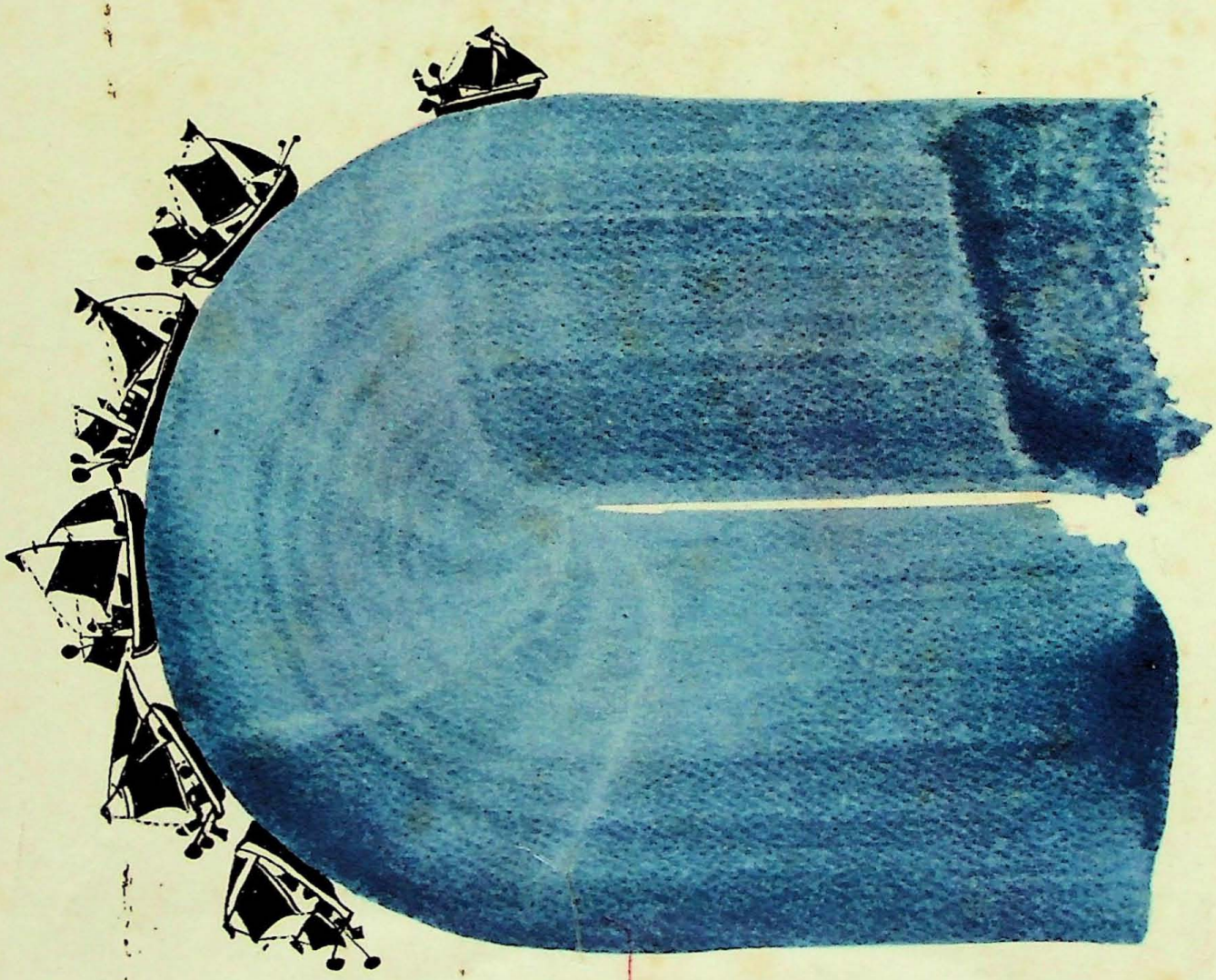
EARTH RHEOLOGY ISOSTASY AND EUSTASY

EDITED BY
NILS-AXEL MÖRNER



Vertical Movements in Continental Southern Brazil During the Cenozoic

VICENTE JOSÉ FÚLFARO AND KENITIRO SUGUIO

Departamento de Paleontologia e Estratigrafia Instituto de Geociências—Universidade de São Paulo, São Paulo—Brazil

Abstract

Many years ago the close relationship between tectonism and sedimentation was established by several authors. However, until the recognition of associated sedimentary deposits, in continental southern Brazil, the occurrence of Cenozoic vertical movements was only suspected by some geologists in our country.

During the last ten years, many papers have shown a strong tectonic control on Cenozoic sedimentation. Frequently the tectonism is related to the reactivation of ancient Precambrian fault lines.

Introduction

During the last decade several review papers on Cenozoic deposits in southern Brazil gave rise to a geologic problem previously not mentioned in the country, a problem related to the field of 'neotectonism', as named by Brazilian geologists.

As the South American Platform is situated in a huge cratonic area, recent movements were even suspected by almost all of the previous investigators. Bjornberg, Gandolfi and Paraguassa (1965) studying the State of São Paulo's eastern tectonic pattern, were the first to deal with the magnitude of the Cenozoic tectonics. Bjornberg (1969) also presented a global review of Cenozoic sedimentation pointing out the great amount of evidence for the Cenozoic tectonic instability of southeastern Brazil. With this point of view, several papers on this problem were published during the last ten years that analyse Cenozoic sedimentation in continental Brazil, almost always as related to synchronous or previous vertical movements (Fulfaro and Suguio, 1968; Fulfaro, 1974; Fulfaro and Suguio, 1974; Fulfaro and Landim, 1976, etc.).

Regional Structural Pattern

The area in discussion here is located in the Brazilian portion of South American Platform with outcrops of Precambrian rocks to the east and Paleozoic, Mesozoic and Cenozoic rocks of the Paraná sedimentary basin, a huge 150,000 km^2 intracratonic basin, to the west.

Fulfaro and Poncano (1974) summarized the main tectonic events of the South American Platform. The Precambrian rocks were rejuvenated during the Brazilian folding cycle (900 to 550 my), which represents the end of the geossynclinal-type tectonic evolution in the Brazilian territory.

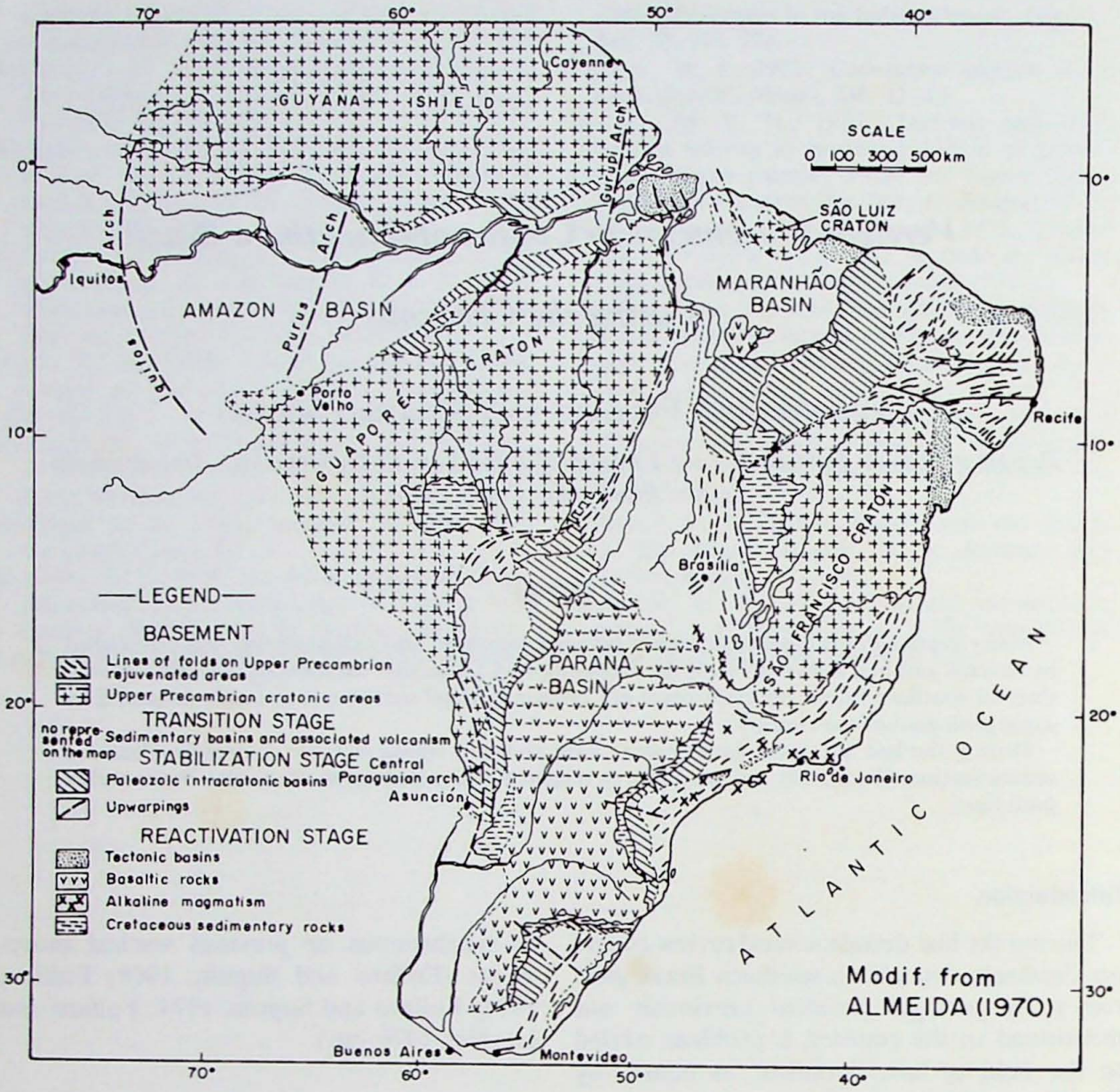


Fig. 1. Structural evolution of the Brazilian platform (modified from Almeida, 1970)

The Brazilian portion of the South American Platform (Fig. 1) underwent a period of geocratic character with a rather prolongated tectonic calm from the end of Precambrian to the end of the Jurassic (Almeida, 1967).

At the end of the Jurassic a strong basic volcanism began which had its maximum intensity in the Early Cretaceous (Amaral, Cordani and Kawashita, 1965) and extended until the beginning of the Tertiary with the emplacement of several alkaline bodies (Amaral and colleagues, 1967). Associated with this volcanism, a new period of rigid tectonics started that is very well documented by diabase dykes in the region (Fulfaro and Suguio, 1967).

During the rigid tectonic phase, the Santos sedimentary basin, situated on the continental shelf, started to subside by means of strong tectonics. Its main tectonic feature is the Santos Fault, which defines the western limit of the basin. This fault passes about 40 km east of the present strandline and is northeast–southwest oriented, with an eastern downfaul-

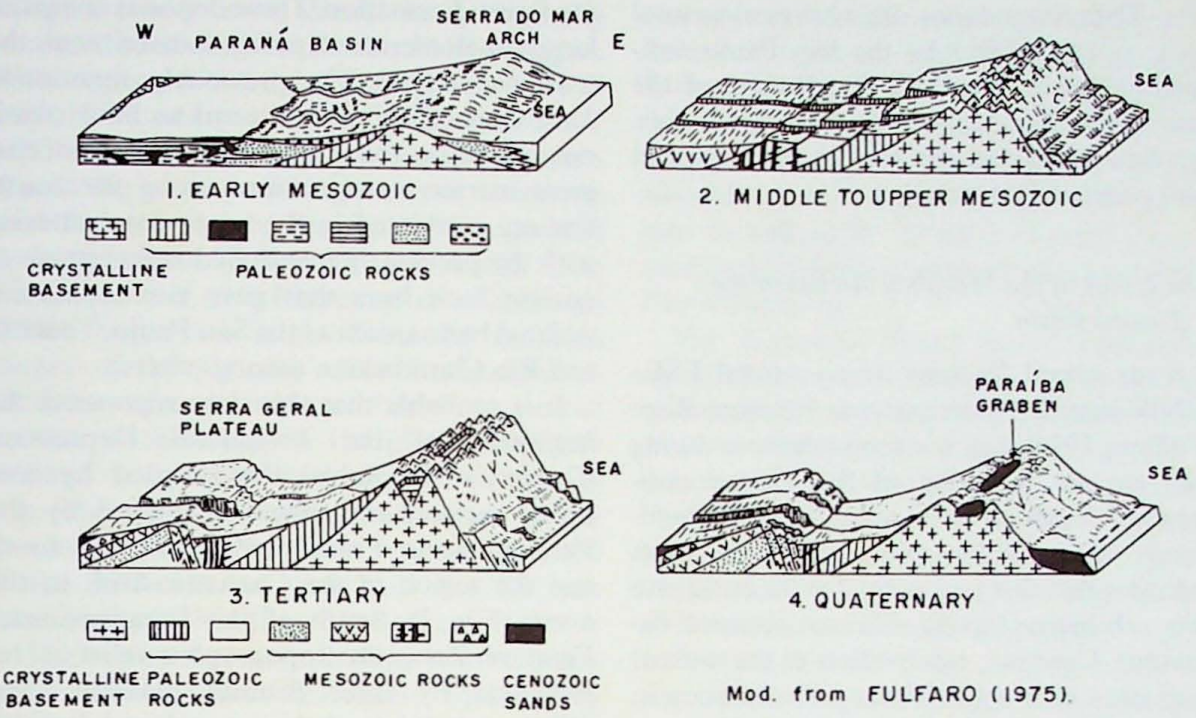


Fig. 2. Vertical movements in the Paraná basin during Mesozoic and Cenozoic (modified from Fulfaro, 1975)

ted block. The Santos basin was active from the Cretaceous to the Tertiary, with intense tectonic movements during all this time interval.

North of the Santos basin, along the coast of the States of Rio de Janeiro and Espírito Santo, the Campus basin, also on the continental shelf, shows a similar evolutionary pattern with tectonic movements documented as recently as 1972 (Veloso and Ladeira, 1973).

The Serra do Mar is another major tectonic feature of the area that formed during this stage (Fig. 2). Its evolution began in the Cretaceous and lasted to the end of the Tertiary or even the beginning of the Quaternary (Freitas, 1951 and Ab' Saber, 1969). The Serra do Mar scarp is considered to represent an erosional fault line associated with the Santos basin. Adding the thickness of the sediments in the Santos basin, about 8000 m, to the altitude of the Serra do Mar, around 1000 m, a 9000 m vertical displacement would thus be indicated for this region.

The effects of the Cretaceous tectonic movements were still present during the Tertiary, perhaps as a stage of the continental drift and rift that led to the origin of the Paraiba do Sul anteclise and also to the graben that cuts it (Fig. 2). This graben, the Taubaté sedimentary basin, is filled by a sedimentary sequence deposited between the end of the Tertiary (Neogene) and the beginning of the Quaternary and has, indubitable tectonic origin. The Taubaté basin sediments are cut by penecontemporaneous and post-depositional faults (Suguio, 1969).

Studies carried out on Cenozoic tectonics in the State of São Paulo, including detailed study of the coastal area, indicate that faults of probable Quaternary age are present, and are characterized by shear surfaces with slickensides in secondary minerals.

Other tectonic lines or fracture zones that have been described in southern Brazil in the past few years include the Torres Syncline, the Ponta Grossa Arch, the Paranapanema Fracture Zone and the Central Paraguayan Arch. All these tectonic features were rejuvenated during the Cenozoic, with vertical movements giving rise to the appearance of sills in the rivers of the initial drainage nets. These movements resulted in the formation of larger sedimentary basins in the upper part of the

sills. Their boundaries are always structural lines, as exemplified by the São Paulo sedimentary basin. Also, the headwaters of the great South American hydrographical basins, the Amazonas and the Rio de la Plata, had their origin in this period.

The Uplift of the Marginal Arches of the Paraná Basin

A structural fracture zone oriented ESE–WNW named Paranapanema Fracture Zone (Fulfaro, 1974), had a strong influence during the tectonic evolution of the Paraná sedimentary basin at least since Late Carboniferous time. Onlap of stratigraphic units indicates that this region divided the basin into two sub-basins having different tectonic behaviour. Cenozoic reactivation of the ancient fault lines with concomitant sedimentation in isolated basins indicates that the same process has continued up to present times.

At the end of Paleozoic times the Paraná basin lost its subsident character and began a depositional period marked only by subaerial sedimentation and increasing aridity. Channel sands, floodplain clayey deposits in an intermittent drainage pattern, and sand dunes were the sedimentary response (São Bento Group) to these changes. From the Late Jurassic to the Early Cretaceous the basin was inundated by extensive basaltic lava flows that covered an area larger than 800,000 km^2; these were followed by alkaline intrusions that continued into the beginning of the Tertiary (60 my ago).

At this time, the Serra do Mar Arch and the Canastra Arch started a period of upwarping that was responsible for sedimentary deposits located to the north of the Paranapanema Fracture Zone, that had acted as the basin limit to south. Renewed uplift of the Serra do Mar Arch during the Tertiary was followed by a decrease of subsidence in the Paraná basin that was directly related to the axis of subsidence to the coastal Santos basin.

The uplift of the marginal arches was represented in the Paraná basin by sedimentation of mass movement deposits with a poorly defined, unconformable contact with underlying Bauru Formation. These deposits comprise large fanglomerate deposits located near the marginal arches. The previously mentioned Late Cretaceous aridity seems to have continued. During the Tertiary, in the Miocene, great marine transgressions along the coastline are correlated in the continental interior with the previously mentioned reactivation of ancient fault lines that gave rise to several isolated basins, such as the São Paulo, Taubaté and Rio Claro basins, among others.

It is probable that this time represents the beginning of the Peripheral Depression (Depressão Periférica) that formed by erosional carving and which is limited by the Paranapanema Fracture Zone to the south and the region of the Canastra Arch to the north (Fig. 2). South of the Paranapanema Fracture Zone the topographic relief is represented by three distinct plateaus. The differential tilting of the coastal and interior regions caused a convexity that gave origin to fractures that were subsequently excavated by drainage, thus producing the present relief.

At present, the general picture of this region is represented by a continued uplift of the continent interior with the rivers predominantly in a sediment by-pass process. These Late Cenozoic tectonic movements are responsible for formation of the southeastern Brazil geomorphological pattern: a coastal mountain region with small isolated sedimentary basins and a Peripheral Depression (Depressão Periférica) adjacent to the Serra Geral basaltic scarp with the basaltic plateau gently tilted to the Paraná river valley.

Downfaulting of the Marginal Arches

Petri and Fulfaro (1976) presented a paper on the Cenozoic tectonic movements along the western margin of the Paraná basin, discussing also the limit between this basin and the Amazonas basin. The Asunción Arch, the western limit of the Paraná basin, was depressed 46 my ago by normal faulting movements of such magnitude that they were accompanied by the extrusion of olivine basalts containing mantle material.

To better understand this Cenozoic move-

ment, a wider area should be geologically analysed including the Parecis Plateau region. This region, located between parallels 11° S and 15° S and meridians 56° W and 60° W of Greenwich, consists of a 650 m-high plateau that is the watershed divide for the Amazonas and Plata fluvial basins, two of the greatest hydrographical basins in the world. The headwaters of the Paraguay river drainage (Plata basin) are situated on the southern slopes of the plateau, while the headwaters of the southern Amazonas basin are located on the northern slopes. The plateau could be defined as a 'cuesta' with a gentle northward dip. The plateau is strongly dissected by the headwaters of the two huge basins so that the limits between two rivers of the different basins may be less than 3 km apart.

The regional geomorphology is structurally conditioned. Lower Paleozoic rocks (Alto Paraguay Group) occupy the lowlands and are arranged in almost symmetrical NE–SW striking folds forming wide synclines and anticlines. Basalts of Mesozoic age (Tapirapuã Formation) in this region constitute the front of the 'cuesta', and the top is covered by sandstones and conglomerates of the same age (Parecis Formation) and Cenozoic deposits as yet unnamed (Fig. 3).

The most important Cenozoic sediments of this plateau, with respect to the present paper, occur on the southern flank. They comprise an extensive conglomeratic sedimentation at the foot of the plateau. The conglomerates, composed of pebbles and cobbles, from the second step at the scarp edge between the Parecis Sandstones and the flat top of the Tapirapuã Basalt, although in some cases they occur directly above the Alto Paraguay Group. The shape of the lithosomes suggests alluvial fans but their three-dimensional feature, as well as the presence of gradations to sandy components, indicates fanglomerates of Post-Parecis age.

The Tapirapuã Basalt has a radiometric age of 135 my and constitutes an isolated basic igneous body related to the huge basaltic lava flows of the Paraná basin with an area of occurrence of 800,000 km^2. The Parecis Formation is considered to be Late Cretaceous in age based mainly on correlation with the fossiliferous Bauru Formation that occurs above the basalt in the Paraná basin.

Paleocurrent directions during sedimentation of the Parecis Formation were directed toward NNE and NNW. These directions were obtained from cross-stratification measurements and from the three-dimensional shape of the formation. The formation had a northern depocentre, and this suggestion is reinforced by increases in thickness that continue as far north as a fault system located at 11°30′ S. The formation is 50 m thick at the front of the plateau and reaches 210 m thick adjoining the fault system. The source area for these sediments would have been located to the south, in the region of outcrops of the Alto Paraguay Group.

Paleocurrent measurements at outcrops of the Cenozoic fanglomerates gave directions of

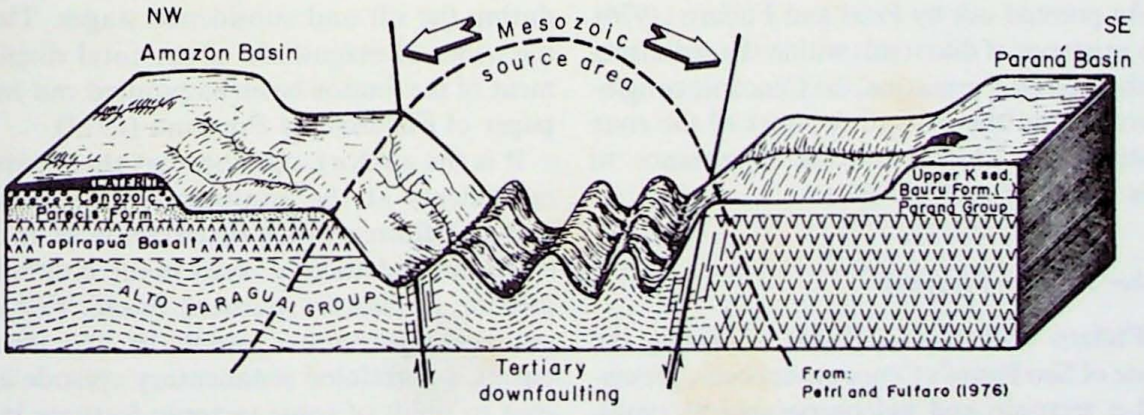


Fig. 3. Mesozoic–Cenozoic tectonic evolution of the Parecis plateau region

sediment transport toward the SSW and SSE. These directions were obtained by cobble imbrication measurements but also agree very well with the fan shapes.

The Serrana Province, the outcrop area of the Alto Paraguay Group in the watershed of the Paraguay and Cuiabá fluvial systems, was the source area during the Late Cretaceous for both sedimentary basins (Parecis Formation and Bauru Formation). During the Cenozoic, vertical movements uplifted the basin margins in relation to the old source area, which is presently in downward fault movement (Fig. 3), initiating the excavation that led to the present relief.

The Serrana Province is a part of a huge structural zone that extends from the mouth of the Amazonas river to the Asunción region, southward of the Parecis area, named Central Paraguayan Arch or Asunción Arch. This arch, as explained above, was the source area for the Paraná basin sediments from the Paleozoic to Mesozoic when it was a highland.

It subsided by downfaulting movement about 46 my ago when the Ypacarai rift valley in Paraguay originated. This age is based on radiometric determination in olivine-basalts that were extruded penecontemporaneously with the fault movement (Stromer, Gomes and Torquato, 1975). To the north, the lowlands of the State of Mato Grosso (Pantanal Matogrossense) are the natural continuation of those Paraguayan depressed areas, and so an identical age can be inferred for the Serrana Province downfaulting movement, which is in good agreement with the Cenozoic sedimentation pattern.

As pointed out by Petri and Fúlfaro (1976), the existence of diamonds within the sediments of the Parecis Formation, the Cenozoic conglomerates and the present deposits of the river system give great economic importance to this model of geologic events.

Other Related Features

Fúlfaro and Suguio (1974), analysing the State of São Paulo's Cenozoic deposits, presented a tectonic and paleogeographical evolutionary model that included southern Brazil. Correlating episodes of sedimentation on the coast and in the continental interior during this period, they say that the existense of roughly E–W oriented fracture zones determined the Cenozoic pattern of sedimentation in tectonic compartments exhibiting different vertical behaviours. During the Cenozoic, some of these restricted areas received sedimentation, for example in the SE, while others, comprising almost all the southern Brazil, were in uplift and thus exposed to erosional processes.

Some alkaline rock intrusions occurred at the beginning of the Tertiary, such as in the Lages area (65 my ago) and some of the younger episodes of Pocos de Caldas (64 my ago). Vertical movements associated with these intrusions are of high magnitude, although most of them are located along the coastal zone and probably related to spreading rates of the continents.

Origin of Vertical Movements

Sloss (1972), analysing the synchrony of sedimentary–tectonic events of the North American Craton and the Russian Platform pointed out that vertical oscillations even at significant distances from continental margins and plate interfaces could have an origin in separate, laterally moving lithospheric plates.

Faure (1976), describing the vertical movements originating from the fracturing of a wide continental lithospheric plate either as a result of drifting on a non-spherical earth or over a persisting bulge in the mantle, estimated that total vertical displacement can be over 10 km during the rift and subsidence stages. This is the order of magnitude of the total displacement of the Santos basin as pointed out in the paper of Fúlfaro and Poncano (1974).

It is the authors' opinion that these vertical movements at the continental margin have had an influence in the reactivation of ancient fault lines and fracture zones in the continental interior, at least in southern Brazil. For each sedimentary–tectonic event in the coastal basins, a correlated sedimentary episode adjacent to uplift of some tectonic features in the continent interior can be detected. Considera-

tions of the mechanism involved in this process is beyond the objective of this paper; however, the correlation of this tecto-sedimentary events should be pointed out.

References

A'b Saber, A. N., 1969. *Ritmo da epirogênese pós-cretácea e setores das superficies neogênicass em São Paulo*, Inst. de Geografia/Univ. de São Paulo, Bol. 13, São Paulo.

Almeida, F. F. M., 1967. *Origem e evolucão da plataforma brasileira*, DNPM/DGM, Bol. 241, Rio de Janeiro.

Amaral, G., Cordani, U. G. and Kawashita, K., 1965. 'Potassium–argon dates of basaltic rocks from southern Brazil', *Geochim. Cosmochim. Acta*, **30**, 159–189.

Amaral, G., Bushee, J., Cordani, U. G., Kawashita, K. and Reynolds, J. A., 1967. 'Potassium–argon ages of alkaline rocks from southern Brazil', *Geochim. Cosmochim. Acta*, **31**, 117–142.

Bjornberg, A. J. S., Gandolfi, N. and Paraguassu, A. B., 1965. 'Novas observações sobre a tectônica do leste do Estado de São Paulo', *Min. e Metal.*, **XLI**, No. 244.

Bjornberg, A. J. S., 1969. *Contribuição ao estudo do Cenozóico Paulista—Tectônica e Sedimentologia*, Thesis, EESC/Univ. São Paulo, unpublished.

Faure, H., 1976. Vertical evolution of continental margins Proceedings of the Intern. Symp. on Cont. Margins of Atlantic Type, *An. Acad. Bras. Ciên.*, **48**, (Supl.), 81–87.

Freitas, R. O., 1951. *Ensaio sobre a tectônica moderna do Brasil*, Fac. Fil. Ciên. Letras/Univ. São Paulo, Bol. 130, Geol. No. 6, São Paulo, 120 pp.

Fúlfaro, V. J., 1974. 'Tectônica do alinhamento estrutural do Paranapanema', *Bol. IG/Inst. Geociên.–USP*, **5**, 129–138.

Fúlfaro, V. J. and Landim, P. M. B., 1976. 'Stratigraphic sequences of the intracratonic Paraná basin', *Newsl. Stratigr.*, **4 (3)**, 150–168.

Fúlfaro, V. J. and Ponçano, W. L., 1974. 'Recent tectonic features in the Serra do Mar region, State of São Paulo, Brazil and their importance to engineering geology', *2nd. Congress of the Intern. Assoc. of Engineering Geology Proceedings*, **1**, II7.1–II7.7.

Fúlfaro, V. J. and Suguio, K., 1967. 'Campos de diques de diabásio da Bacia do Paraná', *Bol. Soc. Bras. Geol.*, **16 (2)**, 23–27.

Fúlfaro, V. J. and Suguio, K., 1968. 'A Formação', Rio Claro (Neocenozóico) e seu ambiente de deposição', *Rev. do IGG*, **20**, (No. 1), 45–60.

Fúlfaro, V. J. and Suguio, K., 1974. 'O Cenozóico Paulista: Gênese e Idade', *Anais do XXVIII Congr. Bras. Geol.*, **3**, 91–102.

Petri, S. and Fúlfaro, V. J., 1976. 'Geology of the Parecis Plateau, Brazil', *25th. Intern. Geol. Congress, Sec. 6–A*, Australia (in press).

Sloss, L. L., 1972. 'Synchrony of Phanerozoic sedimentary–tectonic events of the North American craton and the Russian Platform', *24th. Intern. Geol. Congress Proceedings, Sec. 6*, 24–32, Montreal.

Stormer, J. C., Gomes, C. B. and Torquato, J. R. F., 1975. 'Spinel lherzolite nodules in basanite lavas from Asunción, Paraguay', *Rev. Bras. Geoc.*, **5 (3)**, 176–185.

Suguio, K., 1969. *Contribuição à geologia da Bacia de Taubaté, Vale do Paraiba, Estado de São Paulo*, Fac. Fil. Ciên. Letras/Univ. São Paulo, Bol. Esp., 106 p., São Paulo.

Veloso, J. A. V. and Ladeira, E. A., 1973. *Hipótese sobre a origem do sismo brasileiro de 24/10/1972*, XXVII Congr. Bras. Geol., Resumo de Comunicações, 183–184, Aracaju.