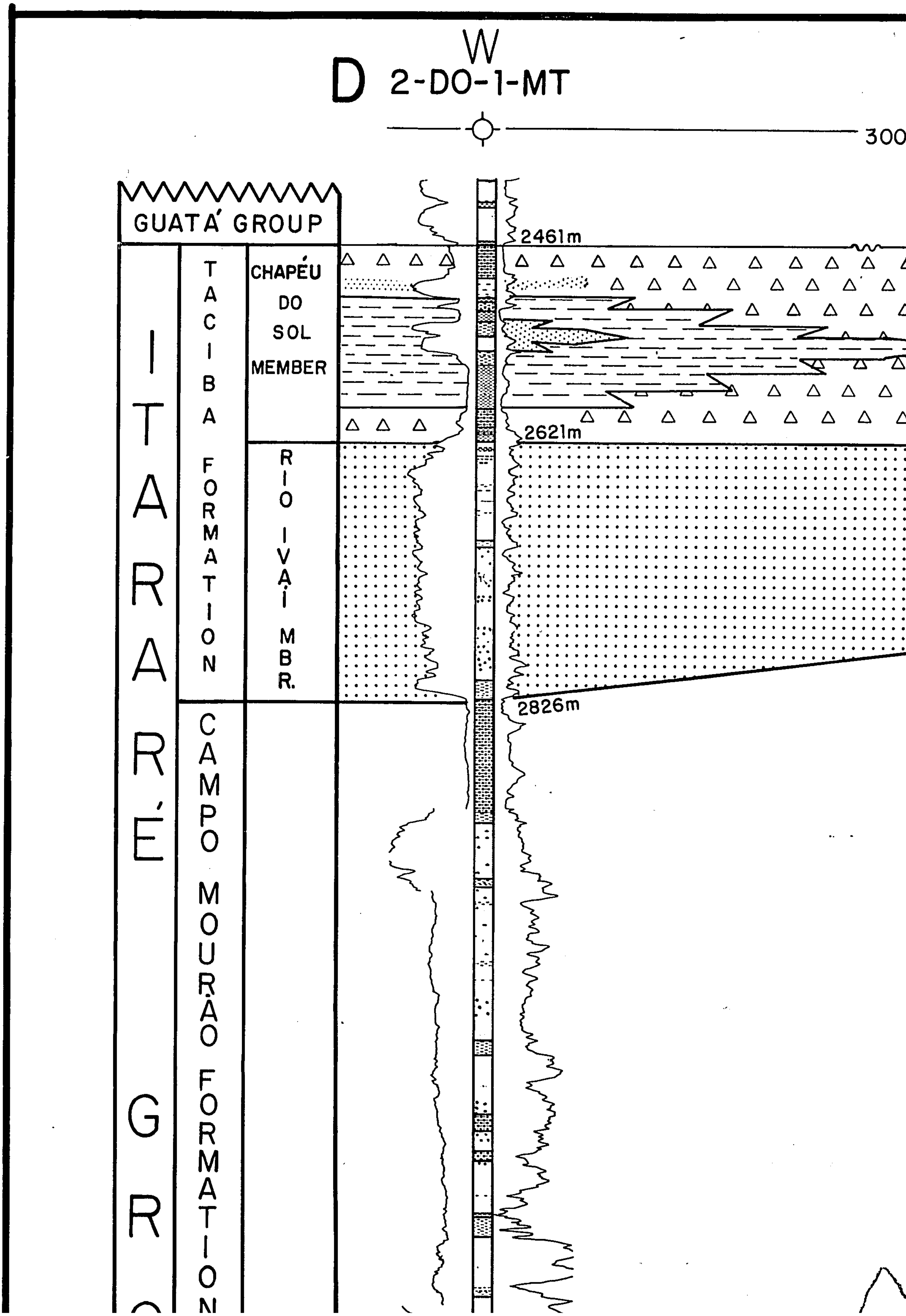
PREDOMINANTLY SANDSTONE
CUIABÁ PAULISTA MEMBER

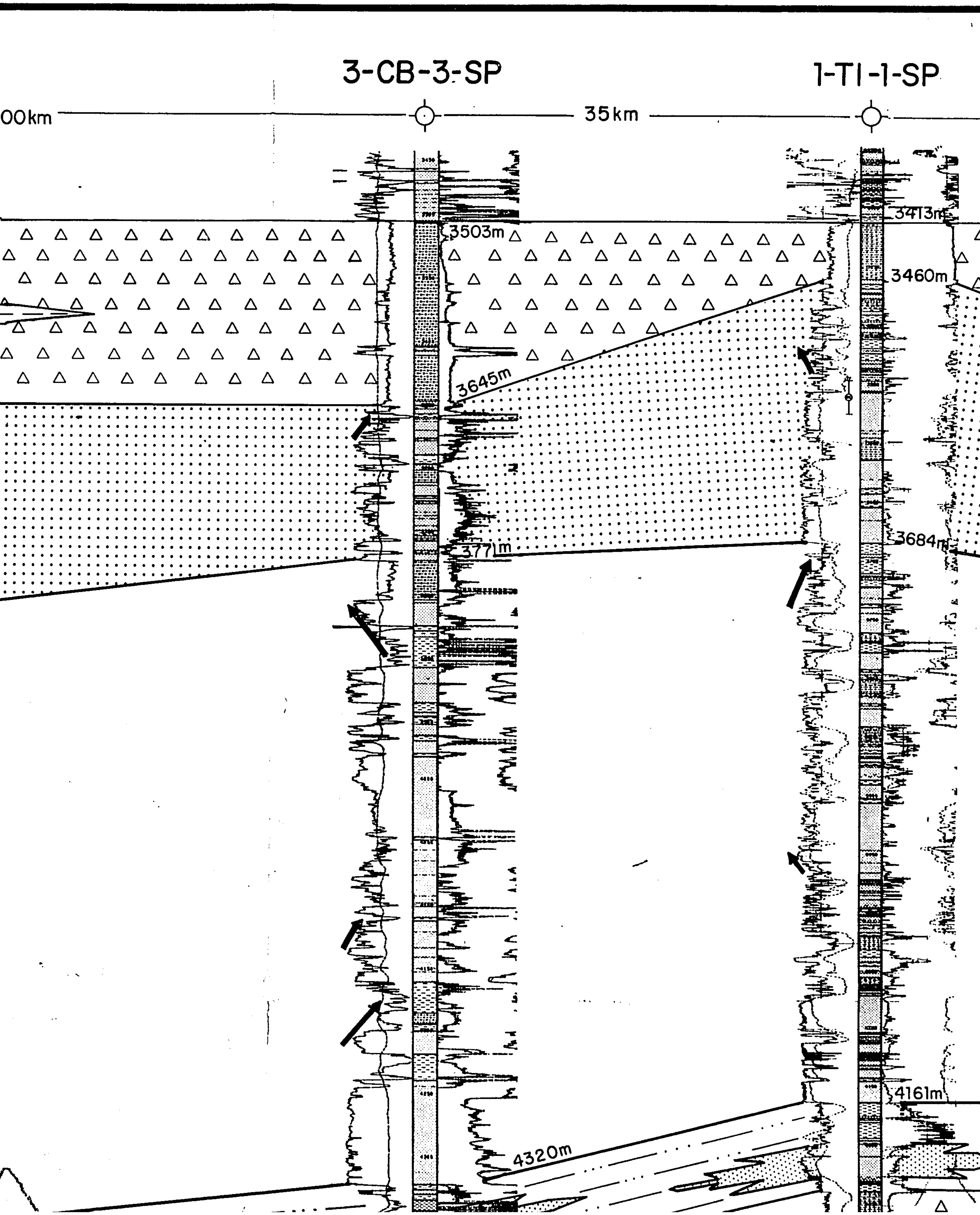
PREDOMINANTLY SANDSTONE, ALSO PEBBLY MUDSTONE AND SILTSTONE. CAMPO MOURÃO FORMATION

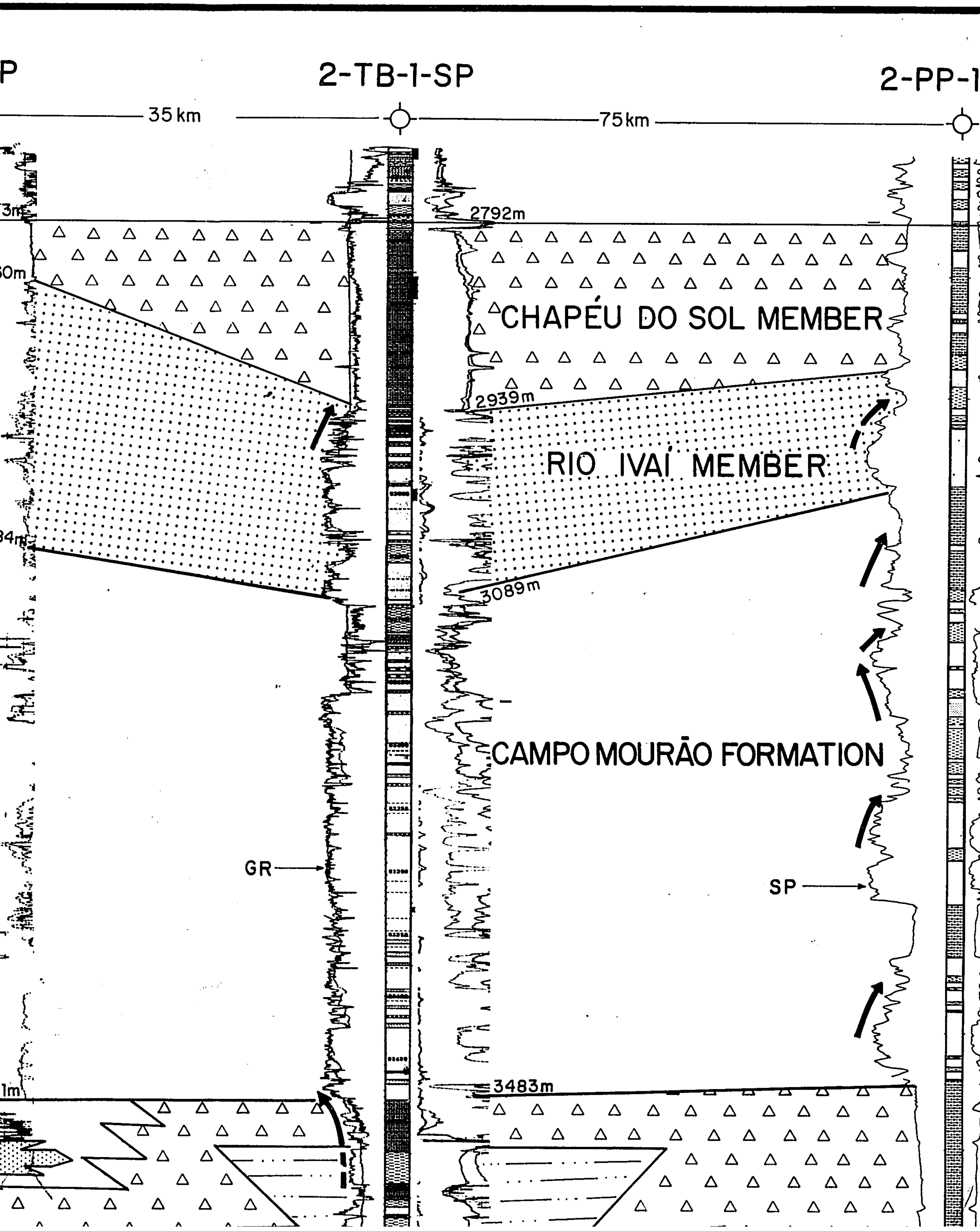
SANDSTONE

FINING UPWARD SEQUENCE

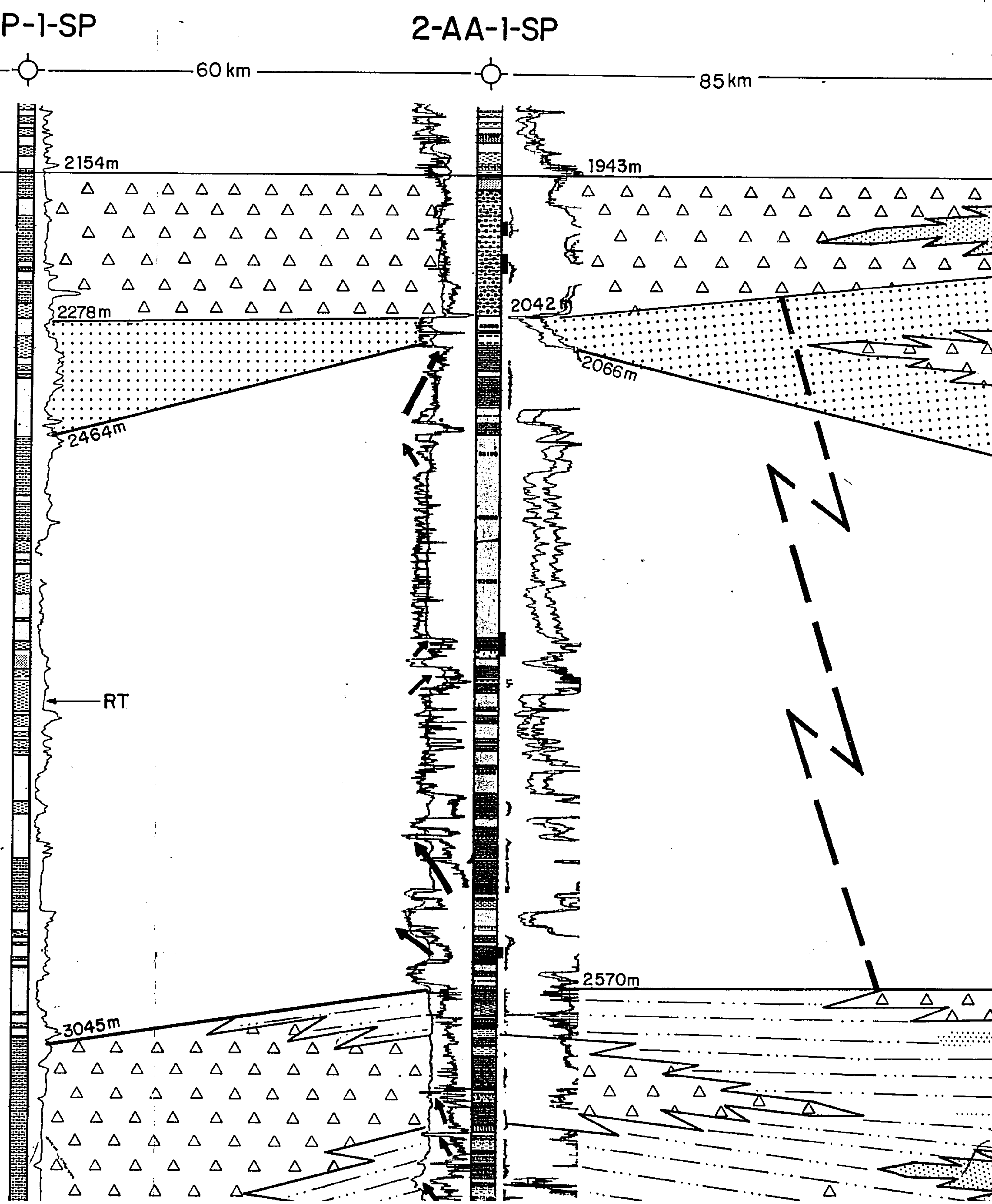
COARSENING UPWARD SEQUENCE

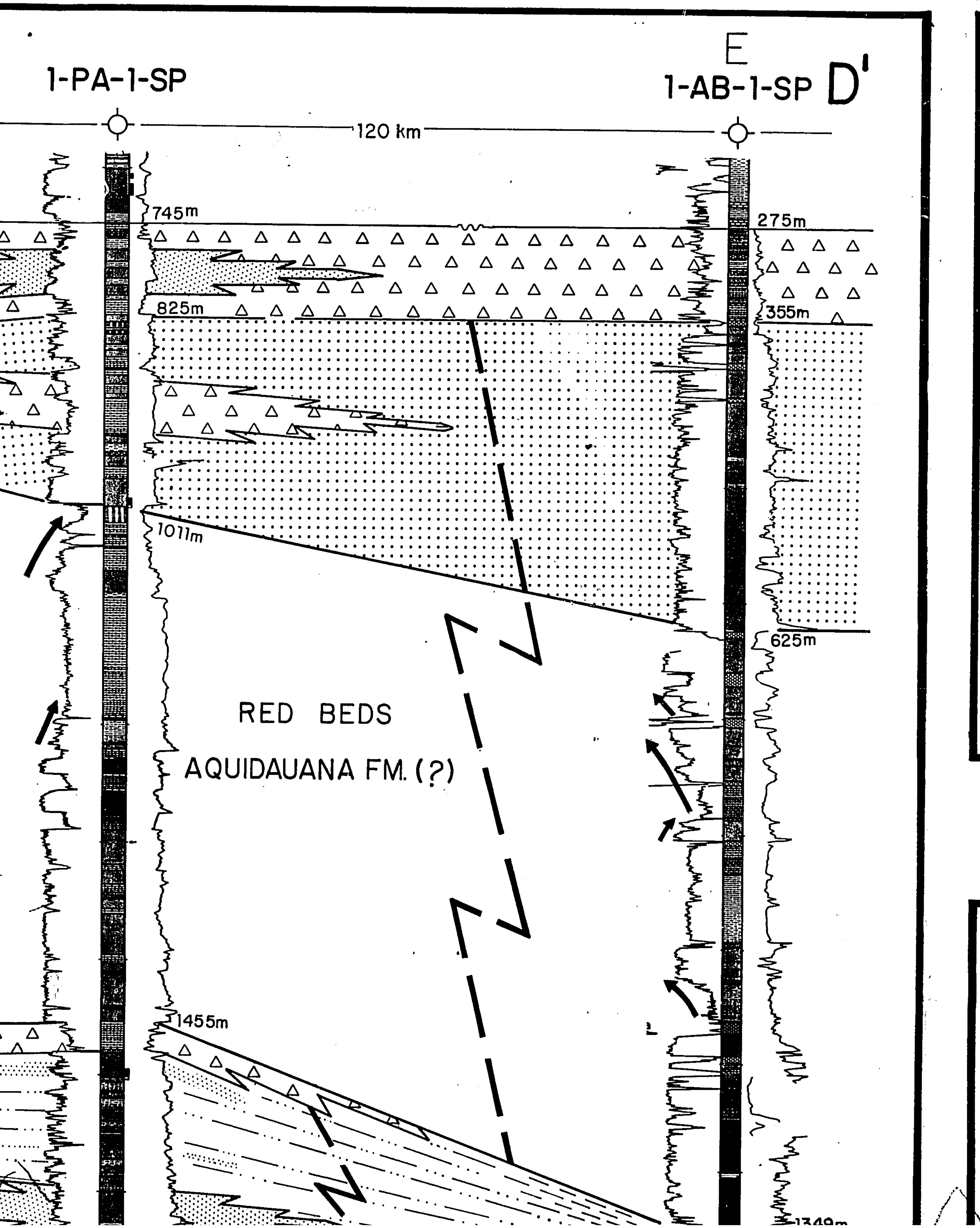

D
W
2-DO-1-MT
300
GUATÁ GROUP
2461m
ITARARÉ GROUP
TACIBA FORMATION
CHAPÉU DO SOL MEMBER
2621m
RIO IVAÍ MBR.
2826m
CAMPO MOURÃO FORMATION

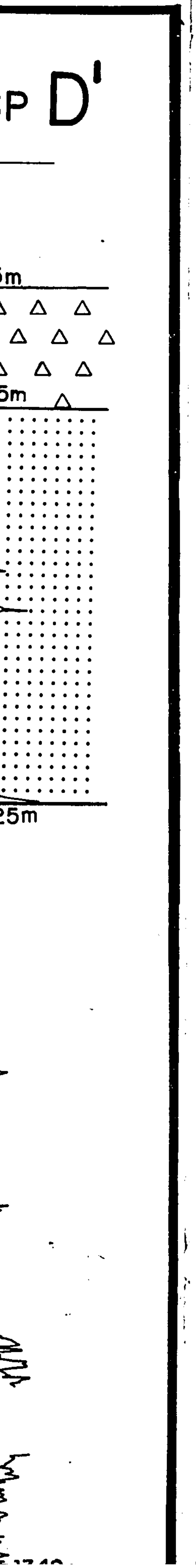

3-CB-3-SP
1-TI-1-SP
00km
35km
3503m
3645m
3771m
4320m
3413m
3460m
3684m
4161m



P
2-TB-1-SP
2-PP-1
35 km
75 km
2792m
2939m
3089m
3483m
CHAPÉU DO SOL MEMBER
RIO IVAÍ MEMBER
CAMPO MOURÃO FORMATION
GR
SP


P-1-SP
2-AA-1-SP
60 km
85 km
2154m
2278m
2464m
RT
3045m
1943m
2042m
2066m
2570m


E
1-PA-1-SP
1-AB-1-SP D'
120 km
745m
825m
1011m
1455m
275m
355m
625m
RED BEDS
AQUIDAUANA FM. (?)



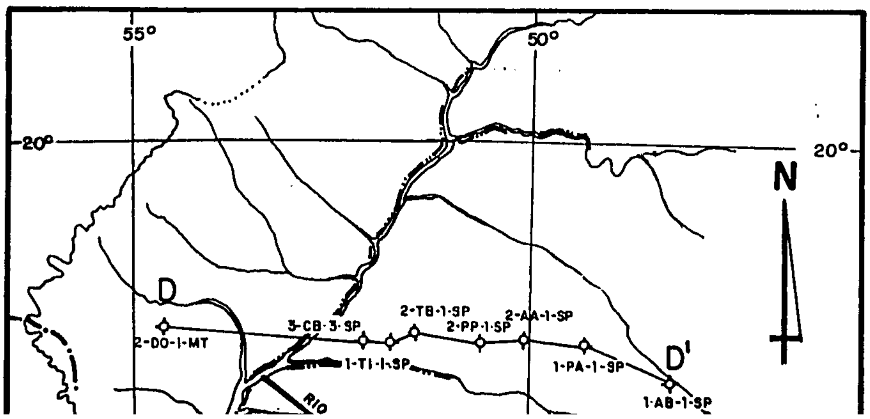
STRATIGRAPHIC CROSS SECTION D-D'

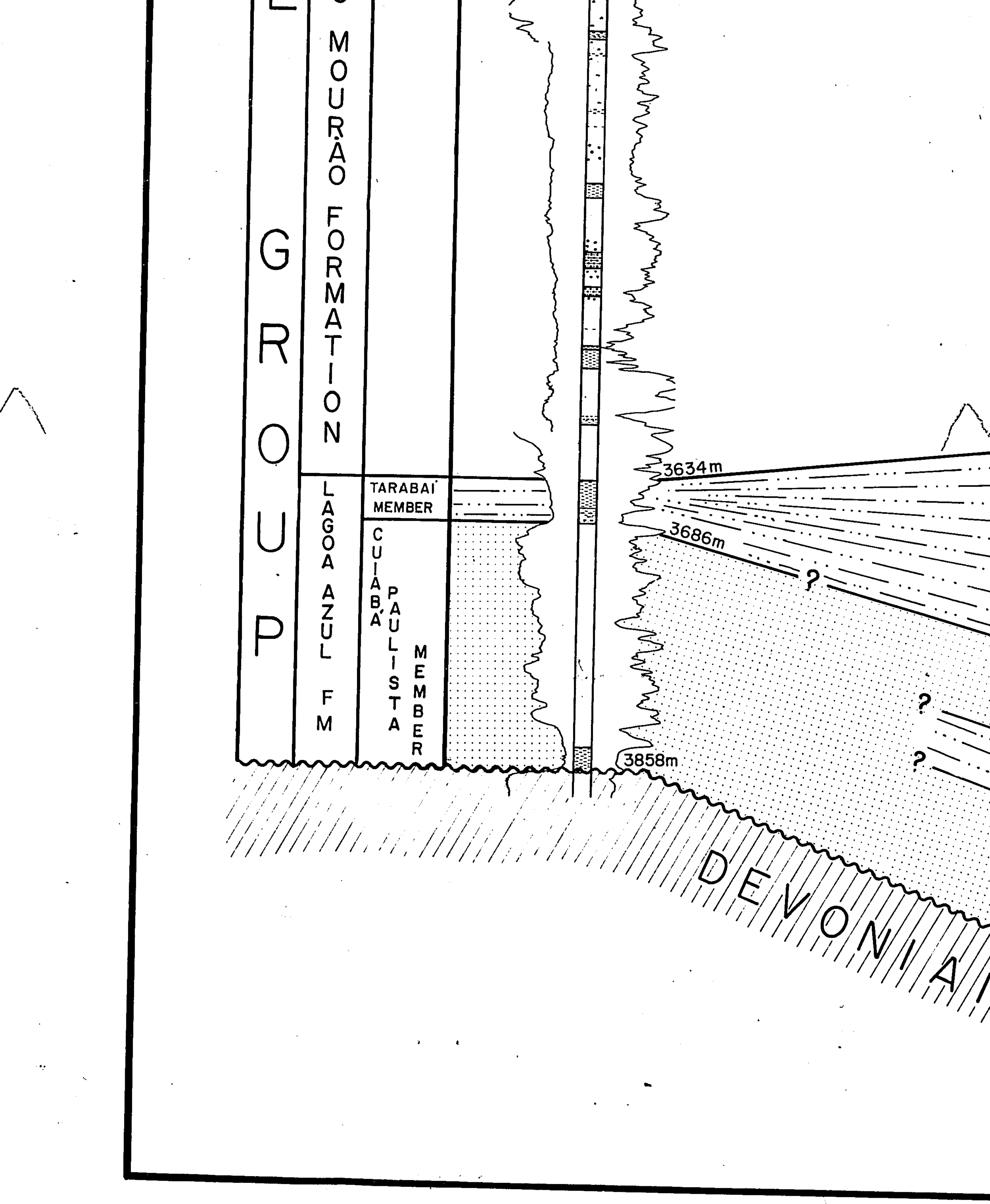
DATUM: TOP OF ITARARÉ GROUP

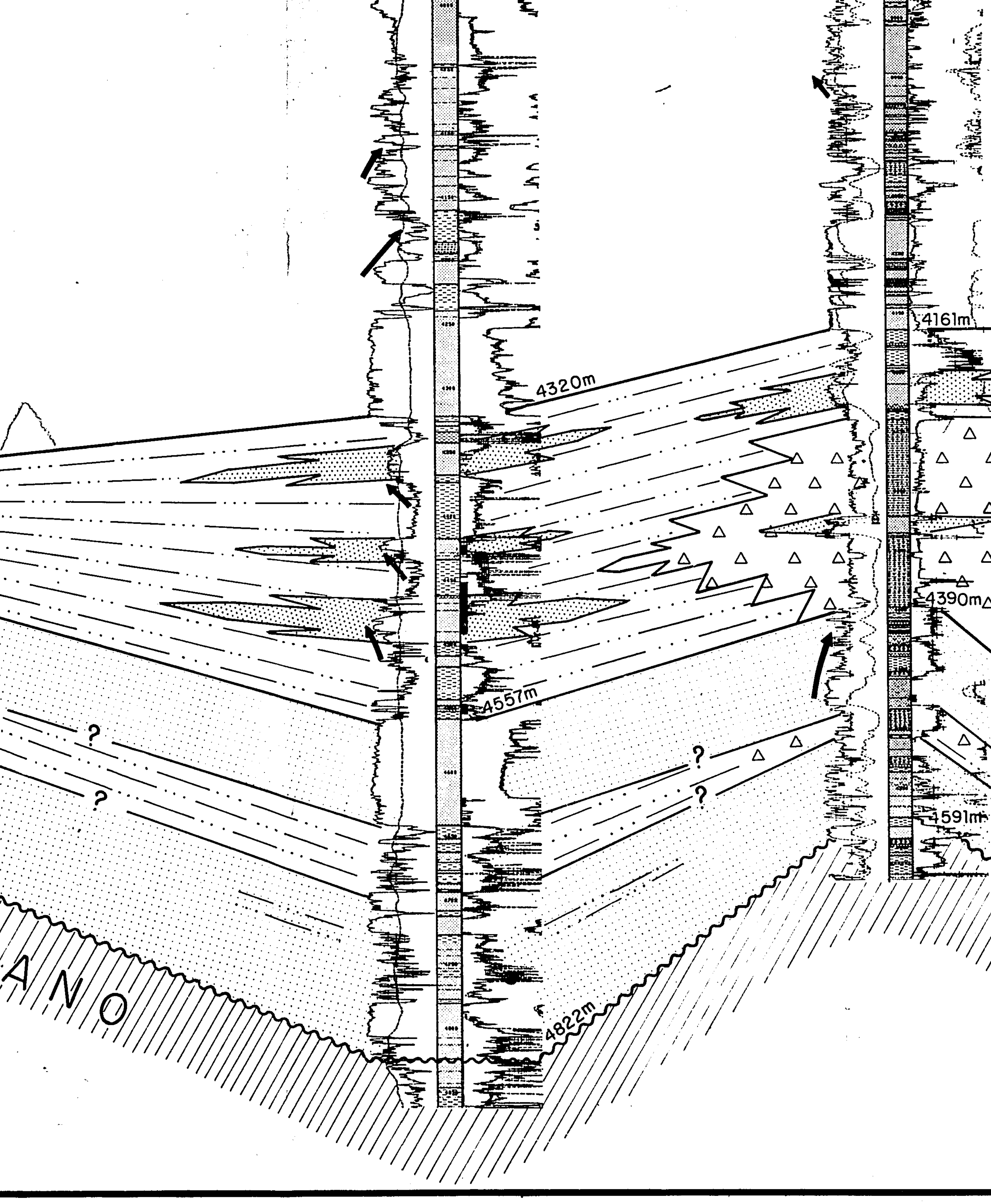
DIABASE EXCLUDED

Fig. 13

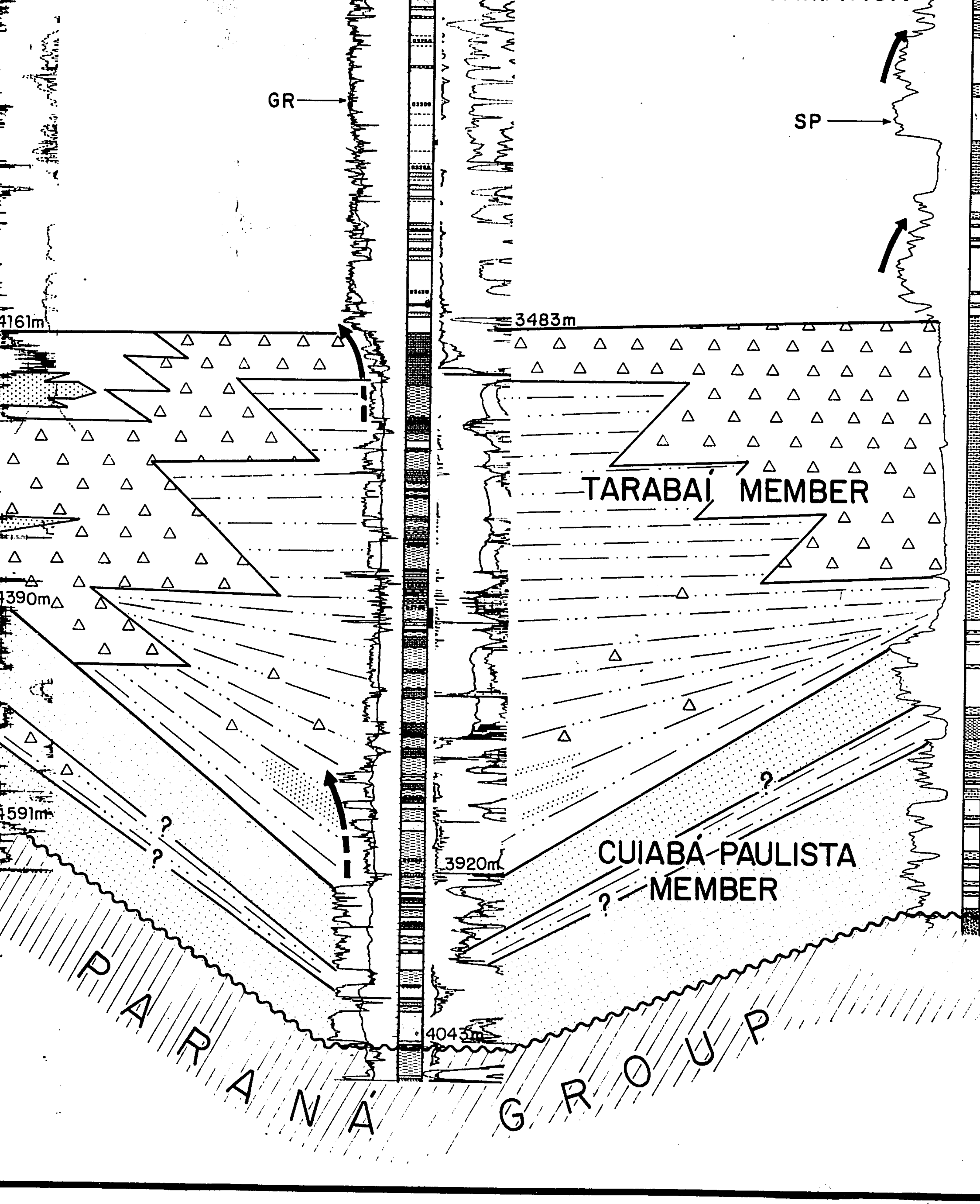
LOCATION MAP

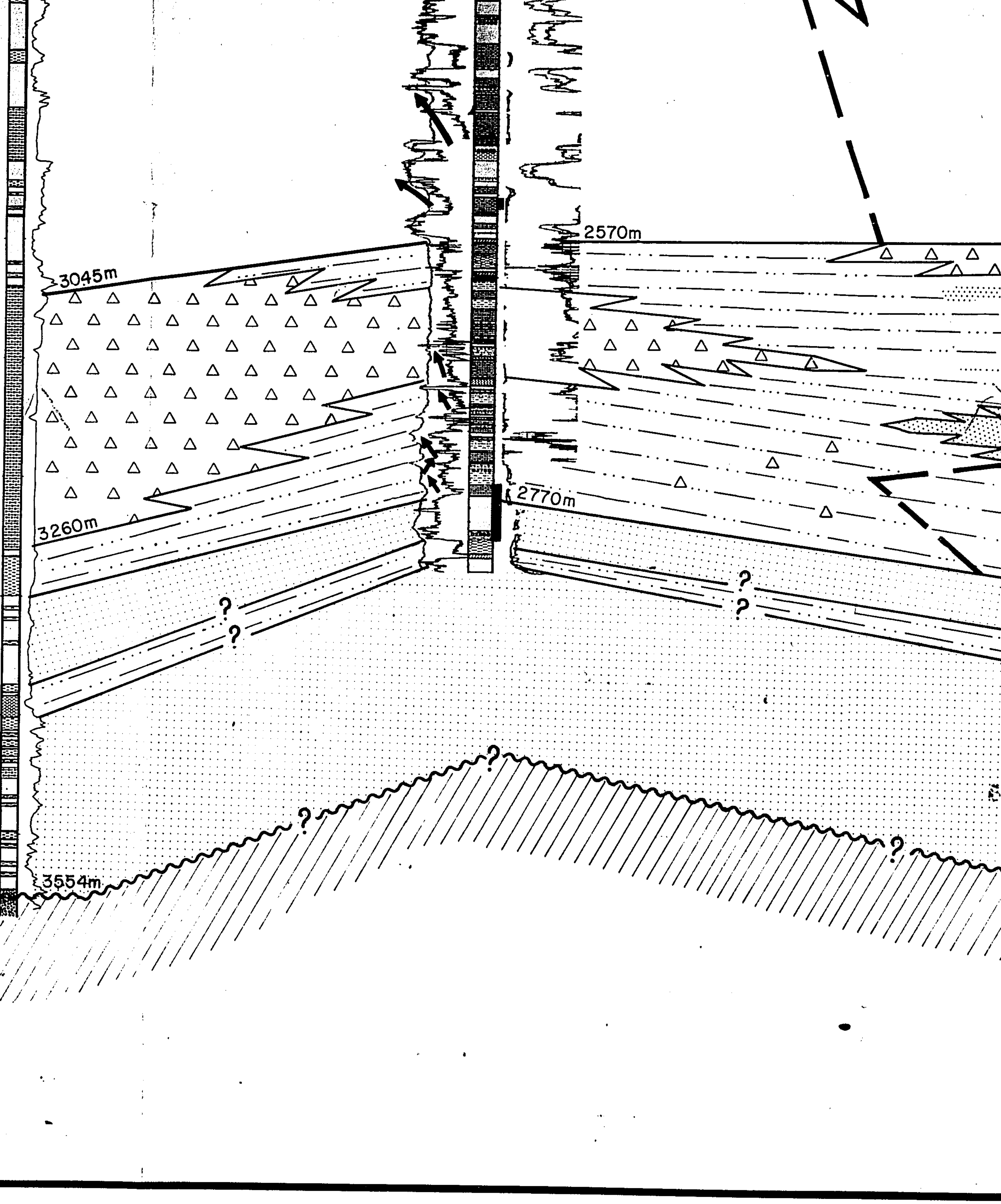



GROUP
MOURÃO FORMATION
LAGOA AZUL FM
TARABAI MEMBER
CUIABÁ PAULISTA MEMBER
3634m
3686m
3858m
?
DEVONIA

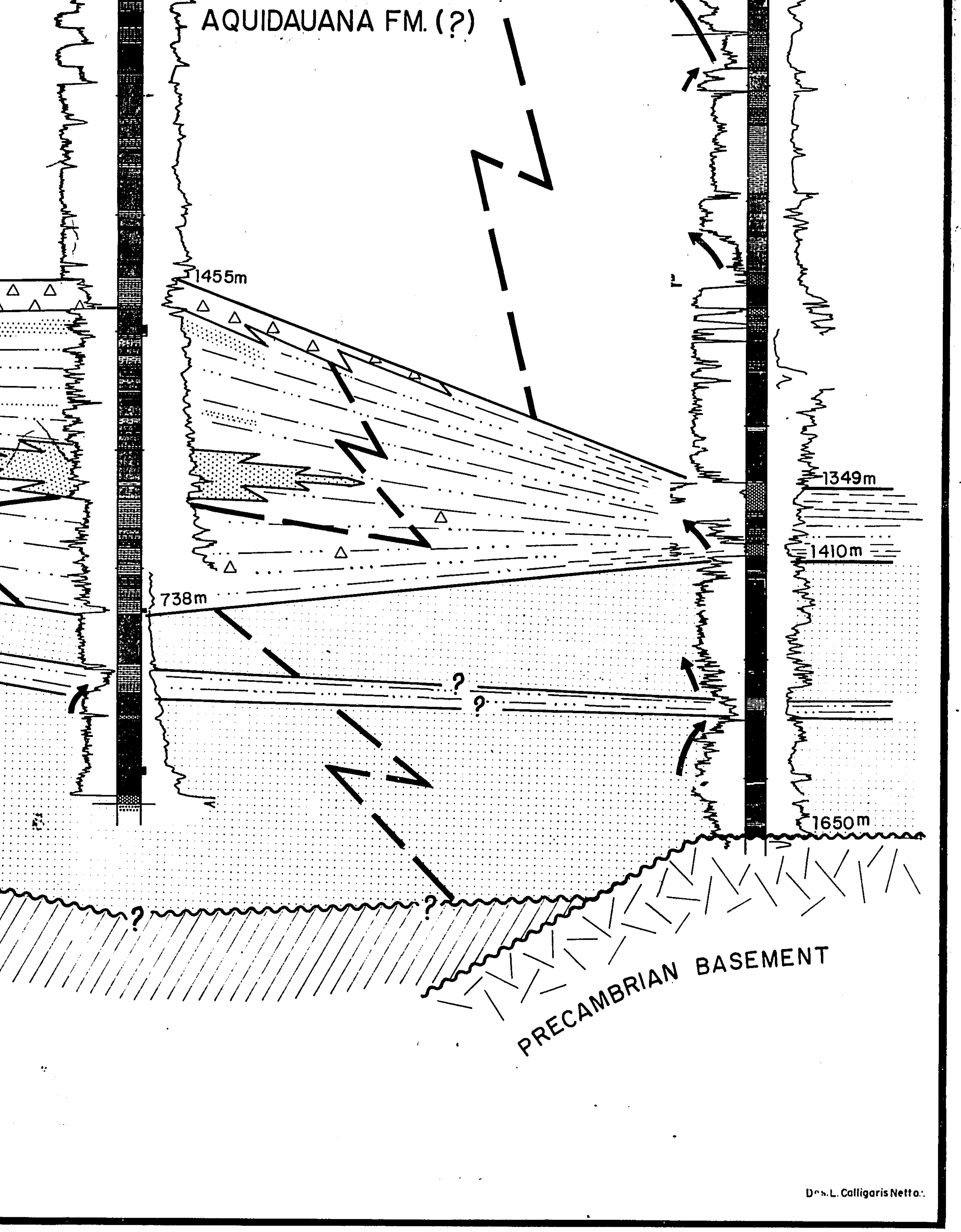


4161m
4320m
4390m
4557m
1591m
4822m
?
?
?
?
ANO


GR
SP
4161m
3483m
TARABAÍ MEMBER
4390m
4591m
3920m
CUIABÁ PAULISTA
MEMBER
4043m
PARANÁ GROUP

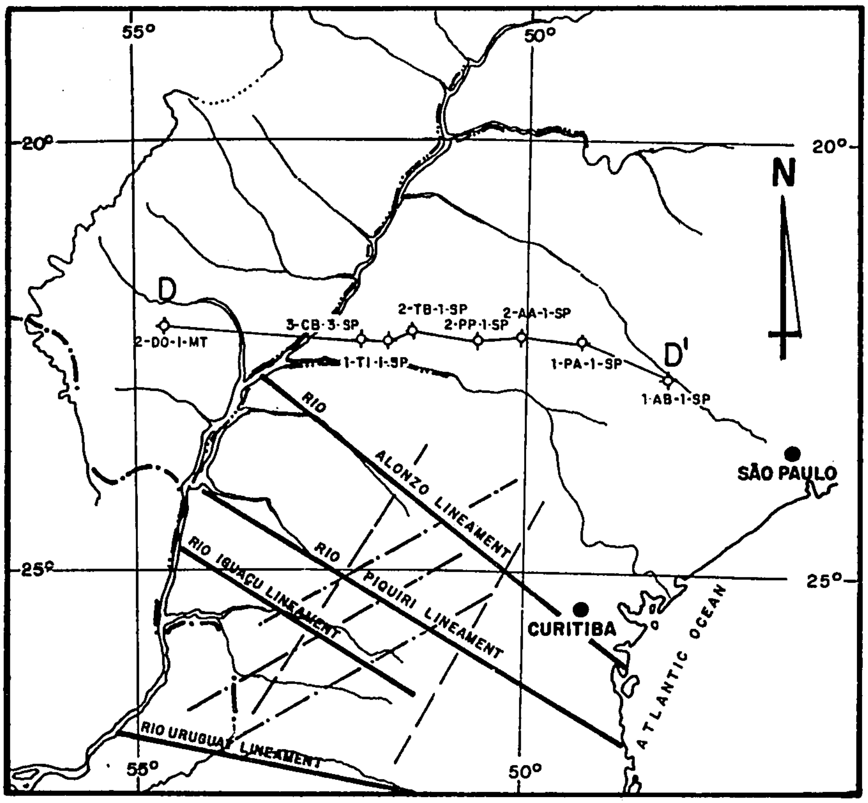


3045m
3260m
3554m
2570m
2770m
?
?
?
?
?
?
?



AQUIDAUANA FM. (?)
1455m
1349m
1410m
738m
?
?
1650m
?
?
PRECAMBRIAN BASEMENT
Des. L. Calligaris Netto.

LOCATION MAP



PREDOMINANTLY PEBBLY MUDSTONE

PREDOMINANTLY SANDSTONE
RIO IVAÍ MEMBER

SHALE

SILTSTONE

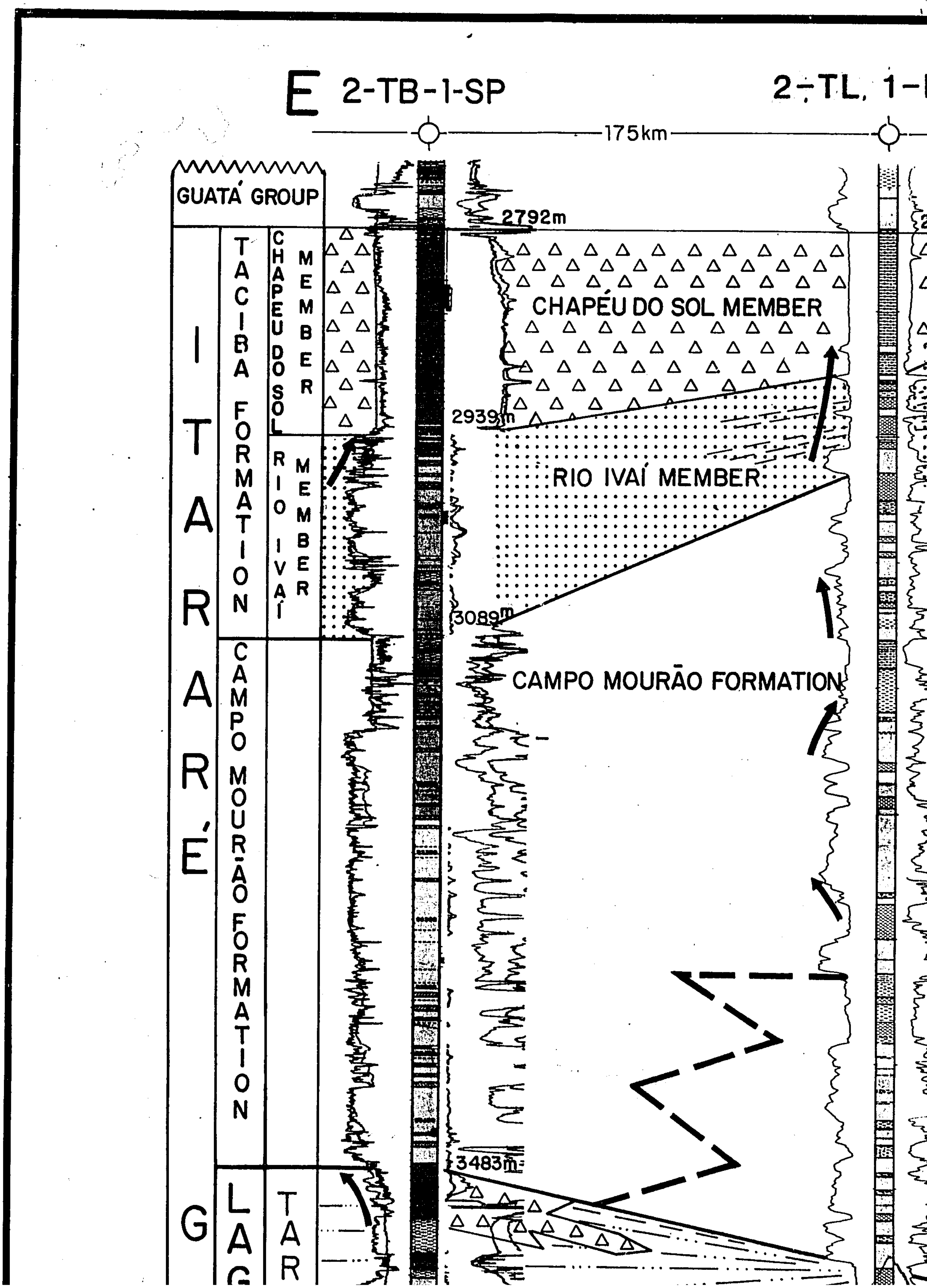
PREDOMINANTLY SANDSTONE
CUIABÁ PAULISTA MEMBER

PREDOMINANTLY SANDSTONE, ALSO PEBBLY MUDSTONE AND SILTSTONE. CAMPO MOURÃO AND AQUIDAUANA FORMATION.

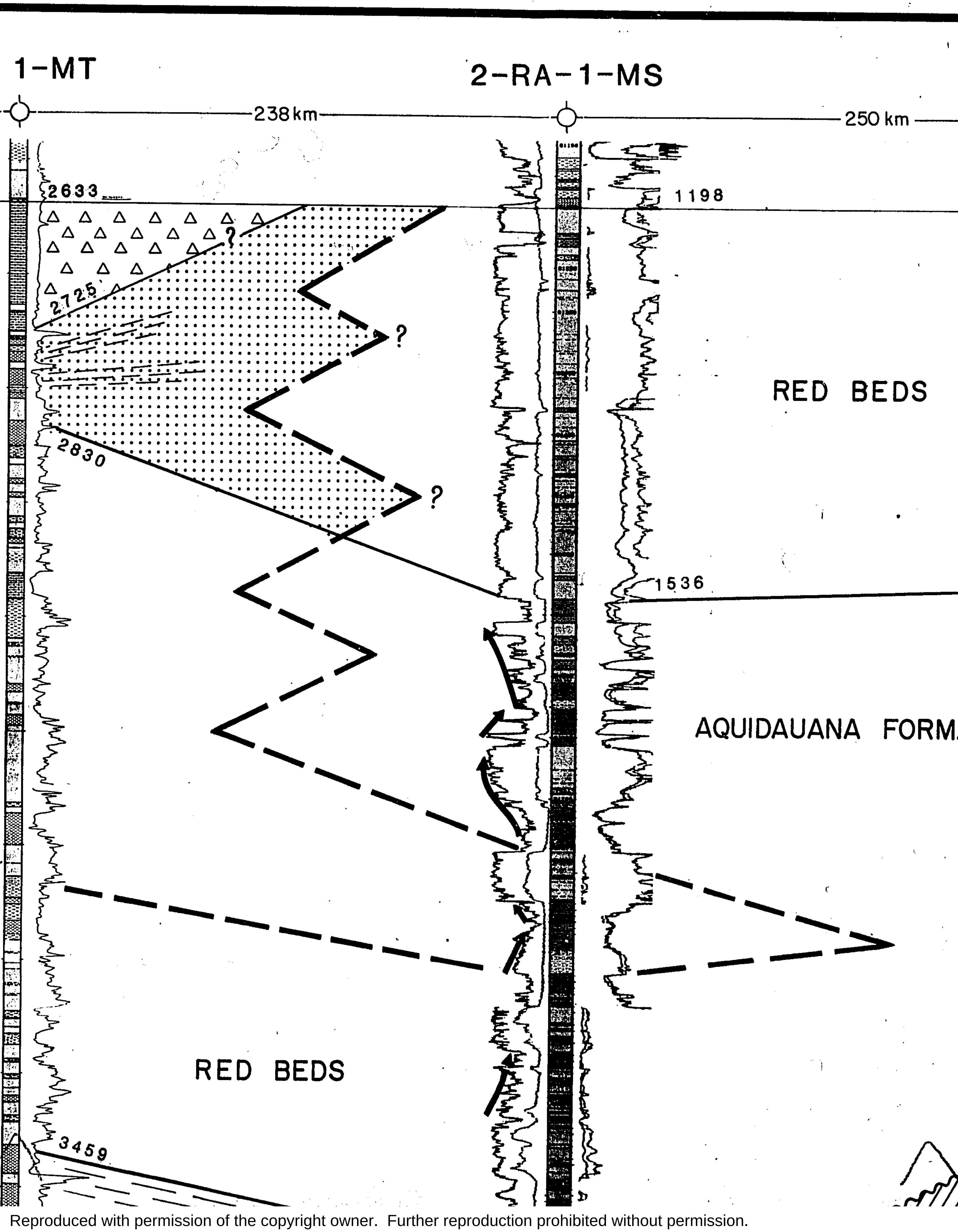
SANDSTONE

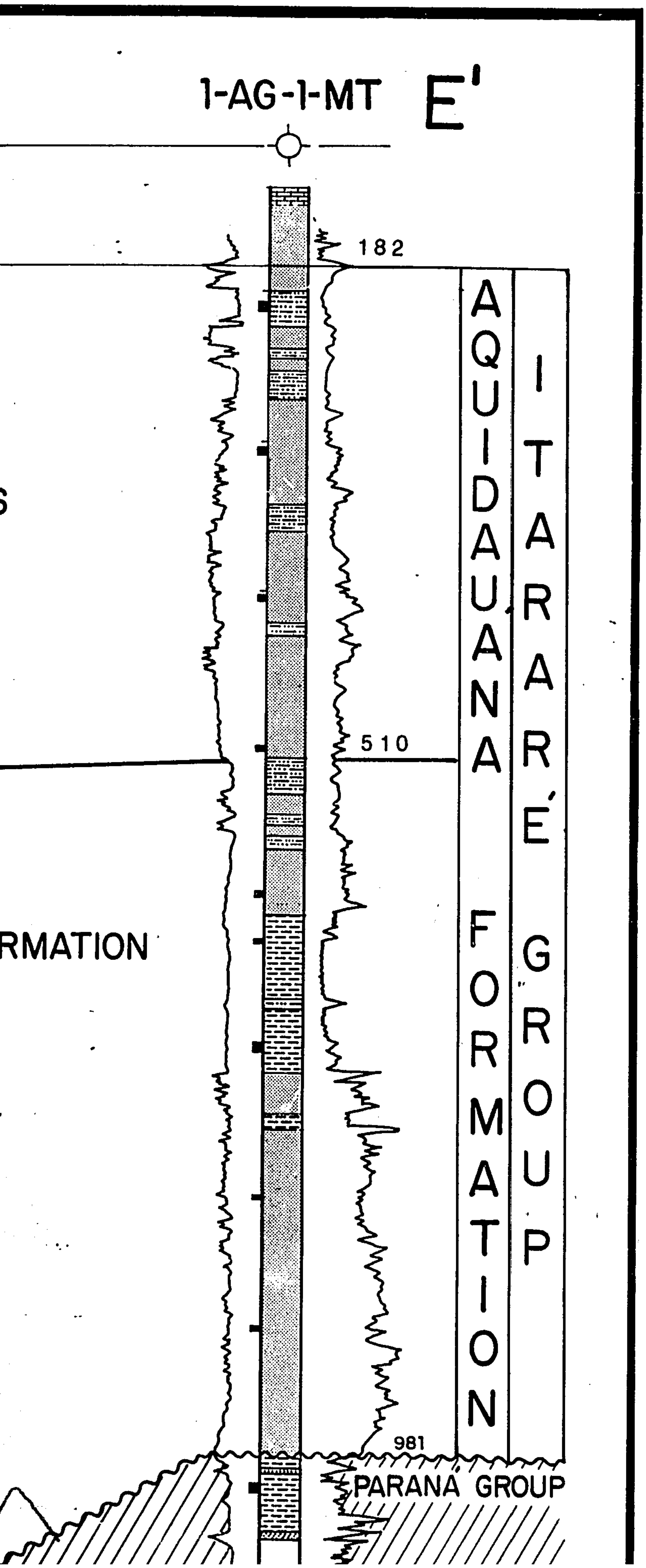
FINING UPWARD SEQUENCE

COARSENING UPWARD SEQUENCE



E 2-TB-1-SP
2-TL. 1-
175km
GUATÁ GROUP
ITARARÉ
TACIBA FORMATION
CHAPÉU DO SOL MEMBER
RIO IVAÍ MEMBER
CAMPO MOURÃO FORMATION
2792m
2939m
3089m
3483m
CHAPÉU DO SOL MEMBER
RIO IVAÍ MEMBER
CAMPO MOURÃO FORMATION


1-MT
2-RA-1-MS
238 km
250 km
2633
2725
2830
3459
1198
1536
RED BEDS
AQUIDAUANA FORM.
RED BEDS

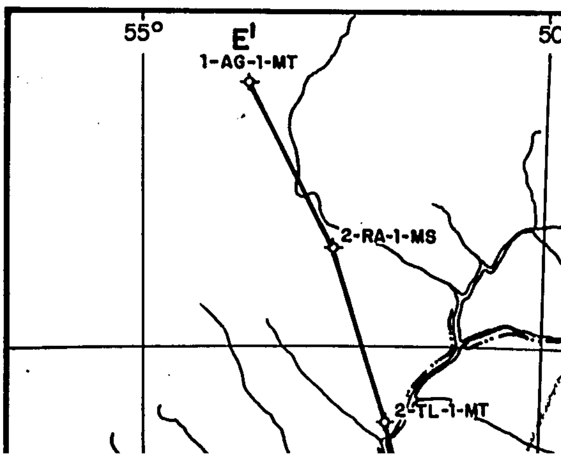


STRATIGRAPHIC CROSS

DATUM: TOP OF ITARAR

DIABASE EXCLU

LOCATION M



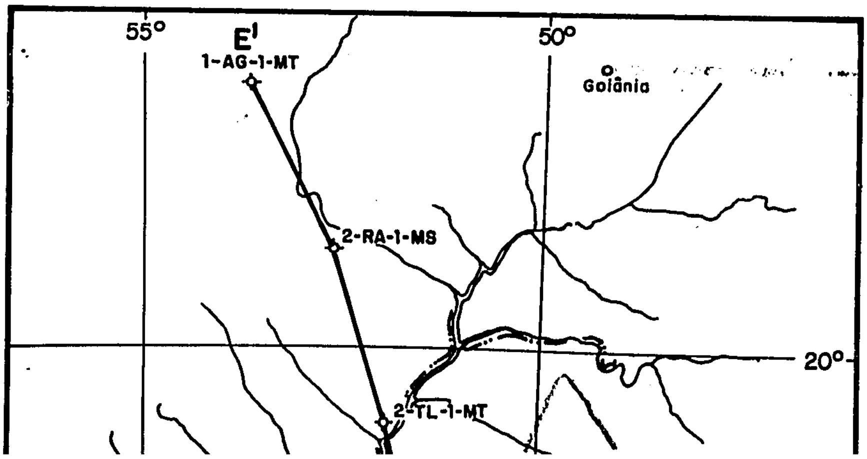
STRATIGRAPHIC CROSS SECTION E-E'

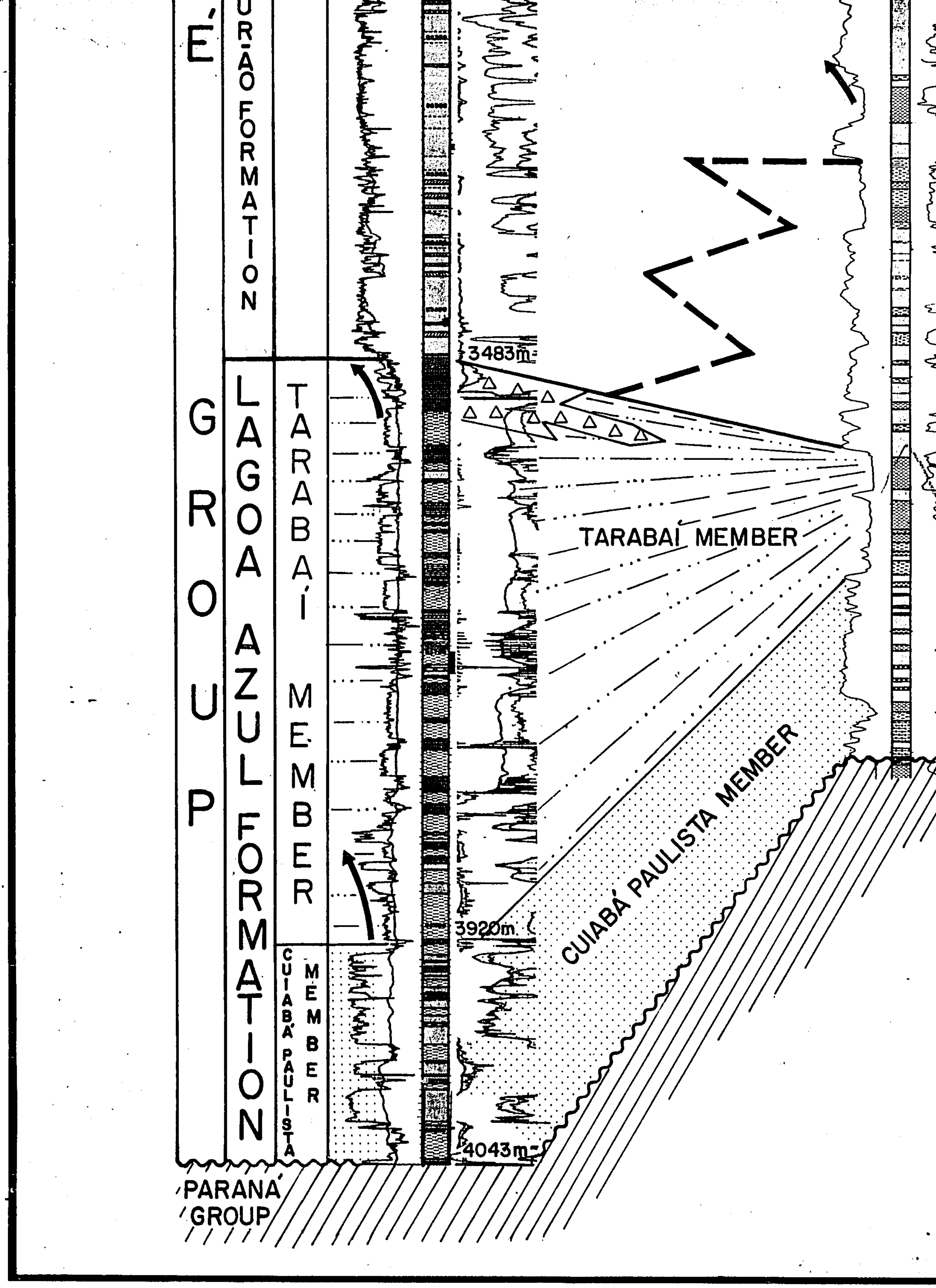
DATUM: TOP OF ITARARÉ GROUP

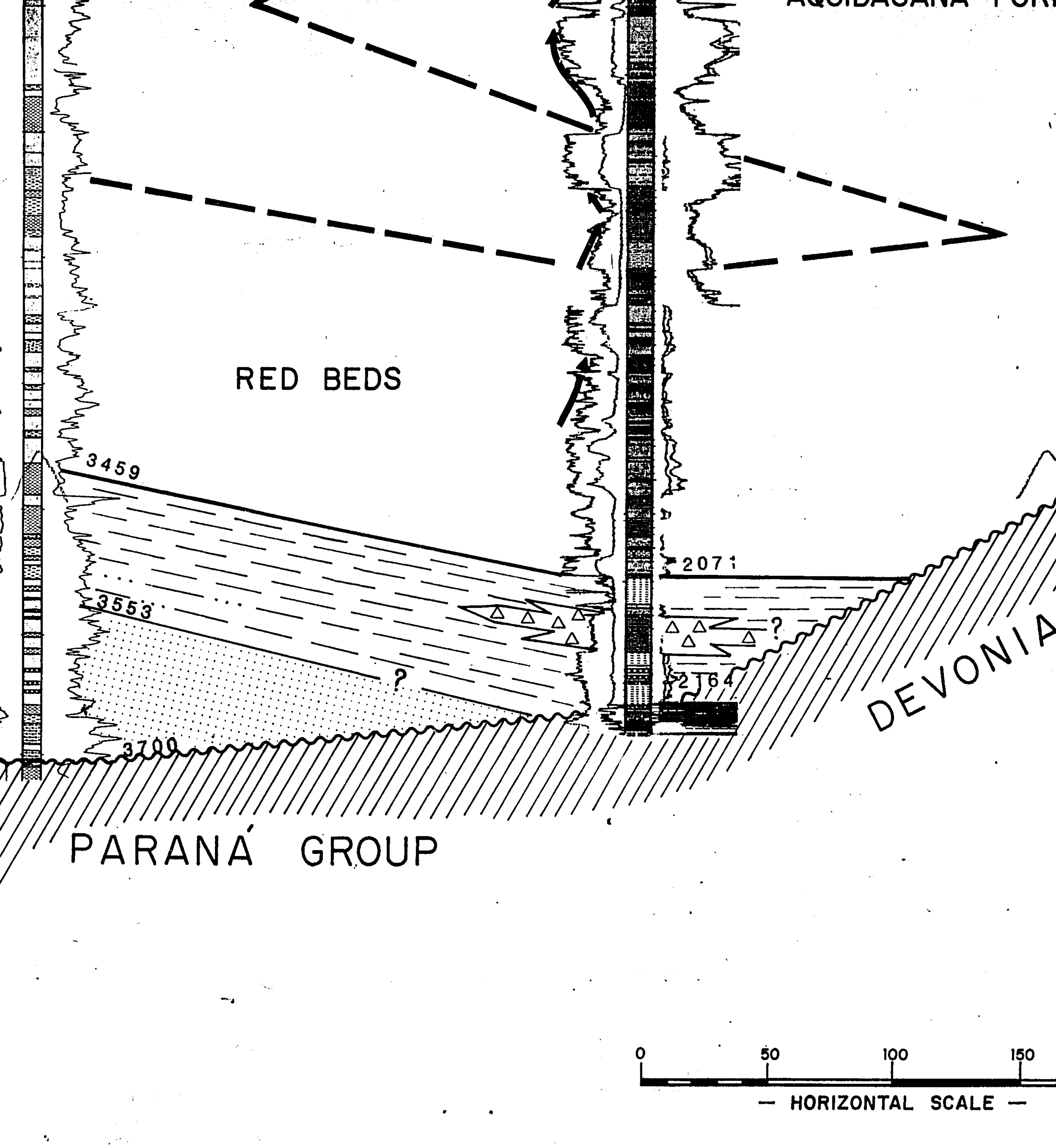
DIABASE EXCLUDED

Fig. 14

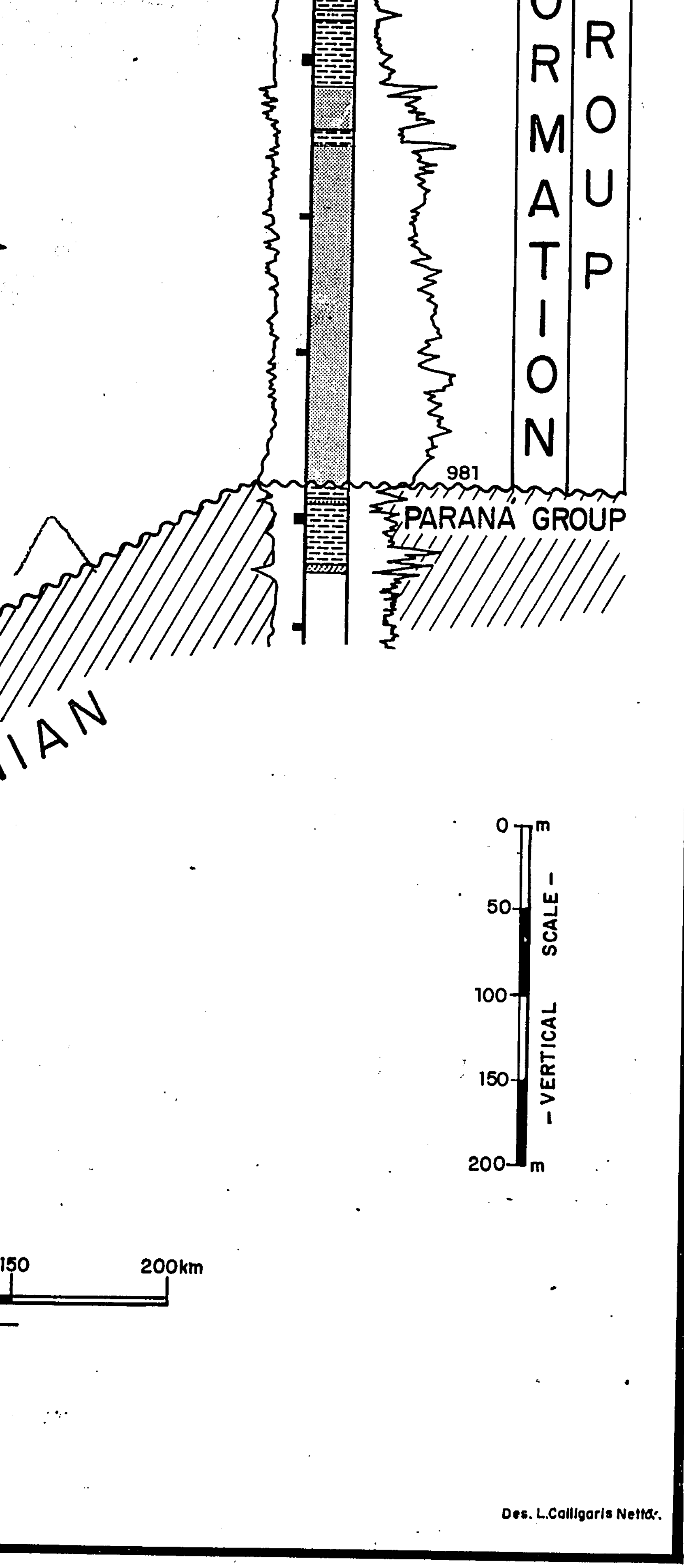
LOCATION MAP



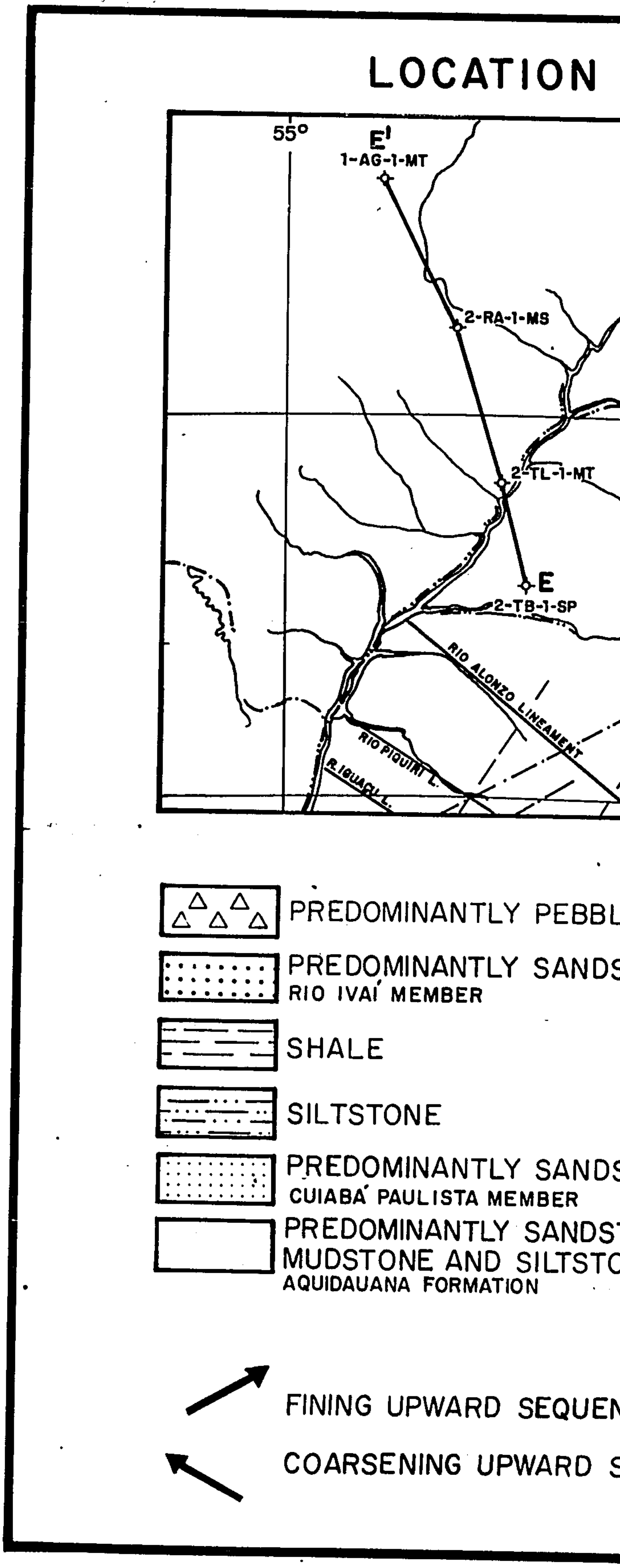

É GROUP
...URÃO FORMATION
LAGOA AZUL FORMATION
TARABAÍ MEMBER
CUIABÁ PAULISTA MEMBER
3483m
3920m
4043m
TARABAÍ MEMBER
CUIABÁ PAULISTA MEMBER
PARANÁ GROUP



AQUIDAUANA FOR
RED BEDS
3459
3553
?
3700
2071
?
2164
DEVONIA
PARANÁ GROUP
0
50
100
150
— HORIZONTAL SCALE —

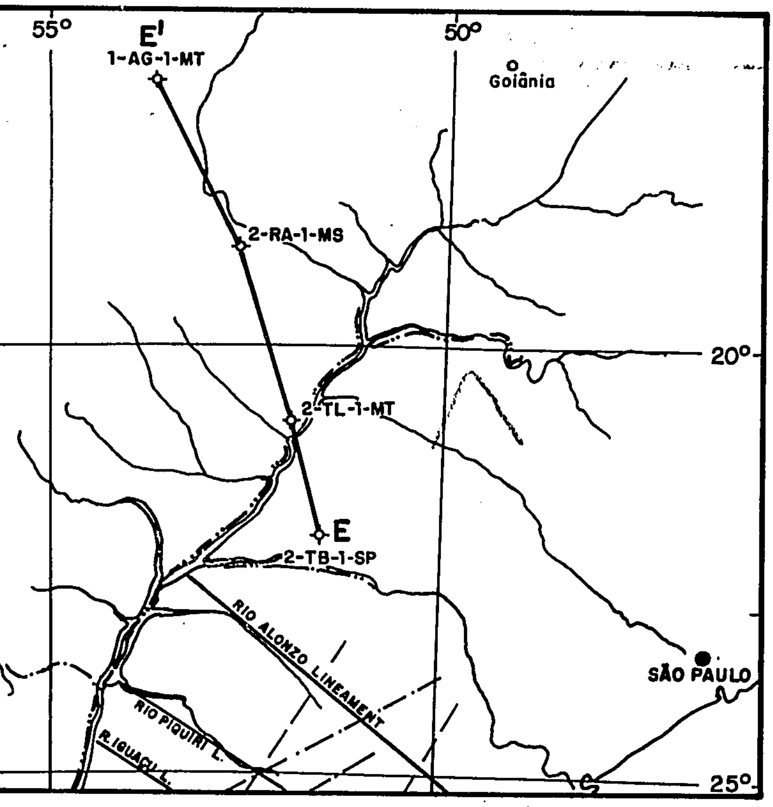


FORMATION
GROUP
981
PARANA GROUP
IAN
0 m
50
100
150
200 m
- VERTICAL SCALE -
150
200km
Des. L.Calligaris Netto.



LOCATION
55°
E'
1-AG-1-MT
2-RA-1-MS
2-TL-1-MT
E
2-TB-1-SP
RIO ALONZO LINEAMENT
RIO PIQUIRI L.
R. IGUAÇU L.
PREDOMINANTLY PEBBL
PREDOMINANTLY SANDS
RIO IVAÍ MEMBER
SHALE
SILTSTONE
PREDOMINANTLY SANDS
CUIABÁ PAULISTA MEMBER
PREDOMINANTLY SANDST
MUDSTONE AND SILTSTO
AQUIDAUANA FORMATION
FINING UPWARD SEQUEN
COARSENING UPWARD S

LOCATION MAP



PREDOMINANTLY PEBBLY MUDSTONE

PREDOMINANTLY SANDSTONE
RIO IVAÍ MEMBER

SHALE

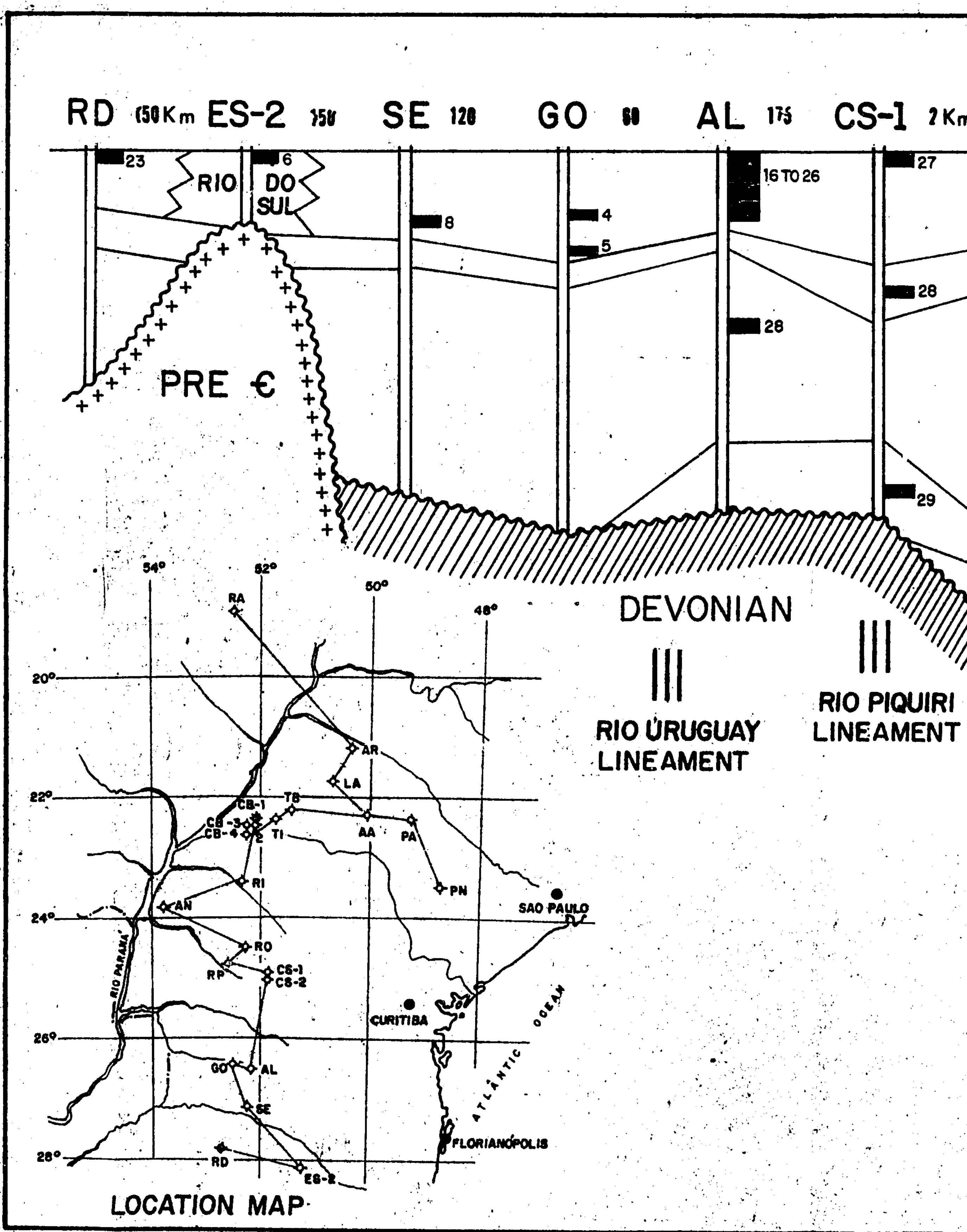
SILTSTONE

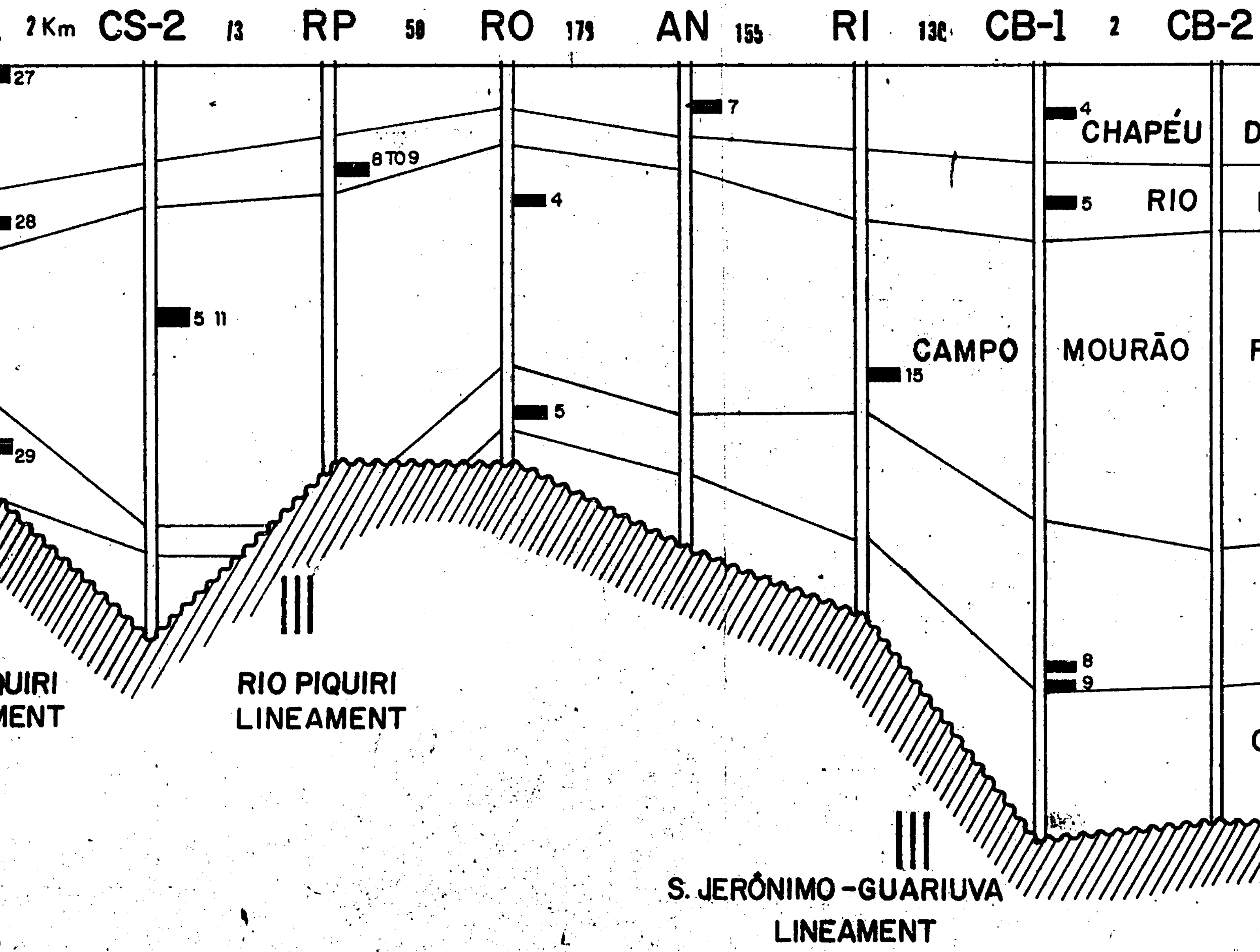
PREDOMINANTLY SANDSTONE
CUIABÁ PAULISTA MEMBER

PREDOMINANTLY SANDSTONE, ALSO PEBBLY MUDSTONE AND SILTSTONE. CAMPO MOURÃO AND AQUIDAUANA FORMATION

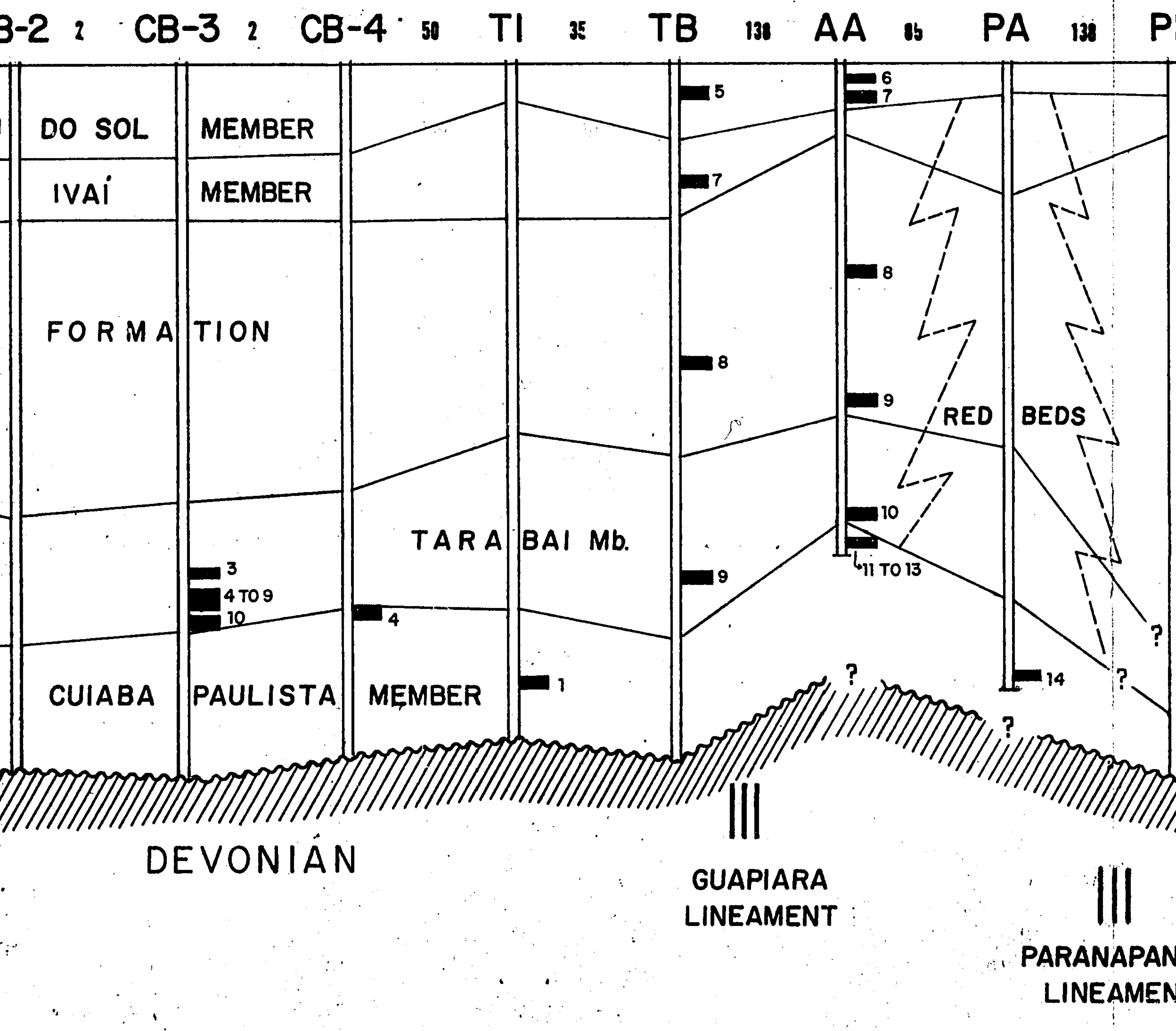
FINING UPWARD SEQUENCE

COARSENING UPWARD SEQUENCE


RD
150 Km
ES-2
150
SE
120
GO
60
AL
175
CS-1
2 Km
23
6
RIO DO SUL
8
4
5
16 TO 26
27
28
28
29
PRE €
DEVONIAN
RIO URUGUAY LINEAMENT
RIO PIQUIRI LINEAMENT
54°
52°
50°
48°
20°
22°
24°
26°
28°
RA
AR
LA
TB
CB-1
CB-3
CB-4
TI
AA
PA
PN
RI
AN
RO
RP
CS-1
CS-2
SAO PAULO
CURITIBA
RIO PARANA
ATLANTIC OCEAN
GO
AL
SE
RD
ES-2
FLORIANOPOLIS
LOCATION MAP

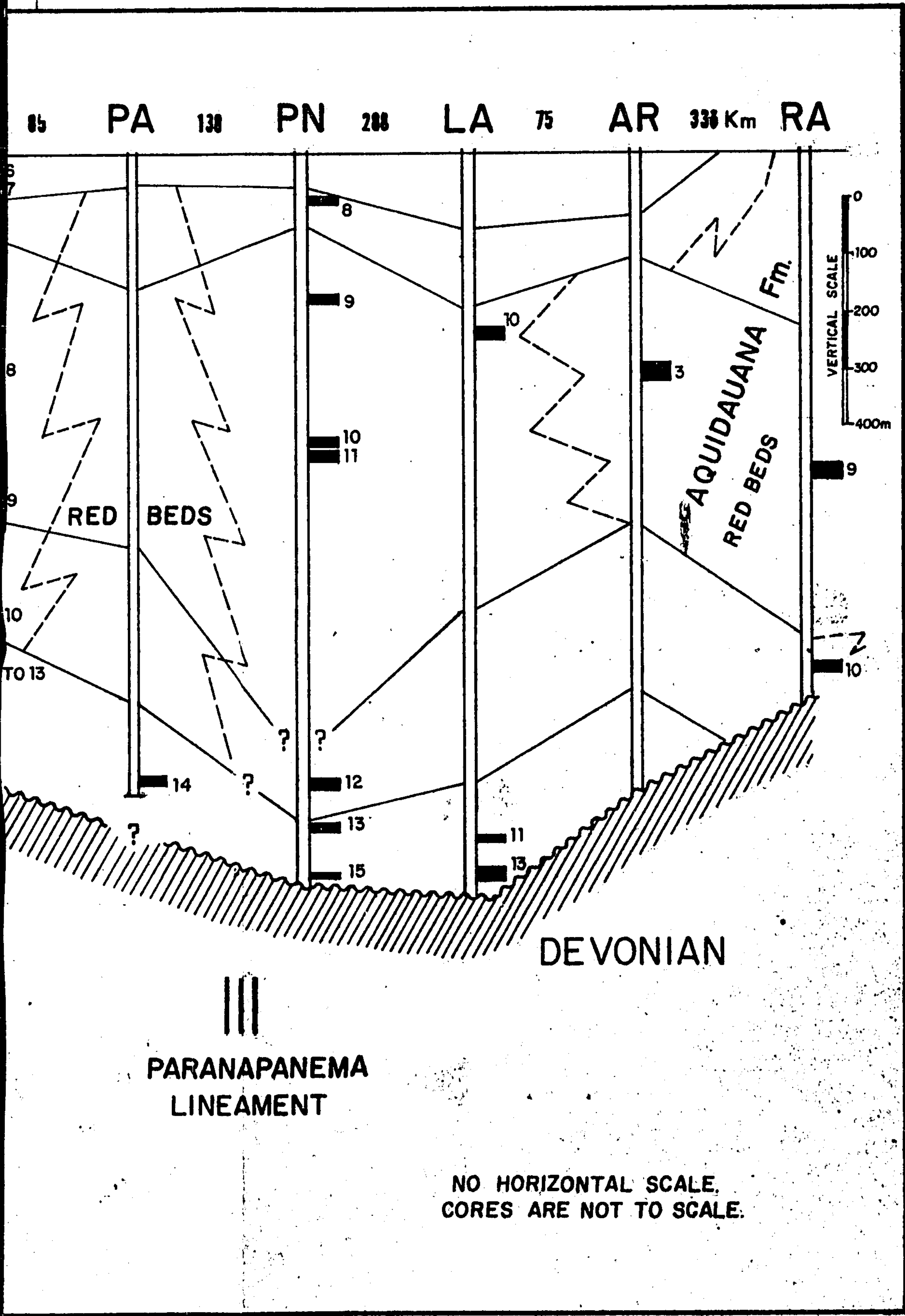

2 Km CS-2 13 RP 59 RO 179 AN 155 RI 130 CB-1 2 CB-2
27
28
29
8 TO 9
5 11
4
5
7
15
4
5
8
9
CHAPÉU
RIO
CAMPO
MOURÃO
QUIRI
MENT
RIO PIQUIRI
LINEAMENT
S. JERÔNIMO-GUARIUVA
LINEAMENT

GENI
POSI



GENERALISED CROSS SECTION WITH THE POSITION OF AVAILABLE CORES.

Fig. 19


85 PA 138 PN 288 LA 75 AR 338 Km RA
VERTICAL SCALE
0
100
200
300
400m
RED BEDS
AQUIDAUANA Fm.
AQUIDAUANA RED BEDS
TO 13
DEVONIAN
PARANAPANEMA LINEAMENT
NO HORIZONTAL SCALE.
CORES ARE NOT TO SCALE.

___ OF ___

367355

SCHOOL: field

DATE: 12.10.87 ISSUE: 48.09

PHYSICAL DESCRIPTION: unbd.

MICROFICHE	MICROFILM	W.O. No.
TOTAL: 1	TOTAL:	
C/R L/C: 1 SCH:	C/R L/C: SCH:	

X	COPYRIGHT
	NOT C/R
	FILM TO C/R
	FILM TO SCH
/	FICHE TO C/R
	FICHE TO SCH

PUBL. NO.	NO. PGS.	NO. EXPOS.	PRICE-POS	AUTHOR NAME (LAST, FIRST, MIDDLE)
87-26,563				SHAW, J.S.

CAM NO.	OPER	ROLL NO.	NO. EXPOS.	REDUC	VOLT	IN	OUT	OPER	IN	OUT
7	Judy	82		20:1	730		1/5			

ST:	BT:	PO:	AP NO.	AP $

TEXT:

PL	PROC				
42			MA00431	00001	MICRO & ABST @ $30.00··MASTERS
42			MA00432	00005	C/R CHGS @ $20.00··MASTERS
42			MA00432	00006	C/R PD-IN-ADV. @ $20.00··MASTERS
42	50		MA00434	00001	PUB. ABST. ONLY @ $25.00··MASTERS
42			MA00439	00001	ABST. & STG NEG @ $25.00··MASTERS
42		1	PD00421	00001	MICRO & ABST @ $40.00··DOCT.
42		1	PD00422	00005	C/R CHGS @ $20.00··DOCT.
42			PD00422	00006	C/R PD-IN-ADV @ $20.00··DOCT.
42	50		PD00424	00001	PUBL ABST ONLY @ $30.00··DOCT.
42	01		PD00429	00000	ABST & STORAGE NEG @ $30.00··DOCT.
42			PD00451	00000	MICRO & ABST @ $50.00··MONO.
42			PD00453	00000	C/R PD-IN-ADV @ $20.00··MONO.
42	01		PD00426	00000	FILM TO SCH @ $8.50··DOCT.
42	02		PD00426	00000	FICHE TO SCH @ $8.50··DOCT.
42	01		MA00436	00000	FILM TO SCH @ $8.50··MASTERS
42	02		MA00436	00000	FICHE TO SCH @ $8.50··MASTERS
42	31		PD00430	00000	ORIGINAL BINDING @ $9.50

FORM 22