MAGMATIC OCCURRENCES OF POST-PERMIAN AGE OF THE SOUTH AMERICAN PLATFORM

F.F.M.de Almeida[1]
C.D.R.Carneiro[2]

ABSTRACT

Several types of magmatic processes related to the breakup of Gondwana affected the greater part of the South American Platform: (1) Tholeiitic intrusions and effusions such as lava flows, sills and dykes, with maximum intensity from the middle Jurassic to the pre-Aptian Early Cretaceous, and Permian-Triassic tholeiitic dykes locally in the northern half of the continent. (2) Alkaline and peralkaline magmatism (mafic to felsic with minor associated carbonatites) developed when South America and Africa were moving apart; this was mostly post-Albian in age but lasted until the Miocene. A few alkaline intrusions are synchronous with the Jurassic-Early Cretaceous volcanism. (3) Several kimberlite intrusions recognized in Brazilian cratonic areas of middle Proterozoic age, as well as in areas affected by late Precambrian orogenic processes.

The maximum thickness of basaltic lava flows and sills in the interior of intracratonic basins reflects the influence of older geological structures. Many Precambrian faults and fractures intruded by diabase show displacement within dyke swarms. Dykes apparently unrelated to older fractures belong to areas subjected to tensional stresses during continental separation. The alkaline magmatism at the borders of the Paraná basin in Brazil, Paraguay and Bolivia is generally controlled by arches and faulted flexures.

The relationship between oceanic fracture zones and Paleogene magmatism in the continental crust is clearly displayed in at least two sites, corresponding to projections of the Romanche and Fernando de Noronha oceanic fracture zones.

INTRODUCTION

The Mesozoic tectono-magmatic activation of the South American Platform has generated a series of typical tectonic associations, such as several coastal and interior sedimentary basins and widespread igneous records. The latter display a diversified character with regard to nature, age and origin. Outstanding progress has been made in the knowledge of factors controlling the distribution of magmatic bodies. ALMEIDA (1983) presented a review of alkaline igneous bodies of southern Brazil, identifying provinces related to the edges and proximal inner zones of the Paraná basin. In 1986, the same author analyzed the distribution and tectonic relations of the post-Paleozoic magmatism of Brazil. A specific study focusing on

[1] Instituto de Geociências da Universidade Estadual de Campinas, Caixa Postal 1170, 13100 Campinas, SP, Brasil.
[2] Instituto de Pesquisas Tecnológicas do Estado de São Paulo, Caixa Postal 7141, 05508 São Paulo, SP, Brasil.

northeastern Brazil (ALMEIDA et al., 1988) detailed the patterns of such magmatism and discussed its age. A summary of the known mafic dyke swarms, including those belonging to the Mesozoic and Tertiary, was presented by SIAL et al. (1987b). SADOWSKI (1987) has pointed out several age-groups of igneous rocks in the South American Platform and related pulses of platform activations to plate kinematics.

In order to understand the activation phenomena in a broad sense, it is necessary to consider the relations between records of the last 180 Ma and other elements of the platform. This paper attempts to summarize the knowledge of the igneous record by comparing the available data on magmatism to other regional and continent-scale intraplate features generated during the last third of the Phanerozoic.

MESOZOIC TECTONO-MAGMATIC ACTIVATION

Unstable areas affected by activation phenomena constitute a new type of mobile region known as geodepressions or diwa structures (GUODA, 1959, 1988). Recently, the concept of plate tectonics has been more widely applied to explain these events, but the real nature of their relations has not yet been adequately established. Mobilistic geologists have paid little attention to the remote interiors of continents, a fact that explains this lack of knowledge.

The tectono-magmatic activation of the South American Platform (ALMEIDA, 1972) shows all the characteristics corresponding to the **autonomous** type discussed by SHCHEGLOV (1968). The following phenomena are observed:

a) intense tectonic pulses during relatively short time intervals;

b) large areas affected by the Mesozoic-Cenozoic igneous activity and by tectonism, especially between the end of the Jurassic and the Aptian;

c) syneclise areas and ancient cratonic borders that have suffered the effects of activation, but with differing intensities;

d) intense movement of fault blocks, preceeded by crustal stretching and other events, that led to the appearance of numerous tectonic basins prior to continental separation. The units generated during this time interval correspond to the Rift Sequence. Between the Mesozoic and the Cenozoic (Drift Sequence), tectonic activity was not as intense.

The igneous activity defining activation phenomena throughout the world has also been observed in the South American Platform and generated a great volume of effusive rocks and numerous mafic intrusive to alkaline igneous bodies. The ages and distribution of the existing records obey certain patterns that have became progressively better understood.

THE IGNEOUS RECORD IN PALEOZOIC SYNECLISES

The great extent of the tholeiitic magmatism affecting all the Brazilian geologic provinces and the adjacent portions of the platform in neighbouring countries is a well-known fact. Figure 1 shows the contour curves of total thicknesses of effusive and intrusive rocks as mapped in the large Brazilian Paleozoic syneclises. The Paraná, Parnaíba and Amazon syneclises display remarkable total thicknesses of sills and flows. The first exhibits thicknesses as great as 1700 m of effusives covering an area of c. 1,200,000 km². The other syneclises, however, have much lower values, corresponding mainly to sills. In southern Brazil and Uruguay, the basalt flows were covered (and intercalated in part) by dacitic and rhyolitic lavas.

The zones of maximum total thickness of pre-lava sediments were also the sites of the maximum total thickness of basaltic effusives (Paraná basin) or the greatest total thickness (Fig. 1) of intrusive diabase (Amazon and Parnaíba basins). In the Parnaíba basin there is no coincidence between the zones of maximum total thickness of flows and sills. Nor do they coincide with the location of the center of the basin. In the Amazon basin, situated upon a cratonic area consolidated more than 1.5 Ga ago, rare flows and the maximum total thickness of sills (803 m) occur along the axis of the basin. AIRES (1983) has pointed out that the axis coincides with zones of intersecting ancient Precambrian alignments.

Some important structural lineaments in the pre-Silurian basement are also represented in Figure 1. They probably represent activated Precambrian fault zones, but a few of them are younger and developed during the late Jurassic and early Cretaceous on the eastern flank of the Paraná basin as the Guapiara, São Jerônimo-Curiúva, Rio Alonzo and Rio Piquiri lineaments. They have played an important role in influencing the development of post-Paleozoic magmatism.

The climax of the magmatic phenomena occurred between the middle Jurassic and the pre-Aptian early Cretaceous, with the maximum igneous activity corresponding to an age between 120 and 130 Ma. During the Triassic and even before (Permian) the basaltic magmatism (sills and dykes) were important in the northern part of the platform.

In the substrate of the sedimentary basins of the continental margin, intrusions and flows have been recognized which show ages and chemical natures frequently identical to those present in adjoining emergent areas (ASMUS, 1984)). Volcaniclastic rocks associated with basalt flows and sedimentary rocks are present in the Campos basin (MISUZAKI, 1987) within subaqueous, lacustrine and subaerial environments, this last represented by red volcanic tuff. Later in the Neocomian, the lakes became progressively shallower and volcanic manifestations less marked (CHANG et al., 1988).

DYKE SWARMS

There are numerous mafic dyke swarms of post-Paleozoic age along well-defined directions cutting the exposed basement and some areas with Paleozoic cover. Figure 2 illustrates the distribution of known dykes north of 14°S latitude listed in Table 1. There is a remarkable time span (250 to 100 Ma) between the ages reported by OLIVEIRA & MONTES (1984) and GIBBS (1987) for dyke swarms in Brazil and the Guianas, respectively. In spite of the fact that some swarms have only a few age determinations and, of these, most are by K/Ar methods (GIBBS, 1987), some age groups can be preliminarily detected: 250 to 200 Ma in the northern portion of the platform (Cassiporé, Guyana, Suriname and part of the Alto Tapajós basin dykes); 180 to 130 Ma in the Takutu and Paru de Este-Monte Alegre zones and the Alto Tapajós lineament. At the present stage of geochronological reconnaissance, other dyke swarms seem to be comprised within the 140 to 110 Ma time interval.

The Permo-Triassic dyke swarms of the northern platform segment extend to neighbouring countries. GIBBS (1987), following up the work of, among others, CHOUDHURI & MILNER (1971), has stressed that the NNW-oriented dyke swarms of northern South America are matched by a symmetrical, parallel suite in West Africa, making up part of a central Atlantic dyke system having a pre-drift total length in excess of 3,000 km. The directional consistency of isolated swarms over distances as great as 300 km must be stressed. Some individual dykes have lengths of about 100 km, as in the Takutu lineament (Fig. 2-A) and in the Cassiporé magmatism (Fig. 2-D). The former is a clear example of adaptation of the basic magmatism to basement fracture zones (Fig. 2-G). It is a long swarm extending from northern Roraima to Guyana (Berbice basin) associated with reactivated faults (during Permian and Jurassic) and penetrated by NE-oriented diabase dykes. The Takutu Graben contains a volcanic-sedimentary fill of Jurassic age. The lavas show a basaltic to andesitic character (Apoteri Formation of Jurassic age; BERRANGÉ & DEARLAY, 1975).

The dykes are more abundant and form swarms in regions affected by the Brasiliano Cycle (Late Precambrian). Along the coastal zone of Amapá, in northern Brazil and in French Guiana the significant Triassic dyke swarm parallel to the coast is exposed within a cratonic area of pre-Brasiliano age.

In the São Francisco Craton, an ancient area of the South American Platform consolidated about 1.8 Ga ago, Mesozoic-Cenozoic diabase dykes are rare. Moreover, in the neighbouring marginal basins there are no dykes, sills or flows (ASMUS, 1982).

The dykes occur in zones that were subjected to tensional stresses during continental separation. They frequently occupy reactivated ancient Precambrian faults in Brazilian geologic provinces and neighbouring countries. Within the Ponta Grossa Arch, on the eastern flank of the Paraná basin, hundreds of dykes constitute four principal swarms (Fig. 3). One of the dykes has a thickness of about 1 km. These dikes are believed to have played an important role as flow-feeding "springs" at the center of the basin (Fig. 3).

There is strong structural control of the flood basalts and diabase dykes and sills along the border of the Paraná basin (ALMEIDA, 1986). They were greatly controlled by zones of crustal weakness represented by basement faults or flexures.

Table 1 shows that the directions of dyke intrusions are mainly ENE-NNE and WNW-NNW. It is exceptional to find N-S and E-W directions, which are also rare in the Precambrian basement. In eastern northeastern Brazil, the direction of the Rio Ceará-Mirim magmatism (Fig. 2-F) does not correspond to basement faults. It is represented by a sub-latitudinal diabase swarm of Middle Jurassic to Early Cretaceous age (GOMES et al., 1981). Also in this region, in the states of Rio Grande do Norte and Paraíba, there are olivine basalts, basanites, ankaratrites and nephelinites of Eocene to Miocene age. Belonging to the Macau Formation, the associated bodies probably constitute an igneous alignment oriented NNW (ALMEIDA et al., 1988), not far from and parallel to the coast line (Fig. 2-E).

ALKALINE MAGMATISM

Three main phases of alkaline magmatic activity have affected the South American Platform since the Permian. The most ancient is not very representative in volume nor widespread (Fecho dos Morros and Pão de Açúcar on the Brazil-Paraguay border and possibly Seis Lagos in northern Amazonas State, Brazil; ISSLER et al., 1975). A second phase, contemporaneous with the tholeiitic basaltic magmatism, occurs around the Paraná basin at its western (Paraguay; PALMIERI & ARRIBAS, 1975) and eastern borders (Brazil and Uruguay, Vale Chico Formation of UMPIERRE & HALPERN, 1971). It is also evident in eastern Bolivia (FLETCHER & LITHERLAND, 1981) on the Amazon Craton at Velasco and Candelária.

Intrusions associated with longitudinal faults and fractures related to the Ponta Grossa Arch in Brazil belong to the second age group. Nevertheless, there are many late Cretaceous alkaline centers, possibly affiliated with the Serra do Mar Anteclise.

Figure 3 displays the position of several bodies of this group as well as several others related to the third group of alkaline intrusions and effusions that formed between Albian and Eocene time. There are many bodies of the third group surrounding the Paraná basin in northeastern Brazil and eastern Paraguay and possibly in Roraima in northern Brazil (e.g., Catrimani; e.g. ISSLER et al., 1975). The chemical nature of this rock group is diversified. At the northeastern border of the Paraná basin, the intrusions and rare effusions exhibit undersaturated alkaline, alkaline-ultrabasic and carbonatitic characters (ULBRICH & GOMES, 1981) and are associated with kimberlite intrusions. The Serra do Mar, in southeastern Brazil, was affected by many Late Cretaceous, mainly felsic alkaline intrusions. Eocene ankaramite flows are known in the Paraíba River Valley (RICCOMINI et al., 1983) and in the Guanabara Bay region, both within the State of Rio de Janeiro. In eastern Paraguay this igneous phase comprises intrusions and effusions of a potassic nature (Sapukai Complex· PALMIERI & ARRIBAS, 1975) and Eocene flows and intrusions of basanites in Asunción (PALMIERI & VELASQUEZ, 1982).

The alkaline intrusions, carbonatites and kimberlites situated along the borders of the Paraná basin show a tendency to occupy arched and faulted regions and rifts. They occur mainly at the intersections of reactivated basement fractures. The Poços de Caldas alkaline complex, however, can not be attributed to this specific setting in view of its great areal extent (c. 800 km) which places it among the largest such complexes in the world; it is located at the nucleus of two ancient mobile belts structurally oriented along NW and NE directions. This fact and the existence of the Mogi Guaçú Uplift are important to explain its origin during the Senonian.

The third phase of magmatism is diversified in northeastern Brazil, with ages ranging up to the Miocene. Oligocene to Miocene alkaline rocks are absent in southern Brazil and adjoining countries. Near Recife, on the coast of the state of Pernambuco, there are alkaline granite intrusions associated with flows and intrusions of rhyolites, trachytes, andesites and basalts (LONG et al., 1986; SIAL et al., 1987a) of Albian age (about 103 Ma; GAVA et al., 1983). In the Ceará basin, drilling at the continental margin indicated the presence of an Eocene volcanic-intrusive center of acid character. There is correspondence between this volcanism and that discovered at the Atlantic High (SZATMARI et al., 1987) situated on the continent and aligned with the Romanche Fracture Zone. The Macau-Queimadas lineament (ALMEIDA et al., 1988) is defined by plugs, sills, and flows belonging to the Macau Formation (about 30 Ma); its direction is NNW and its length 300 km. Near Fortaleza, in the State of Ceará, intrusions of Oligocene age, made up of phonolites and trachytes (BRAGA et al., 1981), are thought to be related to continental extension (Fig. 2-E) of the Fernando de Noronha Fracture Zone (GORINI & BRYAN, 1976). Tertiary mafic magmatism is also known within the sedimentary fill of the Campos and Santos basins (PETROBRÁS, 1983; PETROBRÁS, 1986, apud MACEDO, 1987).

DISCUSSION

Age of the magmatism

During its post-Paleozoic evolution, the South American Platform was affected by at least five magmatic events scattered over the continental area and the oceanic Atlantic margin (Fig. 4) without relations to specific orogens:

a) Permian to Triassic magmatism is well developed in the northern part of the platform (Fig. 4-A). CONCEIÇÃO et al. (1987) suggested that it may be related to an aborted stage of continental separation. The dyke swarms forming the Apatoe (Suriname), Takutu, Rio Trombetas, Paru de Este-Monte Alegre and Cassiporé lineaments belong to this stage. The Araguaia dyke swarm (ALMEIDA et al., 1986) in Central Brazil can also be included in this group, even though it includes some rocks of younger ages;

b) Jurassic-Cretaceous pre-Aptian tholeiitic activity to a large extent affected the South-American platform (Fig. 4-C) south the equator and far from the São Francisco Craton. In the Paraná and Parnaíba basins impressive amounts of basaltic sills and flows were formed. In the former basin some dyke swarms are related to the Ponta Grossa Arch. Along the present continental margin of southeastern Brazil an significant volcanism of Neocomian age covered the area between the Campos, Santos and Espírito Santo offshore basins, with volcaniclastic rocks, sediments, and basalt flows;

c) the Aptian and Albian records are limited to coastal zones and submerged regions like that south of Recife (Ipojuca Formation, Fig. 4-D) and in the lower Aptian sedimentary pile of the Piauí-Camocim sub-basin, a part of the Ceará basin, along the equatorial continental margin. These records seem to be linked to zones subjected to continental separation in later times;

d) Late Cretaceous alkaline magmatism (Fig. 4-E), extending into the Eocene for several bodies, is widespread in southern Brazil, forming the Itatiaia, Passa-Quatro, and Poços de Caldas complexes, among others;

e) Tertiary magmatism during the Eocene to Miocene (Fig. 4-F) was more significant in volume than the Aptian-Albian activity but limited to only a few areas, (northeastern Brazil, eastern Paraguay and a few other places. Along the northeastern continental margin the volcanic rocks are intercalated with sediments. They comprise the Macau Formation and Mecejana, Mundaú, Alto Atlântico and Alto do Ceará volcanism.

The rocks of the five age-groups have distinctive compositions: the first and second are largely tholeiitic in nature but include some alkaline rocks. In the third and fourth age-groups there are mainly felsic alkaline rocks, and, in the most recent group, a basic-alkaline tendency is noticeable. Acid volcanism belonging to the second group is recorded in the southern portion of the Paraná basin (Brazil and Uruguay). There is also some rhyolitic volcanism at the continental margin (Atlantic and Ceará highs), and on the continent, south of Recife, related to the third group.

The Paleogene igneous activity in the southeastern and west-central parts of Brazil seems to be the late magmatic equivalent of the important late Cretaceous alkaline magmatism. In northeastern Brazil the Tertiary magmatism comprises an autonomous episode.

Structural lineaments and dyke orientations

The presence of structural lineaments and their relations to magmatic dykes associated with the activation event have been discussed in Brazilian geological literature, but the reduced number of available datings and even the common lack of data on evidence of reactivation of ancient faults do not allow a more profound study of the subject. The fact that the known dyke swarms in the platform are not numerous (Table 1) must be emphasized, as well as the notable prevalence of ENE-NNE and WNW-NNW directions.

The most prominent dyke swarms are exposed near the coast. Some of them are parallel to the coastline, coinciding with Precambrian structural lineaments (the Cassiporé and Rio Ceará-Mirim magmatism and the Serra do Mar dyke swarms). Other coastal dyke swarms form different angles with the coastline, such as the Takutu, Apatoe, Ponta Grossa Arch and Vitória-Ecoporanga swarms. All of them are probably related to the rift development that originated the Atlantic Ocean north and south of the equator.

In the remote interior of the continent some basic dykes are grouped into lineaments (Paru de Este-Monte Alegre, Trombetas, Tapajós, etc.), others form swarms, but a trend parallel to ancient Precambrian directions is common, even in isolated dykes. Probably, this is due to fracturing along orientations compatible with tensional stresses at the time of intrusion. Some basic dykes do not seem to be related to ancient structures and may correspond to rigid plate fissures imposed by stress fields affecting the lithosphere mainly during the Late Jurassic to Neocomian, the most intense epoch of tectonism and basaltic magma injection.

Zones of maximum incidence of basic magma have been mapped in the largest syneclises. In the Amazon basin there is some evidence of a probable link between the intersection of ancient Precambrian alignments and the distribution of sills (AIRES, 1983).

The relationship between igneous bodies, especially the most recent ones, and geothermal anomalies is still poorly understood as available data are few. In eastern northeastern Brazil, geothermal anomalies accompany the distribution of areas affected by Tertiary magmatism (CARNEIRO et al., 1989) near the cities of Fortaleza and Macau and between Maceió and João Pessoa.

Origin

The Mesozoic to Miocene magmatism recorded within the South American platform does not agree with the idea of hot spots fixed in the mantle under the moving plate as there are no ordered ages as supposed by HERZ (1977) and FLETCHER & LITHERLAND (1981). The magmatism seems to reflect a generalized heating of the mantle of unknown origin but capable of locally producing partial fusion in the lithospheric mantle, the penetration of magma along zones of favourable structures of the continental crust, and even the rupture of Gondwana.

The bodies related to the Rio Ceará-Mirim magmatism were formed by extensional intraplate stresses related to continental drift (FRANÇOLIN & SZATMARI, 1987).

The interpretation of the origin of the igneous phenomena faces difficulties, such as the apparent lack of relationships between alignments and mapped geological faults. The influence of basement structures was probably important during the events between the end of the Jurassic and the Neocomian, but for the flows and younger intrusions, this relationship is not so clear. Assuming that plates are rigid, SADOWSKI (1987) suggested that changes in the state of stress within the plates are the main cause of tectono-magmatic activations. In fact, the relatively high spreading rates between 107 and 72 Ma, and the drop in such rates after this time coincide with the third and fourth age groups of alkaline igneous bodies discussed above. Three separate epochs representing the largest angular changes in rotation pole coordinates are also pointed out by SADOWSKI (1987) in order to explain intraplate magmatism: latitudinal changes at 111-107 Ma and at 84 Ma and a longitudinal change at 38 Ma, all of which correspond to ages of intense igneous activity.

ACKNOWLEDGEMENTS

The authors are grateful to Dr. Valiya M. Hamza and Dr. Waldir L.Ponçano for revision of the English version of the manuscript; to Mrs. Damaris R.Marins, Mr. Aluísio de S. Frota and Mr. Waldir D.Cortez for the figures; and to IPT, the São Paulo State Technological Research Institute, for providing support for this study.

REFERENCES

AIRES, J.R. (1983) Estudo do vulcanismo básico da Bacia Amazônica. Rio de Janeiro, PETROBRAS/ CENPES. 61p. (Relatório, 478).

ALMEIDA, F.F.M. (1972) Tectono-magmatic activation of the South American Platform and associated mineralizations. In: INTERNATIONAL GEOLOGICAL CONGRESS, 24. Montreal, 1972. **Proceedings**. Montreal, IUGS. Sect.3, p.339-346.

ALMEIDA, F.F.M. (1983) Relações tectônicas das rochas alcalinas da região meridional da plataforma Sul-Americana. **Revista Brasileira de Geociências,** 13(3):139-158.

ALMEIDA, F.F.M. (1986) Relações tectônicas e distribuição do magmatismo pós-paleozóico no

Brasil. **Revista Brasileira de Geociências**, 16(4):325-349.

ALMEIDA, F.F.M.; CARNEIRO, C.D.R.; MACHADO JR., D.L.; DEHIRA, L.K. (1988) Magmatismo pós-paleozóico do Nordeste Oriental do Brasil. **Revista Brasileira de Geociências**, **18**(4):451-462.

ALMEIDA, F.F.M.; FERREIRA, F.J.F.; CARNEIRO, C.D.R.; STEFANI, F.L. (1986) Aspectos evolutivos da geossutura Tocantins-Araguaia. In: CONGRESSO BRASILEIRO DE GEOLOGIA, 34., Goiânia, 1986. **Anais**. Goiânia, SBG. v.3, p.1269-1284.

ASMUS, H.E. (1982) Geotectonic significance of Mesozoic-Cenozoic magmatic rocks in the Brazilian continental margin and adjoining emerged area. In: CONGRESO LATINOAMERICANO DE GEOLOGIA, 5., Buenos Aires, 1982. **Actas**. Buenos Aires, Servicio Geológico Nacional. v.3, p.761-779.

ASMUS, H.E. (1984) Geologia da margem continental brasileira. In: Geologia do Brasil. Texto explicativo do mapa geológico do Brasil e da área oceânica adjacente incluindo depósitos minerais. Escala 1:2500000. MME.DNPM (Schobbenhaus, C.; Campos, D. de A.; Derze, G.R. and Asmus, H.E. eds.). 1984, Brasília, p. 443-472.

BERRANGÉ, J.P. & DEARLEY, R. (1975) The Apoteri volcanic formation - tholeiitic flows in the North Savannas Graben of Guyana and Brazil. **Geologische Rundschau**, **64**(3):883-899.

BRAGA, A.P.G; PASSOS, C.A.B.; SOUZA, E.M.de.; FRANÇA, J.B.de; MEDEIROS, M.de F.; ANDRADE, V.A. de (1981) **Geologia da região nordeste do Estado do Ceará. Projeto Fortaleza.** Brasília, DNPM/CPRM. p.1-123. (Geologia,12; Seção Geologia Básica, 9).

CARNEIRO, C.D.R.; HAMZA, V.M.; ALMEIDA, F.F.M. (1989) Ativação tectônica, fluxo geotérmico e sismicidade no nordeste oriental brasileiro. **Revista Brasileira de Geociências**, **19**(3):310-322.

CHANG, H.K.; KOWSMANN, R.O.; FIGUEIREDO, A.M. (1988) New concepts on the development of East Brazilian marginal basins. **Episodes**, **11**(3):194-202.

CHOUDHURI, A. & MILNER, M. (1971) Basic magmatism in Guianas and continental drift. **Nature (Physical Science)**, **232**(33):154-157.

CONCEIÇAO, J.C.J.; ZALAN, P.V.; WOLFF, S. (1987) The South Atlantic rifting. **Boletim de Geociências da Petrobrás**, 2 (2/4):255-265.

FLETCHER, C.J.N. & LITHERLAND, M. (1981) The geology and tectonic setting of the Velasco alkaline province, eastern Bolivia. **Journal Geological Society of London**, 138(5):541-548.

FRANÇOLIN, J.B.L. & SZATMARI, P. (1987) Mecanismo e rifteamento na porção oriental da margem norte brasileira. **Revista Brasileira de Geociências**, **17**(2):195-207.

GAVA, A.: NASCIMENTO, D.A.; VIDAL, J.L.B.; GHIGNONE J.I.; OLIVEIRA, E.P.; SANTIAGO FILHO, A.L.; TEIXEIRA, W.; STANFORD, W.J.P.; RIBEIRO, A.G.; RIBEIRO, J.H.M. (1983) Geologia. In: PROJETO RADAMBRASIL. Folhas SC 24/25.; Aracajú/Recife. Rio de Janeiro, MME/ SG. p.27-376. (Levantamento de Recursos Naturais, 30).

GIBBS, A.K. (1987) Contrasting styles of continental mafic intrusions in the Guiana shield. In: HALLS, H.C. & FAHRIG, W.F.(eds.) Mafic dyke swarms. **Geological Association of Canada. Special Paper, 34**:457-465.

GOMES, J.R.C.; GATO, C.M.P.P.; SOUZA, G.M.C.; LUZ, D.S.; PIRES, J.L.; TEIXEIRA, W.; FRANCA, F.A.B.: CABRAL, E.M.A.; MENOR, E.A.; MONTEIRO, N.; BARROS, M.J.G.; RIBEIRO, E.G.; LIMA, E.A.; FONSECA, R.A. (1981) Geologia. In: PROJETO RADAMBRASIL. Folhas SB 24/25, Jaguaribe e Natal. Rio de Janeiro, MME/SG. p.27-300. (Levantamento de Recursos Naturais, 23).

GORINI, M.A. & BRYAN, G. (1976) The tectonic fabric of the equatorial Atlantic and adjoining continental margins, Gulf of Guinea to northeastern Brazil. **Anais da Academia Brasileira de Ciências, Suplemento, 48**:101-109.

GUODA, C. (1959) Theory of progression with transformation between mobile and stable regions of the Earth's crust. **Acta Geologica Sinica, 39**(3):229-292.

GUODA, C. (1988) **Tectonics of China**. Beijing, Intern. Acad. 258p.

HERZ, N. (1977) Time of spreading in the South Atlantic; information from Brazilian alkalic rocks. **Geological Society of America Bulletin, 88**:101-112.

ISSLER, R.S.; LIMA, M.I.C.de; MONTALVAO, R.M.G.de: SILVA, G.G.da (1975) Magmatismo alcalino do cráton Guianês. X Conferência Geológica Interguianas. **Anais**. p.103-122. Belém, Pará, Brasil. DNPM/MME.

LONG, L.E.; SIAL, A.N.; NEKVASIL, H.; BORBA, G.S. (1986) Origin of granite of Cabo de Santo Agostinho, Northeast Brazil. **Contributions to MIneralogy and Petrology, 92**:311-315.

MACEDO, J.M. (1987) **Evolução estrutural da Bacia de Santos e áreas continentais adjacentes.** Ouro Preto. 165p. (Tese de Mestrado, Universidade Federal de Ouro Preto).

MISUZAKI, A.M.P. (1987) Volcano-sedimentary sequence of Neocomian age in Campos basin (Brazil). **Revista Brasileira de Geociências, 18**(3):247-251.

OLIVEIRA, E.P. & MONTES, M.L. (1984) Os enxames de diques máficos do Brasil. In: CONGRESSO BRASILEIRO DE GEOLOGIA, 33., Rio de Janeiro, 1984. **Anais**. Rio de Janeiro, SBG. v.9, p.4137-4154.

PALMIERI, J.H. & ARRIBAS, A. (1975) El complexo alcalino potássico Sapukai (Paraguay Oriental). In: CONGRESO IBERO-AMERICANO DE GEOLOGIA ECONÓMICA, 2., Buenos Aires, 1975. **Anales**. Buenos Aires. v.4, p.267-300.

PALMIERI, J.H. & VELASQUEZ, J.C. (1982) **Geologia del Paraguay**. Asuncion, Napa. 65p.

PETROBRAS (1983) Arcabouço estrutural da Bacia de Campos e áreas adjacentes. Rio de Janeiro, PETROBRÁS/DEPEX. (Relatório interno, inédito).

PETROBRAS (1986) Projeto análise da Bacia de Santos, Rio de Janeiro, PETROBRÁS/DEPEX. (Relatório interno, no prelo).

RICCOMINI, C.; MELO, M.S.; CARNEIRO, C.D.R.; ALMEIDA, F.F.M.; MIOTO, J.A.; HASSUI, Y. (1983) Sobre a ocorrência de um derrame de ankaramito na Bacia de Volta Redonda (RJ) e sua importância na datação das bacias tafrogênicas continentais do sudeste brasileiro. In: SIMPÓSIO REGIONAL DE GEOLOGIA, 4., São Paulo, 1983. **Resumos.** São Paulo, SBG/NCP. p.23-24.

SADOWSKI, G.R. (1987) A possible relation between pulses of plataform activation and plate kinematics. **Tectonophysics, 143**(1-3):43-57.

SHCHEGLOV, A.D. (1968) Endogenous deposits of the regions of autonomous activation. In: INTERNATIONAL GEOLOGICAL CONGRESS, 23.; Czechoslovakia, 1968. **Proceedings.** Czechoslovakia, Academia. sec.7, p.43-55.

SIAL, A.N.; LONG, L.E.; BORBA, G.S. (1987a) Field trip guide excursion: Cretaceous magmatic province of Cabo, Pernambuco, northeast Brazil. **Revista Brasileira de Geociências, 17**(4): 667-673.

SIAL, A.N.; OLIVEIRA, E.P.; CHOUDHURI, A. (1987b) Mafic Dike Swarms of Brazil. In: Mafic dyke swarms (H.C.Halls and W.F.Fahrig, eds). **Geological Association of Canada Special Paper,** p.467-482.

SZATMARI, P.; FRANÇOLIN, J.B.L.; ZANOTTO, O.; WOLFF, S. (1987) Evolução tectônica da margem equatorial brasileira. **Revista Brasileira de Geociências, 17**(2):180-188.

ULBRICH, H.H.G.J. & GOMES, C.B. (1981) Alkaline rocks from continental Brazil. **Earth-Science Reviews, 17**:135-154.

UMPIERRE, M. & HALPERN, H. (1971) Edades estroncio-rubidio en rocas cristalinas del sur de la Republica Oriental del Uruguay. **Revista de la Asociación Geológica Argentina, 26**(2):133-151.

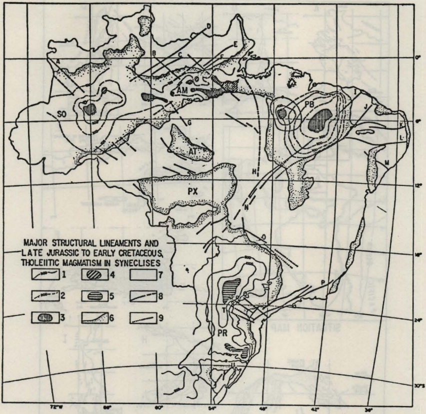

Figure 1 - Present-day areal extent of the post-Paleozoic magmatism in the syneclises of Brazil with emphasis on isopach contours (in meters) of (1) thickness of basalt flows; (2) total thickness of diabase sills. Several areas are emphasized, for example: (3) greatest total thickness of sills; (4) greatest number of drilled sills: (5) thickness of lava flows. Other symbols are as follows: (6) volcano-sedimentary cover; (7) shield - basins: (AM) Amazon, (AT) Alto Tapajós, (PB) Parnaíba, (PR) Paraná, (PX) Parecis-Alto Xingu, (SO) Solimões. Structural lineaments related to: (8) ancient activated fault zones (dashed where approximate); or (9) magnetic anomalies: (A) Traíra, (B) Jamari, (C) Cachorro, (D) Urupi-Pitanga, (E) Jari-Falsino, (F) Jangada, (G) Abacaxis, (H) Tocantins-Araguaia, (I) Sobral-Pedro II, (J) Senador Pompeu, (K) Patos, (L) Pernambuco, (M) Vasa-Barris, (N) Transbrasiliano, (O) Goiânia, (P) Lancinha-Cubatão, (Q) Guapiara, (R) São Jerônimo-Curiuva, (S) Rio Alonso, (T) Rio Piquiri, (U) Encruzilhada do Sul.

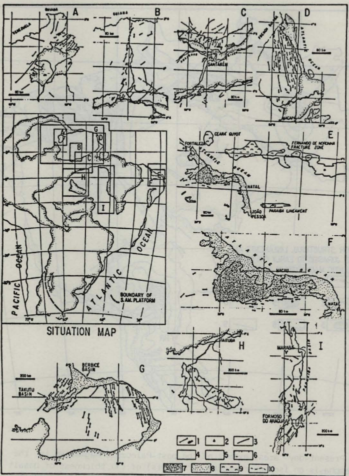

Figure 2 - Distribution of the post-Paleozoic dyke swarms in the northern part of the South American Platform: (A) Takutu lineament; (B) Rio Trombetas lineament; (C) Paru de Este-Monte Alegre lineaments; (D) Cassiporé magmatism; (E) Mecejana-Fernando de Noronha lineament; (F) Rio Ceará Mirim magmatism; (G) Guianas dyke swarms; (H) Alto Tapajós Basin dykes; (I) Formoso do Araguaia lineament. Key symbols: (1) diabase dyke or volcanic cover, (2) alkaline body, (3) fault, (4) exposed basement, (5) Araguaia Fold Belt of Precambrian age, (6) Paleozoic cover, (7) Mesozoic cover, (8) undifferentiated or Cenozoic cover, (9) acoustic basement high, (10) international boundary.

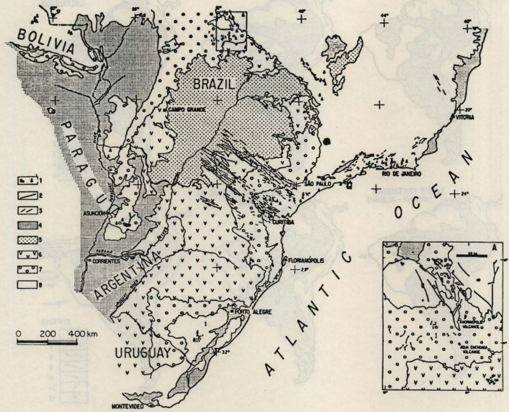

Figure 3 - Distribution of the post-Paleozoic dyke swarms in the southern part of the South American Platform. Key symbols: (1) alkaline bodies, (2) magnetic anomaly, (3) diabase dyke, (4) Cenozoic cover, (5) Mesozoic cover, (6) basalts, (7) Paleozoic cover, (8) basement.

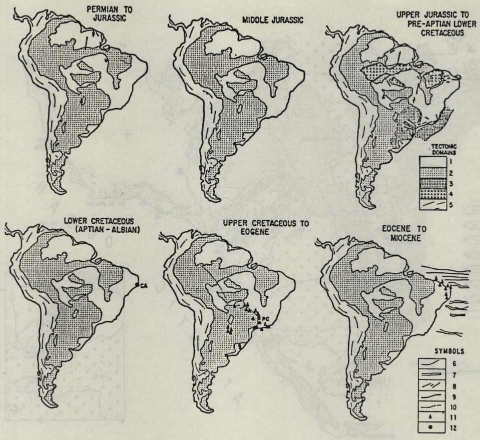

Figure 4 - Reconstruction of the post-Paleozoic magmatism of the South American Platform according to age. Tectonic domains: (1) Precambrian shield areas, (2) platform covers, (3) volcanic covers, (4) intrabasinal sills, (5) Andean Chain. Key to the symbols: (6) contact, (7) oceanic fracture zone, (8) dyke swarm structural trend, (9) present-day limit of intrabasinal sills, (10) present-day limit of Mesozoic flows, (11) approximate position of alkaline bodies, (12) magmatic complexes: (CA) Cabo de Santo Agostinho, (PC) Poços de Caldas.

Table 1 - Main characteristics of the post-Paleozoic dyke swarms (and minor sills) related to the Mesozoic activation of the South American Platform. Symbols: (ab) alkaline basalt; (ad) andesite; (db) diabase; (dr) diorite; (dg) dioritic gabbro; (gb) gabbro; (tb) tholeiitic basalt.

Dyke swarm or related lineament	Lithology	Age (Ma)	Preferred orientation	Approximate length (km)	Approximate maximum width (km)
Berbice dyke swarm	db	c. 200	NE	> 200	200
Apatos dyke swarm	db	230	NNW	> 300	120
Cerro Bolivar dykes	db	200			
Takutu lineament	db	c. 360 114-178	NE	> 350	120
Takutu graben volcanism (Apoteri Fm.)	tb, ab, ad				
Trombetas River lineament	db	P to J-K	N-S	> 350	80
Peru de Este-Monte Alegre lineament	db	135-183	NNE	450	250
Cassiporé magmatism	db	P-TK J-K	NNW	> 400	150
Jari river valley dykes	db	uncertain	N-S and NE		
Alto Tapajós lineament	db	J	NNE and NE	> 500	120
Alto Tapajós basin dykes (Serra do Cachimbo)	db	179-222	NNE and NW	> 300	150
Ceará-Mirim river magmatism	db	Early K	E-W	> 200	50
Formoso do Araguaia dyke swarm	db	169-225	N-S	1100	100
Gorutuba dyke	db				
Eastern border of Parnaíba basin dykes	db	Early K	NE and NW	300	170
Vitória-Ecoporanga lineament	db	170	N40W	100	
Serra do Mar dyke swarm	ad, dr, dg	J-K	N40-50E	> 680	180
Alto Parnaíba dykes	db	J-K	N45W	> 200	100
Ponta Grossa Arch dyke swarms	db gb dr	119-140 120-130 (A)	N50W	> 700	120(B) 380(Z)
Alto Paranaíba Arch dykes	db	Late J-Early K	N40-50W		
Bom Jardim de Goiás dykes	db	Late K	NNE, NNW-NW	200	
São Vicente Arch and Alto Xingu Arch dykes	db	K	ENE		
Asunción Arch dykes	db	J-K	NW-NNW		
Rio Grande Arch dykes	db	J-K	NW		