Mafic Dyke Swarms Associated with Mesozoic Rifting in Eastern Paraguay, South America

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Abstract

A regional airborne magnetic survey has defined numerous linear NW-trending anomalies in eastern Paraguay which have been confirmed by ground magnetic surveys. Geological mapping and drilling indicate that they are caused by diabase dykes. Magnetic interpretation indicates that both dyke and fault modelling can be applied to the same lineament. A minor set of NE-striking anomalies caused by dyke intrusion was also outlined by the survey. The NW-trending dykes were emplaced during late Mesozoic rifting associated with the opening of the South Atlantic. They acted as feeders to the Parana flood basalts and sills.

Résumé

Un levé magnétique aéroporté régional a permis de définir de nombreuses anomalies linéaires d'orientation NW dans l'est du Paraguay. Celles-ci ont été confimrées par des levés magnétiques au sol. Des travaux de cartographie géologique et de forage indiquent que ces anomalies ont été causées par des dykes de diabase. L'interprétation magnétique indique que la modèlisation des dykes et des failles peut être appliquée au même linéament. Un réseau moins étendu d'anomalies NE, causé par l'instrusion de dykes, a également été délimité par le levé. Les dykes d'orientation NW ont été mis en place durant l'épisode de formation de rifts du Mésozoïque supérieur, associé à l'ouverture du sud de l'océan Atlantique. Ils sont servi de conduits nourriciers aux basaltes de plateaux et aux filons-couches du Paraná.

INTRODUCTION

As part of a seven-year mineral exploration program conducted by the Anschutz Corporation of Denver, Colorado, U.S.A., a 60,000 line-kilometre, low-level (93% at 92 m, 7% at 60 m ground-clearance) magnetic survey of eastern Paraguay was flown in August through November, 1978.

Eastern Paraguay (Fig. 1) is largely underlain by Phanerozoic rocks. Precambrian rocks occur in the NW and SW parts of the country; Triassic sandstones and siltstones (red beds) capped by Cretaceous flood basalts are found along the eastern boundary, and gently east-dipping Paleozoic strata form the lower part of the western Parana Basin. Intrusive and extrusive alkaline rocks were emplaced during and after eruption of the Cretaceous flood basalts.

Recent studies in eastern Paraguay and adjacent areas have indicated Mesozoic rifting associated with basaltic dyke swarms along the western margin of the Parana Basin (DeGraff, 1985; Mariano and Druecker, 1985; Foder *et al.*, 1985). Regional domal uplift of the incipient South Atlantic during the late Triassic was followed by rifting and movement of the South American plate away from the African plate from the late Jurassic to early Cretaceous (Herz, 1977). Fletcher and Litherland (1981) have suggested that many of the 145 to 120 Ma alkaline complexes in southern Brazil and eastern Paraguay are located along linear belts that may represent the failed arms of a triple junction active during the initial rifting of the South American - African plate.

Tectonic studies of the South American platform by Almeida (1983) have stressed the importance of arches, flexures and rifts in the control of Mesozoic magmatism. The NW-trending Torres syncline (Fig. 2) may be a rift zone related to continental basaltic volcanism. This syncline is on strike, to the NW, with a broad zone of mafic dykes. As with other continental flood basalts, the Parana lavas are believed to have been fed by a system of dykes (Carmichael *et al.*, 1974).

Gravity data and interpretation of Landsat images indicate that the western part of the Parana basin in eastern Paraguay experienced NE-SW-directed crustal extension presumably during late Mesozoic time (DeGraff *et al.*, 1981; Degraff, 1985). Major zones of normal faulting in the SE portion of the study area have NW trends, similar in orientation to the mafic dykes (Fig. 3). The Asuncion rift zone, extending at least 200 km SE of Asuncion, Paraguay, is a compound graben between 25 and 40 km wide, filled in some parts, by nearly 2500 m of sedimentary rocks. Alkaline rocks are generally confined to this rift structure.

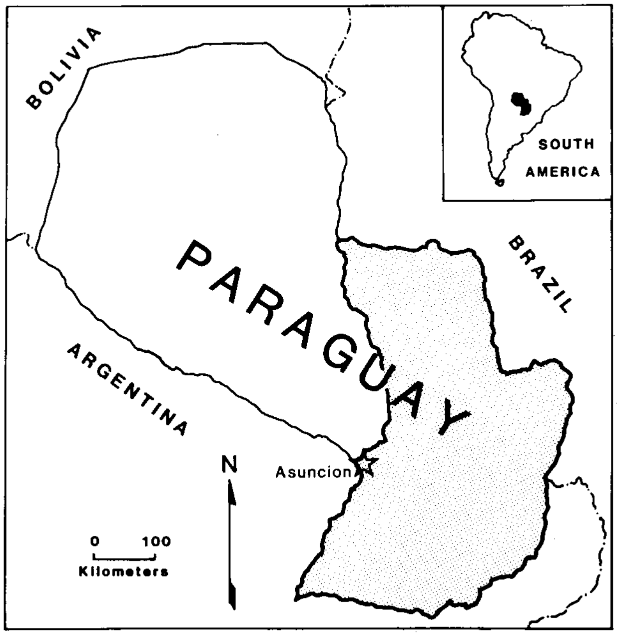

Figure 1. Location map of Paraguay, South America. Eastern Paraguay is shaded and comprises the general study area.

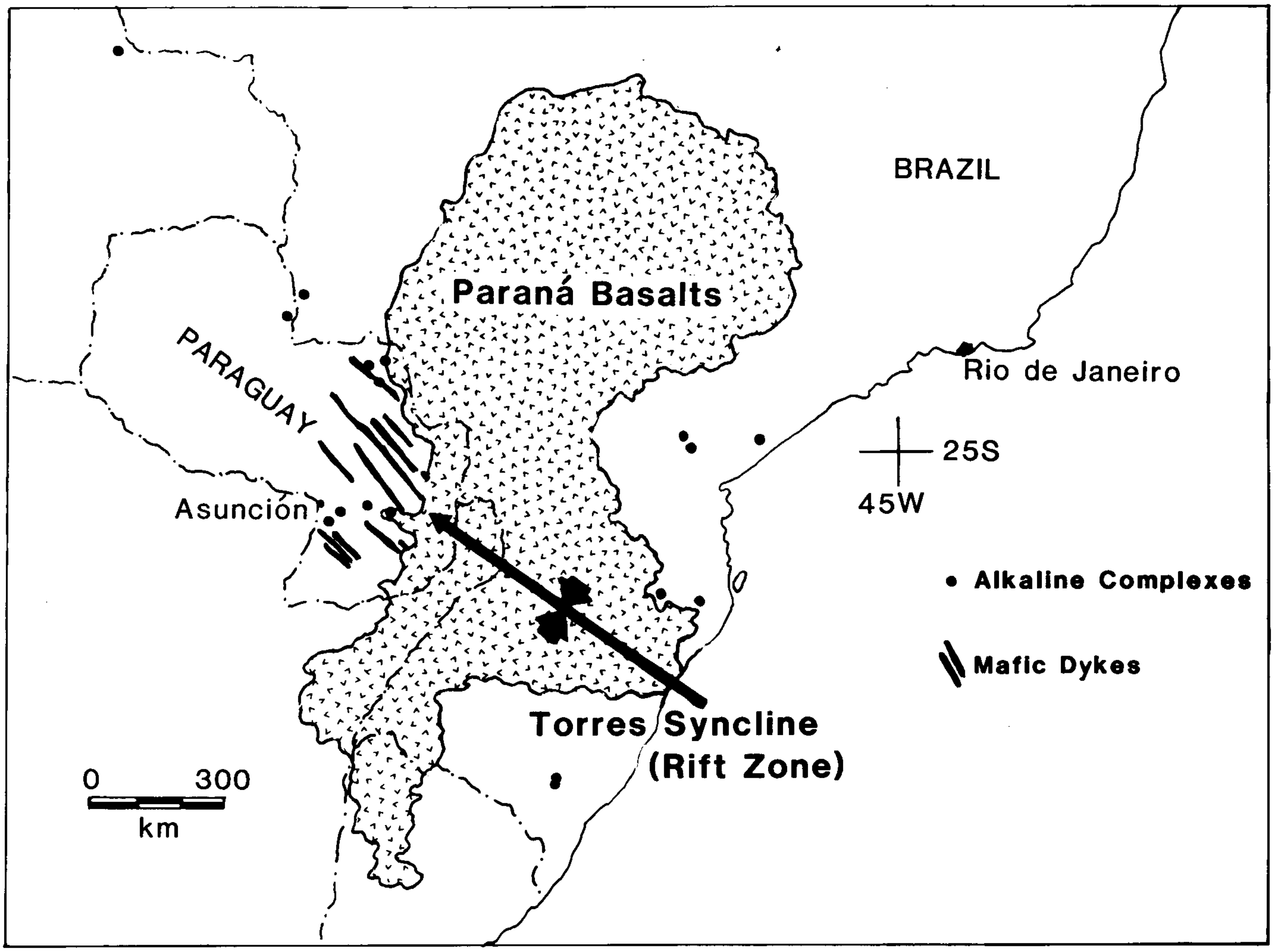

Figure 2. *Mesozoic rift tectonics of the Parana Basin. The areal limits of the Parana flood basalts are shown by the V-pattern. Alkaline complexes, shown as black dots, rim the basin.*

The subtropical climate of eastern Paraguay produces moderately deep lateritic weathering of mafic rocks, especially of the plateau flood basalts and diabase dykes. Weathered dykes were first reported by Eckel (1959) during reconnaissance field mapping but determination of their extent was hindered by lack of outcrop.

Mafic dyke swarms related to the Cretaceous opening of the South Atlantic also occur along the eastern margin of South America (May, 1971).

MAFIC DYKES

Stacked profiles from the aeromagnetic survey recorded a multitude of pronounced NW-trending magnetic anomalies (Fig. 4). These linear anomalies, indicating material of high magnetic susceptibility, suggested the presence of diabase dykes. The aeromagnetic data combined with ground observations and drill-hole data indicate that the diabase dykes range from 5 to 150 km in length and from 1 to 100 m in width. Dyke anomalies with amplitudes as low as 8 nanoteslas (nT) could be recognized as readily as anomalies with amplitudes as high as 1800 nT. Also, on profiles, the high-amplitude anomalies do not mask the low-amplitude ones as sometimes happens on contoured aeromagnetic maps. The shortcoming of the aeromagnetic work was the large flight-line spacing (5 km) which did not permit the mapping of dykes less than 10 km long. As previously mentioned, these dykes are not mappable in Paraguay by other means due to the deep weathering, lack of access, and the large size of the area. In the central part of the study area, samples were taken from a quarry that exposed a 15-m-wide diabase dyke in contact with Permo-Carboniferous sedimentary rocks. Several small sills, 1 to 3 m thick, emanate from the dyke along sedimentary bedding planes. The dyke is tholeiitic and composed of lath-shaped plagioclase and interstitial pigeonite with local subophitic texture. Magnetite is an important accessory, making up from 5 to 10 per cent of the rock by volume. There is a temporal, spatial and chemical association between these diabase dykes and the extensive sills and continental flood basalts of the westen Parana Basin, so the dykes are probably part of a major fissure-feeder system for the Parana eruptives. K-Ar dating provides an age range of 106 to 149 Ma with peak magmatism about 120 to 130 Ma for both flows and dykes (Cordani and Vandoros, 1967). An additional whole-rock K-Ar date of 127 ± 10 Ma was obtained for a diabase dyke that outcrops in east-central Paraguagy (Comte and Hasui, 1971).

The dominant strike-direction of the dykes is N40°W to N45°W. This is called the Set A direction. Several dykes were recognized at approximately right angles to this set and these are termed the Set A′ dykes. A few dykes with other strikes are indicated on the aeromagnetic maps but these are not discussed in the examples. The vast majority of dykes cause positive anomalies, that is, their magnetic vector is in approximately the same direction as that of the present Earth's field. However, a small percentage of dykes cause negative magnetic anomalies. These must have cooled and solidified when the polarity of the Earth's field was opposite to the present field.

Basic to an understanding of the dyke anomalies is the calculation of the theoretical curves which are generated under prescribed conditions. Figure 5 shows the theoretical anomaly for a Set A dyke in eastern Paraguay. The dyke is assumed to be vertical and striking N45°W. The anomaly is calculated for a profile perpendicular to the strike of the dyke. Magnetic field values used in the calculations were a declination of 8°W and a field inclination of −22°.

Type examples

Set A dykes in eastern Paraguay commonly cause positive aeromagnetic anomalies. One of these, the Curuguaty magnetic anomaly in a remote area of east-central Paraguay (Figs 4 and 6A) is unusual in that, even though it is strong and the body causing it is presumably of considerable width, it is relatively isolated. Commonly several strong Set A anomalies occur parallel to each other in close proximity. However, in this case there are only two weaker parallel dykes, one to the north and one to the south of the main anomaly. This dyke is approximately 100 km long. The maximum amplitude of the anomaly at 100 m terrain clearance is about 450 nT. Note the nearly vertical, consistent slope of the "crossover", which may indicate a shallow depth to the top of the dyke. The steep slope and departure from the theoretical curve results from the wide, 70-m sampling interval of the magnetometer.

The Pilar magnetic anomaly is located in SW Paraguay near the Argentine border (Fig. 4). The magnetic profiles are plotted on N-S flight lines with a 5-km line spacing (Fig. 6B). The magnetic high to the south establishes this as a reversely magnetized N45°W dyke. These dykes undoubtedly differ in age from some of the normally magnetized ones, and may reflect a period of magnetic reversal during intrusive activity.

Many of the anomalies thought to be caused by Set A′ dykes, (Fig. 4), are indefinite and short so in some cases it is not clear that they are caused by mafic dykes. However, the San José magnetic anomaly shown in Figure 6C is unmistakable. It occurs in a magnetically "quiet" area, so the NE trend of the anomaly is clearly visible. The amplitude is quite variable over the 21-km strike length of the anomaly with a low of 73 nT and a high of 845 nT (not shown) at 65-m terrain clearance. Dykes of this set are undoubtedly more common than Figure 4 indicates, but their short length and variable amplitude makes recognition difficult.

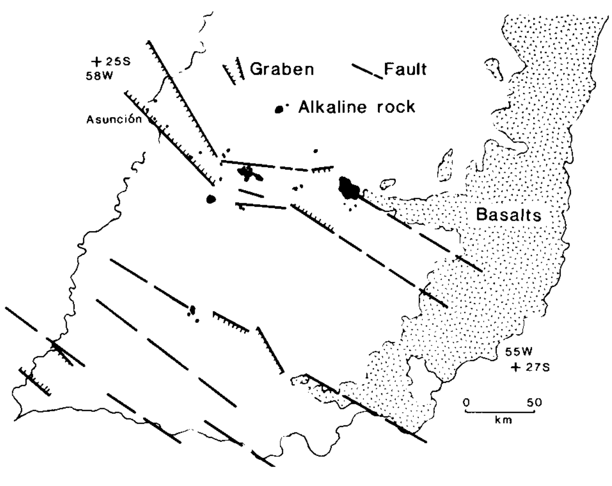

Figure 3. *Rift tectonics and alkaline magmatism of SE Paraguay (after DeGraff, 1985). The large NW-trending compound graben is designated the Asuncion Rift.*

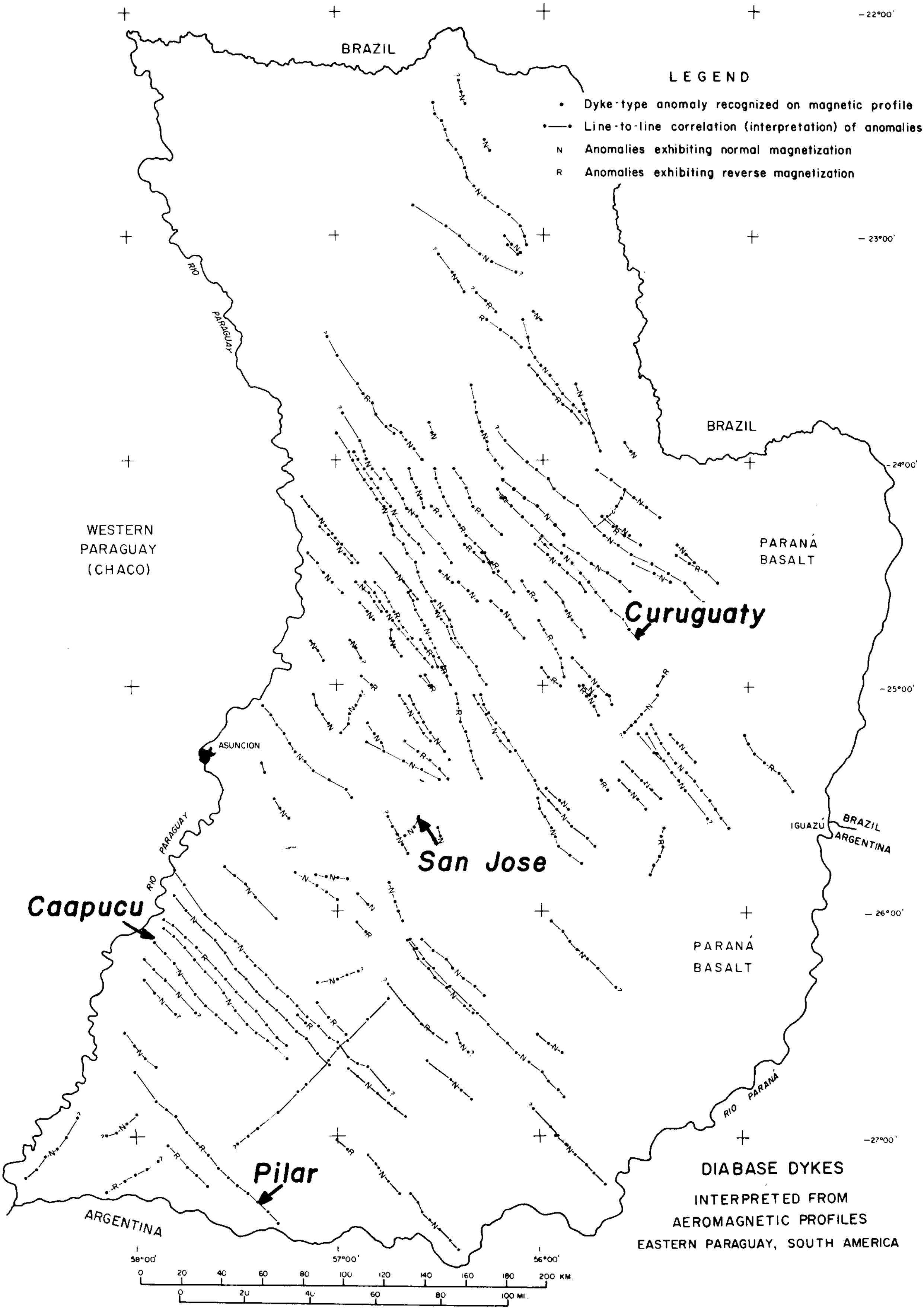

Figure 4. *Diabase dykes (lines connecting dots) interpreted from aeromagnetic profiles of eastern Paraguay. No dykes are shown along the eastern boundary because dyke anomalies could not be recognized within the outcrop area of the Parana basalts. The lack of dykes in the NW corner of the study area is real, however, as pre-dyke rocks (Precambrian through Ordovician) outcrop here.*

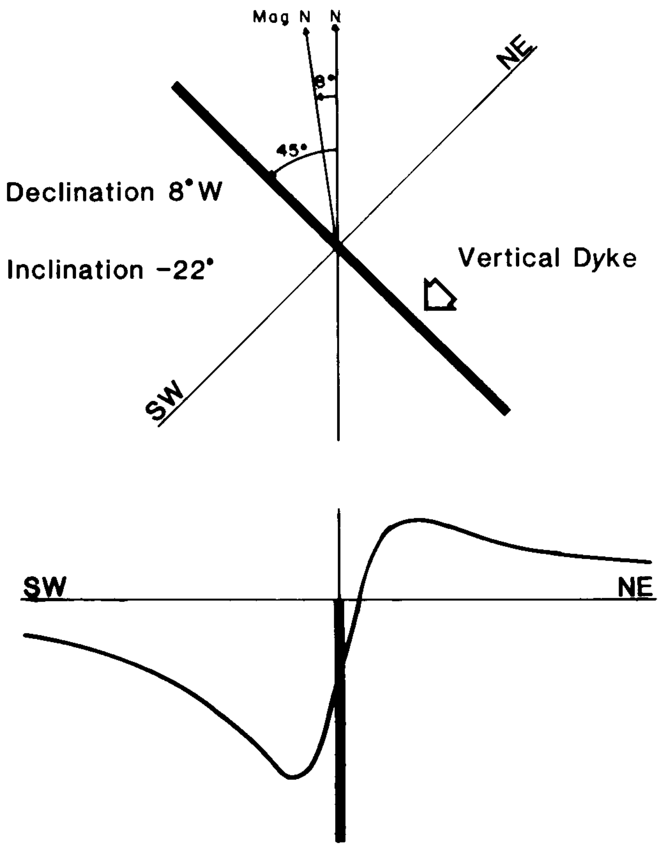

Figure 5. Theoretical curve of magnetic anomaly over normally magnetized Set A dyke.

The Caapucu magnetic anomalies are located in the SW part of the study area (Fig. 4). This group of five dykes is shown to illustrate the clarity with which multiple dykes can be interpreted from the low-level aeromagnetic survey (Fig. 6D). Note that the middle dyke in the group is reversely magnetized. Also note the consistency between adjacent anomalies showing the same dyke on all flight lines with either a positive or negative anomaly. This criterion was used in selecting the anomalies shown in Figure 4, although in a few cases, negative anomalies seem to be colinear with positive ones.

Dyke map

Figure 4 shows the diabase dykes interpreted from stacked profiles of the reconnaissance airborne magnetic survey of eastern Paraguay. The original profiles were plotted at a horizontal scale of 1:200,000 and were available at two vertical scales, 0.9 inch = 200 nT (single-parameter stack) and 1000 nT (three-parameter stack). Typical clear-cut examples of individual dykes were shown in the previous section. However, many dyke anomalies are not so well defined. They lack continuity, or are obscured by other magnetic anomalies. In particular, it was impossible to recognize dyke anomalies in the eastern part of the study area which is underlain by flood basalts. The "type area" for the dykes may be considered the area between 24°S and 25°S latitude lying just west of the basalt flows. We believe that this density of dykes exists throughout most of the study area, except in the extreme northwest, where diabase dykes are apparently lacking.

One factor that greatly influences recognition of the dykes is the wide flight-line spacing. Co-linear anomalies appearing on less than three consecutive profiles were not interpreted as dykes. Dykes of Set A (N45°W) appear to be longest, so the length criterion biases the study strongly against recognition of dykes of other sets. Dykes that run parallel, or subparallel, to the flight lines may not be recognized. The conjugate, or N-S direction, roughly parallel to the magnetic field would show no consistent anomaly pattern over dykes. The typical anomaly pattern over narrow, N-trending dykes is a closely spaced series of highs and lows resulting from breaks due to faulting of the dykes or to other reasons.

CONCLUSIONS

Mafic dyke swarms in eastern Paraguay were emplaced during late Mesozoic continental rifting associated with the opening of the South Atlantic. They cause prominent aeromagnetic anomalies with a dominant NW-SE strike-direction. They are related to filling of tensional fractures. Compositionally the diabases are tholeiites, probably part

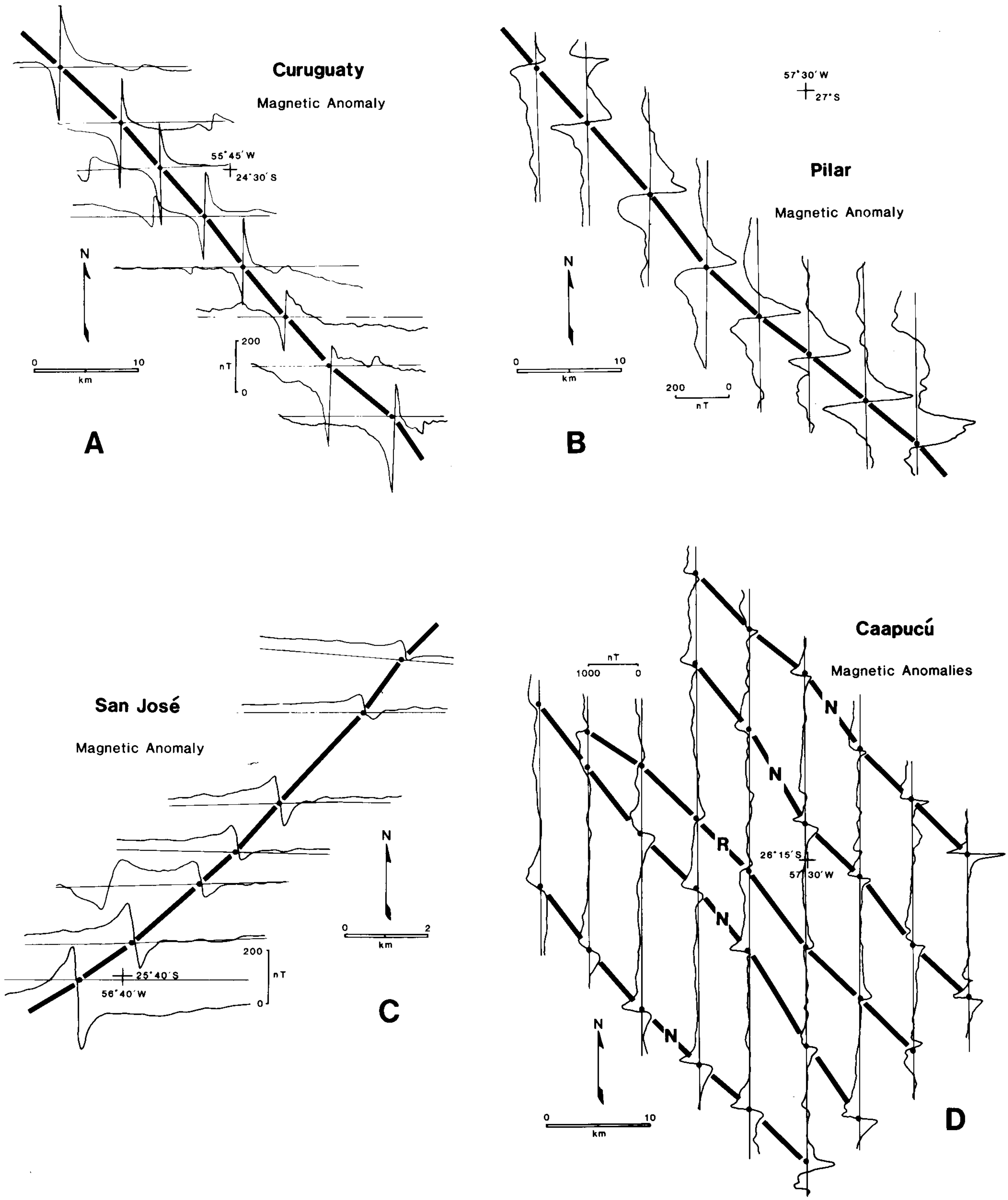

Figure 6. Type examples of magnetic anomalies interpreted as dykes, with locations shown on Figure 4. A: Normal Set A dyke. B: Reversed Set A dyke. C: Normal Set A′dyke. D: Set A dykes.

of an extensive fissure-feeder system to the Parana flood basalts and sills.

If the diabase dykes of eastern Paraguay occupy sets of pre-existing reactivated basement fractures, (Gay, 1973) the dominant basement-fracture direction was N45°W with a less-prominent N45°E direction. These fractures appear to have been opened and injected with dyke material during rifting episodes, but this does not necessarily mean that the basement is not fractured in other directions nor are these necessarily the dominant basement-fracture directions. There are N-S and E-W dykes as well, plus a number of N25°W anomalies that may be caused by basement faulting rather than by dyke material.

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