

Juxtaposed Mesozoic diabase dike sets from the Carolinas: A preliminary assessment

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ABSTRACT

Aeromagnetic anomaly maps of the North Carolina Piedmont provide confirming evidence of juxtaposed Mesozoic diabase dike sets. Dikes in North Carolina may be divided into four domains, on the basis of dike orientations. Most dikes are olivine normative, but there are apparent systematic differences in chemical compositions that are reflected in different orientations and ages. Two orientations dominate: northwest and north-south. The northwest-trending set dominates in the South Carolina Piedmont, and the north-south set extends through much of the central Virginia Piedmont and under the Coastal Plain in South Carolina. The north-south dikes are part of a set that converges near Charleston and Georgetown, South Carolina, and diverges northward into Virginia. Preliminary information suggests that the north-south dikes are younger than the more common northwest-trending dikes. Current models proposed for stress regimes associated with the breakup of Pangea can accommodate the northwest set, but not the north-south convergent set. This convergent set may be evidence for crustal deformation above a mantle plume centered near Charleston and Georgetown in Middle Jurassic time. It is possible that presumed mafic plutons under the Coastal Plain near Charleston, regional seismicity patterns, and orientations of the diabase dikes are all related to an intersection of zones of crustal weakness inherited from mid-Mesozoic time. The western margin of northwest-trending dikes may be related to tectonic features inherited from pre-Mesozoic time.

INTRODUCTION

Mesozoic diabase (dolerite) dike swarms in eastern North America have been the subject of considerable interest and speculation for many years, particularly after King (1961) recognized their overall radial

distribution pattern (Fig. 1). Additional research on the dikes was spurred by the realization that their ages approximate the time of the assumed breakup of Pangea in middle Mesozoic time. Their attitudes provide insight into possible stress regimes

that existed during the breakup (de Boer, 1967; May, 1971; Swanson, 1982).

Geochemical and petrologic research (e.g., Weigand and Ragland, 1970) demonstrated that diabase magma types in eastern North America are geographically distinct. Olivine diabases dominate in the Carolinas; quartz diabases are more abundant north of Virginia; and both types apparently are in roughly equal abundance in Virginia, Georgia, and Alabama. Bryan et al. (1977), as well as de Boer and Snider (1979), have attempted to fit this variation in magma types to existing plate-tectonic models.

Our purpose here is to test and revise existing tectonic models in the Carolinas. The map by Burt et al. (1978) is a particularly useful compilation of U.S. Geological Survey open-file aeromagnetic data and known locations of diabase dikes from the North Carolina Piedmont. This area may be divided into four juxtaposed domains, on the basis of dike orientations (Figs. 2, 3): (1) domain I, dominated by northwest-trending dikes; (2) domain II, north-south; (3) domain III, north-west, with some

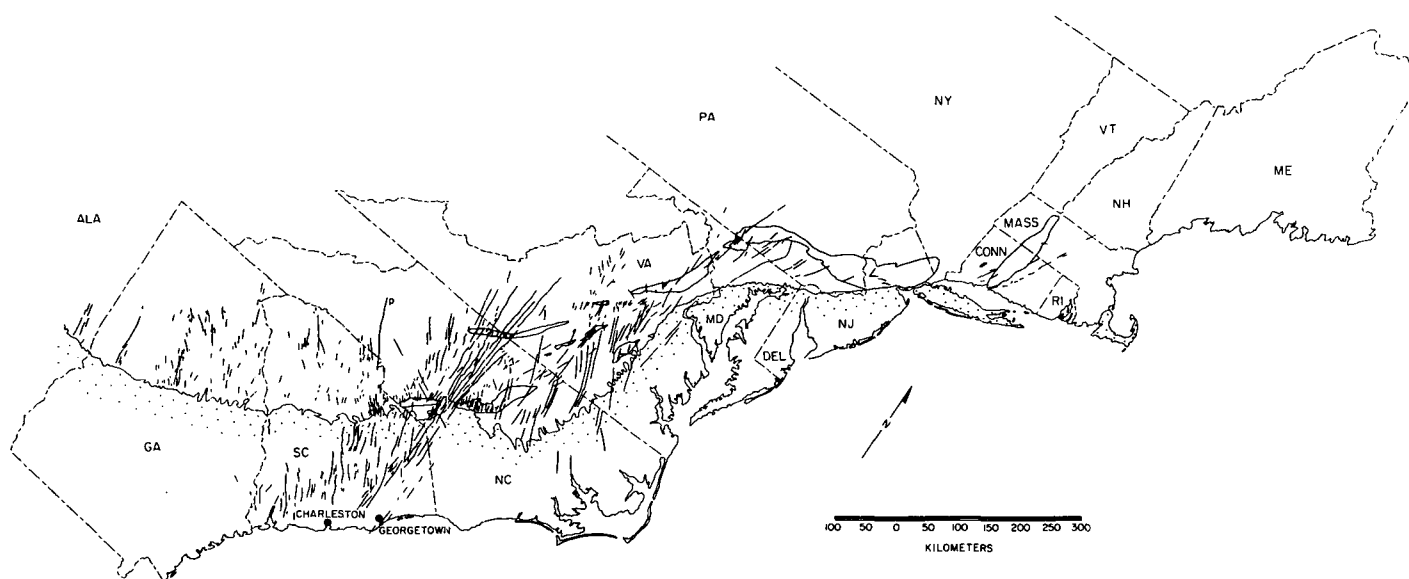


Figure 1. Interpretative compilation of diabase dikes in eastern North America. Outlined areas indicate Triassic basins. Stipple marks extent of Atlantic Coastal Plain. P = Pageland dike. Compilation is based upon both aeromagnetics and field observations for the Carolinas and Virginia. Information for remaining states is almost totally from field occurrences (e.g., King, 1961).

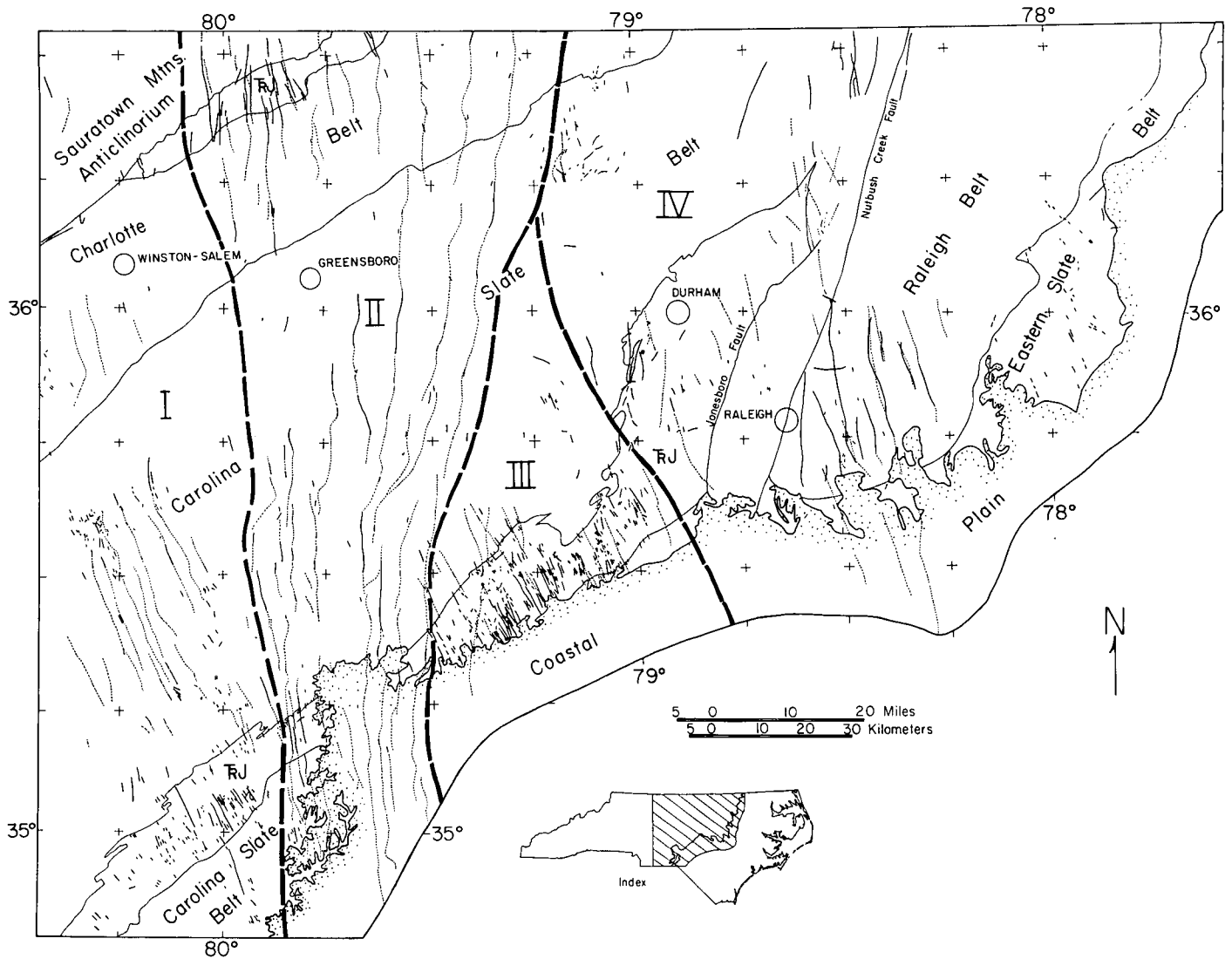


Figure 2. Diabase dikes in North Carolina Piedmont (modified from compilation by Burt et al., 1978). Dotted lines indicate aeromagnetic anomalies only; solid lines indicate both field occurrences and aeromagnetic anomalies. Heavy dashed lines delineate domains I-IV. T J indicates Triassic basins.

north-south; (4) domain IV, similar to I. The northwest trends in the Carolinas are in agreement with the overall radial pattern for dike swarms in eastern North America; the north-south orientations are not. May (1971, Fig. 1) suggested that the radial dike pattern in eastern North America might be extended to the entire circum-Atlantic region by restoring the continents to a pre-drift configuration. This radial pattern does not appear to be a continuum but rather a collection of dike sets of different ages and chemistries (Weigand and Ragland, 1970; Bertrand and Coffrant, 1977; Smith and Noltmier, 1979; Sutter and Smith, 1979).

We chose North Carolina for this preliminary investigation because domains from which samples can be collected are most easily recognized there and more chemical data are available. Popenoe and Zietz

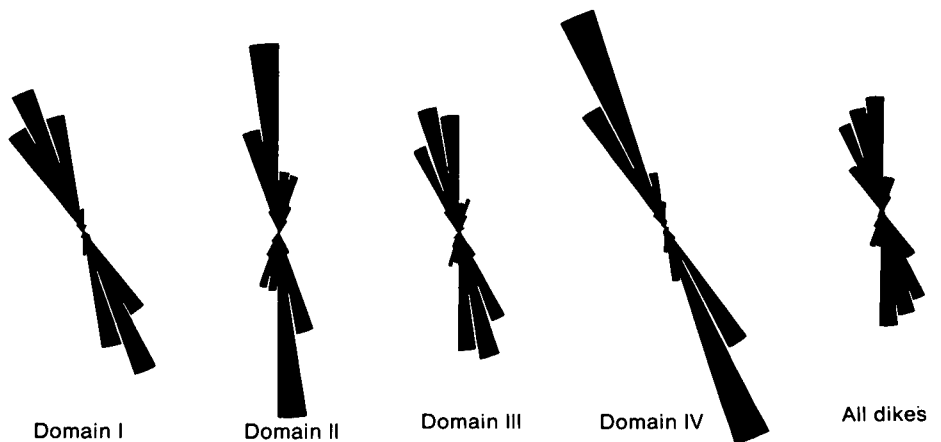


Figure 3. Rose diagrams for domains shown in Figure 2. Note dominance of northwest trends in domains I and IV, whereas north-south orientations dominate in domain II.

(1977) have recognized the north-south and northwest-trending dikes on the basis of aeromagnetics in the South Carolina Coastal Plain, but no samples are available. Elsewhere, with the exception of the central Virginia Piedmont where few chemical analyses are available, the domains are not as clearly defined (Fig. 1).

DIABASE DIKES IN EASTERN NORTH AMERICA

Perhaps the first realization that diabases in the Carolinas were, on the average, compositionally different from the majority of dikes, sills, and flows in the northeastern United States grew out of a petrographic study by Hermes (1964), who recognized the widespread distribution of olivine diabases in the South. This conclusion was subsequently confirmed by Ragland et al. (1968), who reported that most diabase dikes in North Carolina were more similar in composition to oceanic tholeiites than to the more typical quartz tholeiitic types common in the northeastern United States. A geochemical survey of diabase dikes throughout eastern North America (Weigand and Ragland, 1970; Ragland et al., 1971) confirmed this geographic distribution of magma types. These authors were the first to propose three main types: (1) high-TiO₂ quartz-normative; (2) low-TiO₂ quartz-normative; and (3) olivine-normative. They also proposed a fourth subtype, high-Fe₂O₃ quartz-normative, which may be a differentiate of the high-TiO₂ quartz-normative type (Maxey, 1973). Subsequent studies confirmed these types and their geographic distribution (e.g., Smith et al., 1975; Bertrand and Coffrant, 1977; Papezik and Hodych, 1980).

Because of their association with the Triassic-Jurassic basins in eastern North America, the dikes were long believed to be primarily of Triassic age. De Boer (1967), however, concluded from paleomagnetic evidence that most of the dikes are Jurassic. Conversely, Armstrong and Besancon (1970) reported clusters of conventional K-Ar ages around 200 and 230 m.y. Other studies, however, have demonstrated that some ages determined by conventional K-Ar methods are anomalously high because of contamination by radiogenic Ar (e.g., Dooley, 1977). Additional studies have suggested two clusters of ages around 165–175 m.y. and 180–190 m.y. for all early-mid-Mesozoic mafic rocks (e.g., Deininger et al., 1975; Dooley, 1977; Smith and Noltmier, 1979; Sutter and Smith, 1979). Deininger et al. (1975) reported that the younger cluster is low-TiO₂ quartz-normative and the older cluster is olivine-

normative; the relative ages of these clusters were confirmed by Smith et al. (1975).

Some tectonic models that attempt to explain regional attitudes and distributions of the dikes presume that the dikes were intruded into extension fractures that were produced primarily during the breakup of Pangea (May, 1971; de Boer and Snider, 1979). In contrast, de Boer (1967) and Swanson (1982) argued that some dikes occupy shear fractures, so the true situation may be quite complex. De Boer (1967) suggested a dominance of tensional fractures in the southeastern United States shear fractures, with sinistral polarity in the Northeast. Manspeizer et al. (1978) have proposed that Late Triassic east-west shear took place during the initial formation of the present Atlantic.

Weigand and Ragland (1970), utilizing de Boer's model, concluded that olivine-normative magmas, little changed from their point of origin in the upper mantle, may have risen more easily along extension fractures and thus had relatively little opportunity to fractionate and/or become contaminated during ascent. Conversely, quartz-normative magmas from the Northeast might have been relatively contaminated and fractionated derivatives from an olivine-normative parent. De Boer and Snider (1979), however, felt that the diabases in the Carolinas are indicative of a hotspot there in Jurassic time. A related idea was proposed by Bryan et al. (1977), but they concluded that the hotspot was more likely in New England and related to the present-day Azores hotspot. This would account for the diabases in the Northeast being more large ion lithophile (LIL) enriched than those in the Carolinas.

DIABASE DIKES IN THE PIEDMONT OF NORTH CAROLINA

The Mesozoic diabase dikes from North Carolina may be divided spatially into four principal domains and exhibit two dominant trends, N10°–30°W and north-south (Figs. 2, 3). We have compiled and plotted all known chemical data (Weigand, 1970; Ragland et al., 1968) for diabases from this area (Figs. 4, 5). Data on these figures suggest that diabases from domains I and II are compositionally different for the alkalis, alkaline earths, Zr, and SiO₂. Moreover, these data suggest that olivine diabases, heretofore not subdivided, can be divided into two and perhaps three groups.

In general, diabases from domain I have lower concentrations of LIL elements than do those from domain II. Diabases from domain IV, although data are inconclusive, are apparently similar to those from

domain I, whereas domain III remains an enigma. Domain III has some characteristics of I (CaO, K₂O, and Rb) and some of II (SiO₂, Zr, and Sr); it perhaps represents a third magma type or a combination of domains I and II (Figs. 4, 5). These chemical differences between domains parallel differences based upon orientations; i.e., I and IV are similar to each other and different from II.

It is interesting to note that TiO₂ and Cu, which are quite useful in distinguishing between different groups of quartz-normative diabases (Weigand and Ragland, 1970; Smith et al., 1975), are not useful in subdividing olivine-normative diabases. The most useful are the LIL elements. LIL data from Virginia and South Carolina (Weigand, 1970) suggest, as predicted, that domains I and IV are compositionally more similar to diabases in South Carolina, whereas II is more similar to those in Virginia.

Little information is available concerning the relative or absolute ages of diabases from these domains. Research is currently in progress to resolve this question. The only study with sufficiently detailed sample locations (Smith and Hare, 1983) tentatively concluded through paleomagnetism that the north-trending dikes from domain II are on average younger than the northwest-trending dikes. No absolute ages were assigned, however, and mean directions are not significantly different. Cross-cutting relationships, which are not numerous and are plagued by poor exposure, imply that domain II is younger.

DISCUSSION AND CONCLUSIONS

It is worthwhile to speculate about the possible tectonic significance of these dike sets. Orientation of the northwest-trending set (domains I and IV) in the Carolinas fits tectonic models proposed by May (1971) and de Boer and Snider (1979), which require that all dikes occupy extension fractures that radiate about an area somewhere near the present-day Caribbean. The north-south set (domain II) does not fit these models. Swanson (1982) offered another explanation in which he speculated that basin flows, sills, and some dikes emplaced at about 190 m.y. ago accompanied a major event of dextral rotational shear between North America and Africa. This event was thought to have been followed by sinistral shear and emplacement of the northwest-trending dikes (corresponding to most dikes in the southern Appalachians) at about 190 m.y. ago. This model is at least in part an oversimplification, because most dikes dated in the southern Appalachians apparently belong

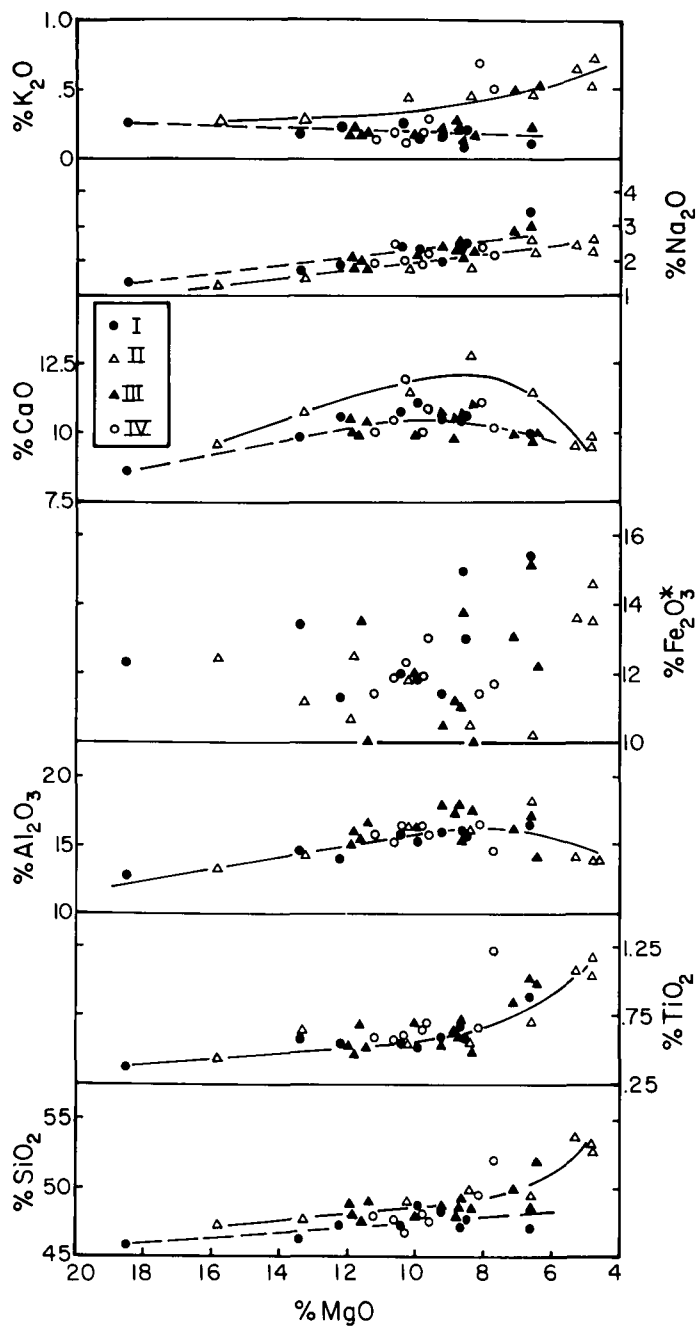


Figure 4. Major-element variation diagrams for diabases from domains I-IV. Data are compiled from Weigand (1970) and Ragland et al. (1968).

to the older set (~190 m.y. old; Dooley, 1977).

It is clear from Figure 1 that the north-south set (which is apparently younger and is more LIL enriched) is convergent upon an area between Charleston and Georgetown, South Carolina. Existence of this convergent pattern is a fascinating discovery. We hesitate to call it a radial swarm because at present there is no conclusive evidence that it extends beyond about 30° of arc, if that much (Fig. 1). Eventually, we hope to determine if this is indeed a radial

swarm. The convergent pattern clearly extends as far north as the central Virginia Piedmont and perhaps farther (Fig. 1). Geophysical studies (e.g., Long and Champion, 1977; Popenoe and Zietz, 1977) indicate the presence of large positive magnetic and gravity anomalies in the vicinity of Charleston and Georgetown, which are interpreted as being caused by mafic or ultramafic rocks in the subsurface (Kane, 1977). In fact, Popenoe and Zietz (1977, Fig. 7) recognized the northwest-trending set (domain I, this paper) and the north-

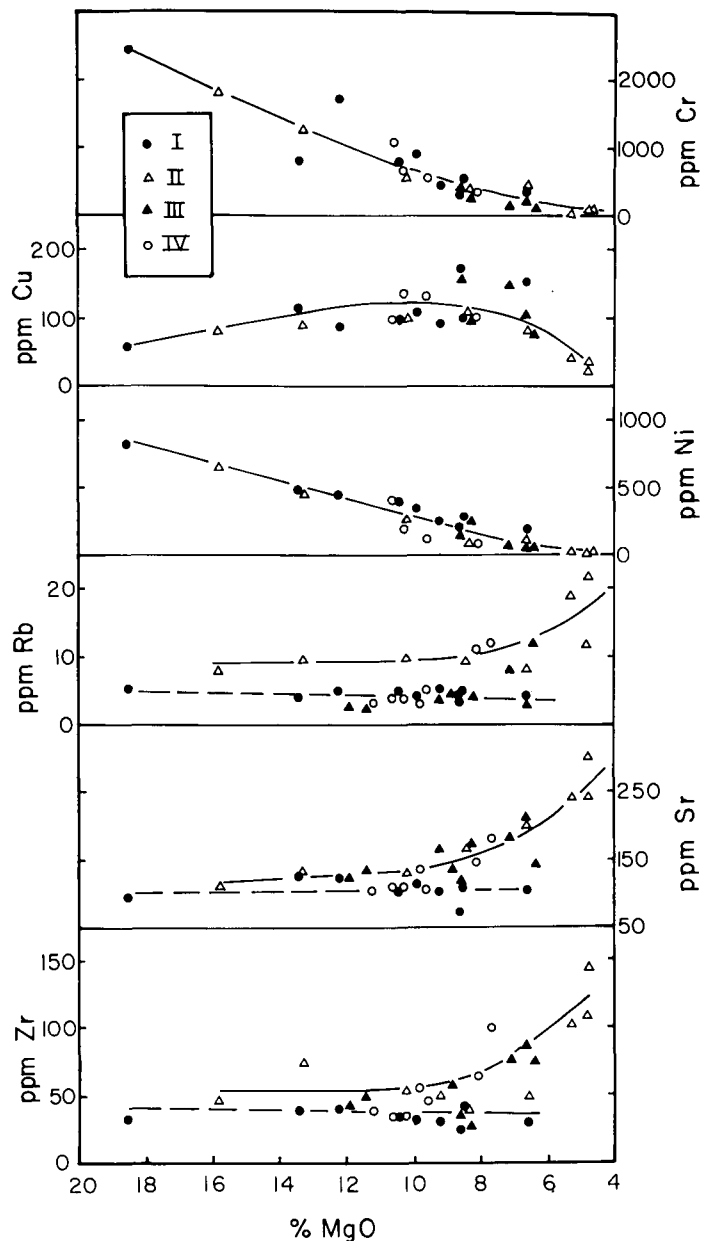


Figure 5. Trace-element variation diagrams for diabases from domains I-IV. Data are compiled from Weigand (1970) and Ragland et al. (1968).

south dikes (domain II) under the South Carolina Coastal Plain. Mesozoic basalts from a drill hole in the area are remarkably similar in composition to high-TiO₂ quartz-normative diabases of eastern North America (Weigand and Ragland, 1970; Gottfried et al., 1977).

Domain II dikes (the north-south group that converges upon Charleston and Georgetown) are, on average, more laterally continuous than the northwest-trending group (Fig. 2). Moreover, they commonly exhibit much larger positive aeromagnetic anomalies than do the northwest-trending dikes, implying that they tend to be thicker and/or more verti-

cally continuous. Field data and coarser average grain size also indicate that they are thicker.

One of the largest dikes in the Southeast, the Pageland dike (Steele and Ragland, 1976), has the orientation to be one of the convergent set (Fig. 1). This dike, 342 m wide in Lancaster County, South Carolina, extends across the entire Piedmont into the Grandfather Mountain window in North Carolina (Fig. 1). Its anomalous chemistry (LIL enriched and SiO₂ saturated compared to more typical olivine-normative dikes of this area) can be explained if it is one of the convergent set.

There is a possibility that this younger convergent set may represent the 165–175-m.y.-ago event and that the northwest set was emplaced during the older 180–190-m.y.-ago event. Manspeizer (1980) proposed that separation of North America and Africa occurred in five stages. Perhaps the northwest set was a part of his Episode IVa (Rhaetian-Hettangian), whereas the north-south set corresponded to Episode IVb (Sinemurian and later). The tentative results of Smith and Hare (1983), however, suggest that the northwest and north-south sets are not that different in age.

De Boer and Snider (1979, Fig. 10) have proposed the migration of a triple junction from southern Georgia in Carnian time to the Blake Plateau vicinity in Middle Jurassic, with a hotspot centered under the

North Carolina Piedmont during this time. Perhaps radial fracturing that accompanies crustal upwarping over a mantle plume ("hotspot epeirogeny"; Crough, 1979) centered near Charleston and Georgetown occurred during Middle Jurassic time. The comparative LIL-enriched chemistry of the domain II dikes is compatible with that for mantle plumes (White et al., 1976). It should be mentioned, however, that there is no obvious plume track in the Atlantic off the coast of Charleston and Georgetown.

It is tempting to conclude that the dike set convergent upon Charleston and Georgetown is in some way connected with the 1886 Charleston earthquake (Talwani, 1982, 1983). A northwest trend of seismicity near Charleston through South Carolina has existed since the mid-1700s (Talwani, 1982) and undoubtedly before. Talwani has also found a deeper, north-northeast seismic zone in the same area. He concluded that the Charleston earthquakes occurred at the intersection of a pre-existing zone of weakness, which may be an extension of the Blake Spur Fracture Zone in the Atlantic, with Triassic boundary faults (Talwani, 1983). Recalling that prominent gravity and magnetic highs exist in this zone of intersection as well, perhaps the convergence of the domain II dikes on this area is no coincidence. The model of "hotspot epeirogeny" (Crough, 1979)

should be given serious consideration in this area.

Examination of the dike sets in light of several major linear tectonic features in the southeastern and south-central Piedmont is useful. The only strong correlation between the western limit of northwest-trending dikes and any linear feature is its approximate coincidence with the Brevard fault in Alabama through northeast Georgia (Fig. 6). A possible correlation exists between this western boundary and the 0-milligal gravity gradient in northern North Carolina and Virginia (Fig. 6). The 0-milligal gravity gradient roughly marks the eastern margin of the North American craton (Hatcher and Zietz, 1980). Along the southern extremity of this western boundary the Brevard Zone may denote a fundamental change in continental deep-crustal structure that controls dike emplacement, whereas along its northern extremity it marks the eastern boundary of continental basement. Note that the convergent set (domain II in North Carolina), including the Pageland dike, crosscuts all linear features and extends into the Blue Ridge (Fig. 6).

The reasons for paucity of dikes in some areas are not known, nor are the reasons known for the scalloped, embayed western limit of the northwest dike set in the Carolinas and northeast Georgia (Fig. 6). Alter-

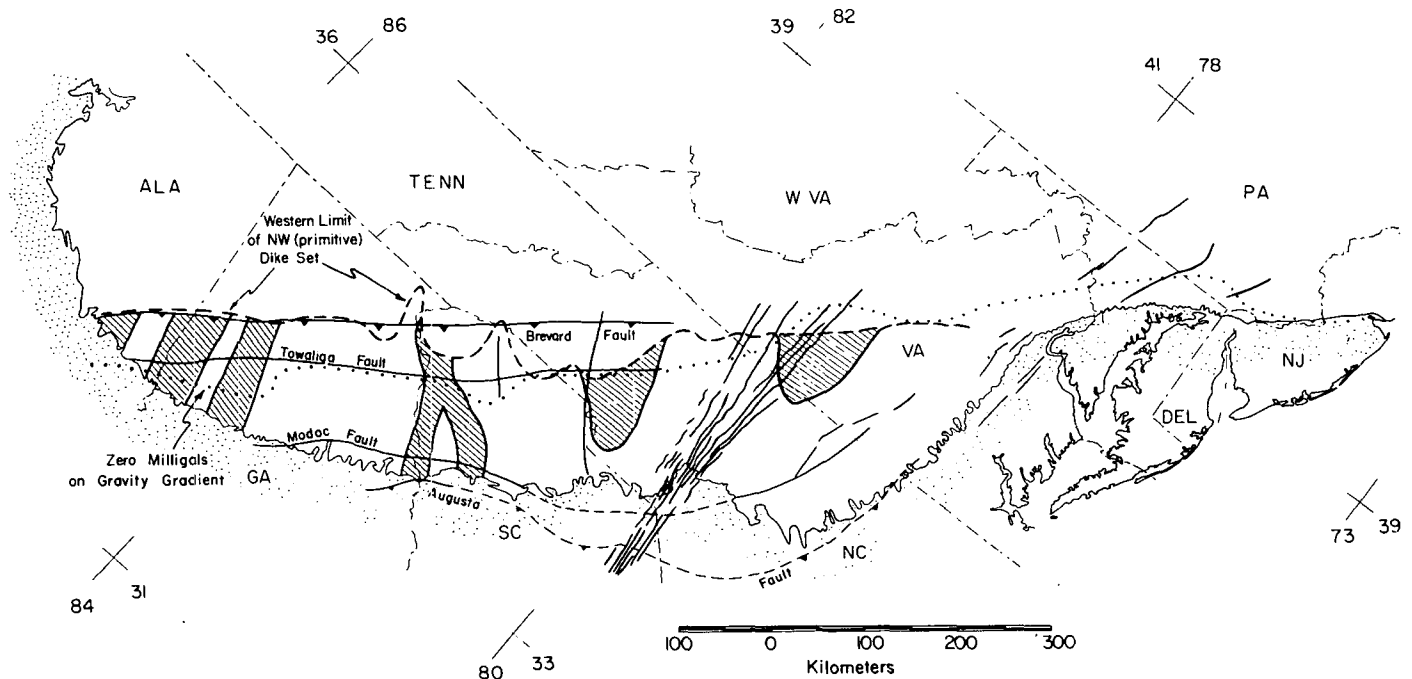


Figure 6. Map showing relationship of dike sets to major tectonic linear features in southeastern and south-central Piedmont. Dashed line marks western limit of northwest set, and convergent set is shown. Diagonally ruled areas denote regions in which dikes are rare or absent. Stipple indicates western margin of Coastal Plain. Pageland dike extends from western edge of Coastal Plain between words "Brevard" and "Fault" into Blue Ridge.

nating zones in which dikes are plentiful and then scarce may reflect differences in ductile vs. brittle behavior of deep crustal lithologies. The scalloped, embayed margin may denote a northwest-, northeast-trending orthogonal series of recesses and salients inherited from the pre-Mesozoic basement (Thomas, 1977).

If our speculations are correct, the north-south dikes of domain II are a part of a Middle Jurassic dike set that is convergent upon Charleston-Georgetown, South Carolina. It is compositionally different from and apparently postdates the more typical northwest-trending dikes exemplified by domains I and IV. It is possible that the presumed mafic plutons in the subsurface of the area, regional seismicity, and orientations of the diabase dikes are all related to an intersection of zones of crustal weakness inherited from mid-Mesozoic time. In contrast, the western margin of the northwest-trending dike set may be related to tectonic features inherited from pre-Mesozoic time. Ultimately we hope to place better constraints on Mesozoic tectonic models for this region than speculations presented herein allow.

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