STRUCTURAL CONTROL OF MESOZOIC MAGMATISM IN NEW ENGLAND

J. Gregory McHone and Sally N. Shake[1]

ABSTRACT

Topographic and geophysical lineaments that express major fracture zones, rifts, and basement structures show strong correlations with the trends and locations of Mesozoic dikes and plutons across the New England region of eastern North America. Some of the tectonic patterns represent older crustal fabrics and structures that were reactivated during Atlantic rifting events in early Jurassic and early Cretaceous times. Major topographic trends include N-S and NE-SW (Appalachian parallel) lineaments, and a series of NW-trending lines that transect the northern Appalachians of New England. NE-trending dikes are common only in the regions possessing NE-SW lineaments, while E-W to NW-SE dike trends occur near similar topographic lineaments west of the Appalachian highlands. Faults and fracture zones related to the lineaments are controlled by crustal structures within and beneath the allochthonous terranes of the orogen. Extension of some of these structures during Mesozoic plate movements produced the dike swarms, chains of plutons, and rift basins.

INTRODUCTION

The recognition of structural patterns in New England has traditionally been made by field geologists who are primarily interested in Paleozoic lithologies and orogenic events. In contrast, most igneous petrologists have concerned themselves with studies that detail the evolution of magmas within New England plutons. A few geologists have pointed out patterns from geophysical anomalies (Diment, 1968; Barosh, 1986), pluton alignments (Chapman, 1968), faults (Philpotts, 1970; Kumarapeli and Saull, 1966), joint sets (Wise, 1982 and 1983), and topographic lineaments (Wise, 1976; Barosh, 1986; Shake and McHone, 1987) in the New England region, with elements apparently related to an interaction of tectonism and magmatism during the Mesozoic Era. This paper describes additional correlations of tectonic and igneous patterns in New England, with important implications about the lithospheric control of intraplate magmatism.

MESOZOIC IGNEOUS PROVINCES

Igneous activity in New England and adjacent Quebec occurred in concert with Atlantic Ocean rifting and magmatic events around the Mesozoic North Atlantic basin (MacIntyre, 1977). McHone and Butler (1984) recognize four Mesozoic igneous provinces in New England based on the radiometric ages, distribution, physical aspects, and petrology of the intrusions. The boundaries of the provinces and the locations of major plutons are shown in Figure 1. Dates and orientation data are shown in more detail in a map published separately by McHone (1984).

The oldest intrusive group comprises the Coastal New England (CNE) province, with three syenitic plutons in southeastern Maine and an indeterminate number of olivine dolerite dikes with northeasterly trends in southern Maine (McHone and Trygstad, 1982), coastal New Hampshire (Bellini, 1981), and probably southeastern New England (McHone and others, 1987). The intrusions show early to middle Triassic radiometric ages. Many hundreds

---

[1] Department of Geological Sciences, University of Kentucky, Lexington, Kentucky 40506-0059 USA

R. Mason (ed.), Basement Tectonics 7, 399–407.

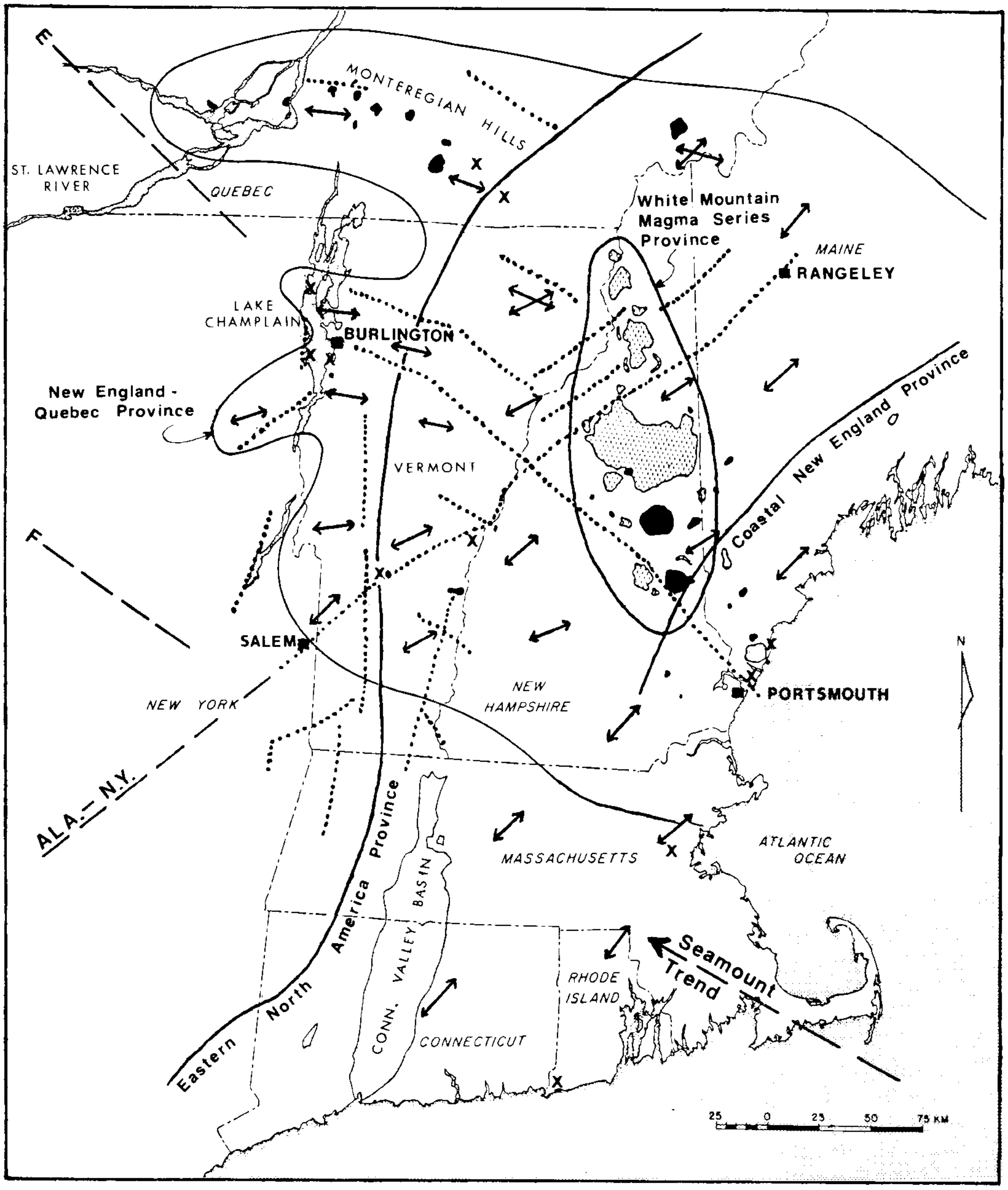

FIGURE 1. Mesozoic igneous provinces (solid outlines), generalized dike trends (double arrows), and major cross-trending topographic lineaments (dotted lines) in the New England region. Intrusive breccias are located at each X. Dashed lines represent geophysical lineaments mentioned in the text. Solid-color areas show early Cretaceous plutons, and patterned areas show Jurassic plutons.

more dolerite dikes, tholeiitic in composition, trend from N40°E to N60°E across eastern New England and Atlantic Canada, and belong to the early Jurassic Eastern North America dolerite province of the eastern Appalachians (Weigand and Ragland, 1970).

The large early to middle Jurassic plutons of the classic White Mountain magma series (WMMS) province (Billings, 1956) are mainly granitoids and syenitoids, and form an elongate N-S zone in central to northern New Hampshire (Figure 1). After relatively little magmatism in the late Jurassic, thousands of alkalic lamprophyre dikes and at least 20 gabbro/syenite plutons,including the Monteregian Hills (Figure 1), intruded northern New England, southernmost Quebec, and the northeastern border of New York. The dikes show trends E-W to NE from west to east across New England, and about WNW in southern Quebec. These early Cretaceous rocks form the New England - Quebec (NEQ) province of McHone and Butler (1984), and unlike the earlier groups, completely transect the Appalachian orogen (Figure 1).

Also in Cretaceous and possibly Jurassic time (Duncan, 1984; Hurtubise and others, 1987), alkalic volcanism produced a chain of seamounts that extend some 1200 km southeasterly from Georges Bank off the New England coast (Vogt and Tucholke, 1978). Because they trend toward New England (Figure 1), the New England seamounts have often been correlated with the WMMS and/or NEQ plutons of New England (Foland and Faul, 1977). The seamounts and continental intrusions are linked in two prevalent models for their origins: (1) a fixed mantle plume, or "hotspot" that was overridden by the North American plate (Crough, 1981; Morgan, 1981), or (2) a fracture zone or transform fault crossing the continent-ocean boundary, along which magmatism could have been "simultaneous, episodic, or migratory, depending upon the timing and orientation of associated stress patterns" (Vogt and Tucholke, 1978, p. 847). Radiometric dating by Duncan (1984) indicates an early to late Cretaceous progression of latest volcanism from west to east.

REGIONAL STRUCTURAL TRENDS

The western New England segment of the Appalachian orogen is marked by a change from the common northeasterly structural trends to one that is almost north-south. Figure 2 summarizes some of the major structures of the region. To the north and east of western New England, both folds and faults tend to return from north-south back to northeasterly trends. High-angle faults along the Connecticut River Valley and the Lake Champlain Valley display both N-S and NE trends, with NE tending to offset N-S faults. Several E-W faults are also present in the Champlain Valley and in the St. Lawrence Valley of adjacent Quebec (Figure 2). Kumarapeli and Saull (1967) and McHone (1982; 1987) have suggested that these high-angle faults were active during Mesozoic rifting and magmatic events.

Both the Connecticut River Valley and the Lake Champlain Valley are north-south basins created by vertical diastrophism. The Connecticut Valley border faults were active during the middle Jurassic or later, as shown by offset sediments in the basin (Wise, 1982) and by radiometric dating of extensions of the same faults in western New Hampshire (Lyons and Snellenburg, 1971). Champlain Valley faults both offset and are offset by some Cretaceous dikes, suggesting contemporaneous activity (McHone, 1987). The Western Champlain Valley faults also act as borders for the eastern Adirondack Mountains of New York (Figure 2), where they apparently record Proterozoic movement (Willems and others, 1983), and could have been reactivated during Adirondack uplift in the late Mesozoic (Crough, 1981) or Cenozoic (Isachsen,1975).

The Champlain Valley lacks the Triassic-Jurassic sediments so abundant in the southern Connecticut River Valley, which for the Champlain Valley may indicate younger tectonism, or deeper erosion. Adapting models from Sanders (1963) and Crough (1981), McHone (1982) suggested middle to late Mesozoic uplift for the Adirondacks, Green Mountains, and White Mountains: a "basin and range" tectonism that is responsible for much of the present-day topography.

In contrast, the major folds and thrust faults of New England were produced by Paleozoic orogenic compression, and apparently exist in allochthonous sheets that overlie a less-deformed platform sequence in western New England (Stanley and Ratcliff, 1985). In the model developed by Cook and Oliver (1981), these allochthonous terranes also cover an ancient continental margin and oceanic crust under eastern New England and elsewhere in the Appalachians. This relict continent-ocean border may be along a triple-junction rift arm (Rankin, 1976), or along a zone of NE-trending rifts and/or NW-trending transforms (Thomas, 1983): a product, in either case, of Eocambrian divergence for the New England region.

The present compressional Appalachian structures roughly conform to the shape of this early rift margin, which survived in the lithosphere and influenced Mesozoic tectonic and magmatic events. For example, the Connecticut River basin is bounded by faults that are localized by the margin of the Bronson Hill anticlinorium (Wise, 1982). Other Mesozoic basins in the eastern Appalachians also have border faults that were reactivated from older crustal or basement structures (Lindholm, 1978).

Joint sets in New England are commonly independent of rock type and local foliation cleavages, but tend to parallel fault patterns in the Champlain and Connecticut Valleys. Like the faults, joints in the Connecticut River basin appear to be inherited from older, deep-crustal anisotropies that propagated into Mesozoic rocks (Wise, 1982). An extensional E-W joint set in the Champlain

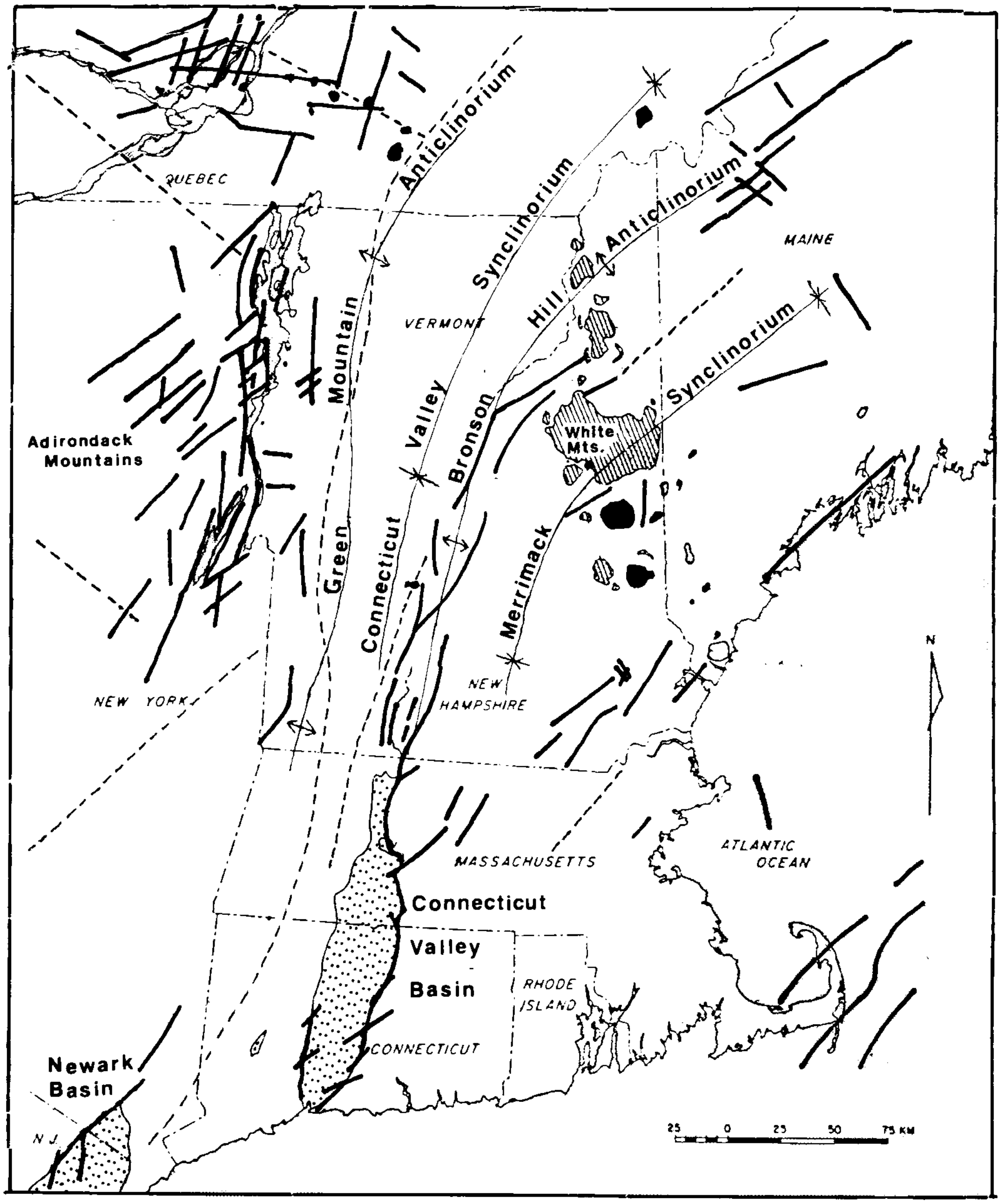

FIGURE 2. Mesozoic (?) high-angle faults (heavy lines), selected geophysical lineaments (dashed lines), and major fold axes of the New England region.

Valley of Vermont is parallel to the major Cretaceous dike trend (McHone, 1987), but Champlain Valley joints can also be related to Paleozoic tectonism (Stanley, 1974).

At many Mesozoic dike localities in New England, joint intensity increases nearer the intrusion, presumably a measure of strain during extension and magma movement, if not outright faulting. In some cases, sets of joints parallel to dike swarms show other signs of extension, such as quartz and dike fillings, and open spaces. Shearing and offset of dike-filled fractures are not common, occurring in less than ten percent of dikes observed by McHone (1978). Most areas of New England have more joint sets than major dike trends, although some areas have several major and minor dike trends that follow different joint sets. It seems likely that dikes and many joints formed independently but contemporaneously, controlled by the same stresses acting upon near-vertical anisotropies in the crust.

GEOPHYSICAL LINEAMENTS

Gravity and magnetic lineaments in New England also show N-S and NE orientations. A portion of the well-known Appalachian gravity high is expressed in a sharp, N-S gradient that underlies the Green Mountains of Vermont (Figure 2). The Appalachian gravity high also approximates the western limit of most Mesozoic sedimentary basins and dolerite dike swarms of eastern North America (King, 1971), even where it turns north in New England. In the covered basement model of Cook and Oliver (1981), the Appalachian gravity high marks an interface between ancient continental and oceanic crusts. Previously, Diment (1968) proposed that the gravity high records a high-angle fault that brings mantle or ocean-like basement rocks nearer the surface east of the Green Mountains.

In either of the above models, the gravity high locates a major, high-angle basement anisotropy. As a strain boundary, it was active enough during Mesozoic rifting to limit the early Jurassic basins and dolerite dikes to the eastern side of the Appalachians. Because the dolerites represent mantle-derived melts, this strain boundary may extend through the lithosphere.

Another magnetic and gravity high has been traced from Alabama to eastern New York by King and Zietz (1978). This lineament shows no conformability with the arcuate pattern of the western Appalachian rocks. It is not generally traced through Vermont because of the overwhelming effects of the gravity and magnetic pattern of the Green Mountains (King and Zietz, 1978), but the lineament reappears on geophysical maps of eastern New Hampshire and northeastern Maine (Figure 2; Zietz and others, 1980; Haworth and others, 1981). The New York-Alabama lineament can be interpreted as a major break, perhaps a strike-slip fault, within the eastern North America basement (King and Zietz, 1978, p. 315).

West of New England, Diment and others (1980) have described a widely-spaced set of magnetic and gravity lineaments that trend nearly perpendicular to the New York-Alabama lineament (including lines E and F of Figure 1). Other than being breaks in geophysical patterns, the physical nature of these lineaments is not clear. However, Parrish and Lavin (1982) suggest that the lineaments represent fracture zones, partly because their intersections with borders of the Rome Trough in the basement of the Appalachian Plateau are locations for Mesozoic kimberlite intrusions. This model is similar to emplacement controls suggested by Haggerty (1981) for kimberlites in western Africa.

TOPOGRAPHIC LINEAMENTS

Several studies of topographic lineaments have been completed in the New England area, most recently by Wise (1976), Green (1977), Isachsen and others (1983), Barosh (1986), and Fakundiny (1986). The work emphasizes correlations of topographic lineaments with faults, fractures, and lithologic contacts. Shake and McHone (1987) have made a new study of topographic lineaments for central New England (mainly Vermont and New Hampshire), utilizing both a LANDSAT satellite image and plastic relief maps. Figure 3 represents lineaments longer than 20 km that were traced from the satellite image.

Lineaments in Figure 3 can be grouped into three general trends that vary in abundance across the study area. In the western portion (mainly the Adirondacks of New York) lineaments trend generally northeast, with a few east-west (essentially as determined independently by Isachsen and others, 1983 and Fakundiny, 1986). Many of these lineaments represent faults and fracture zones in Grenvillian basement rocks. Long lineaments trend generally north-south to slightly east of north in Vermont, and correlate with Paleozoic thrust-fault terminations and major fold hinges (discussed recently by Stanley and Ratcliffe, 1985). New Hampshire is dominated by both NE and NW-trending lineaments (Figure 3). The NE-trending lines generally conform to the regional fault patterns, some of which are Mesozoic, but the NW-trending lines have no obvious correlation with local geology.

Two very long topographic lineaments transect north-central New England and are shown separately on Figure 1, along with several adjacent lines that are parallel but shorter. The most distinct of these (also mapped by Wise, 1976 and Barosh, 1986) extends southeasterly from Burlington, Vermont, along the Winooski and Waits River Valleys, dissecting the Green Mountains and eastern Vermont topography. The line continues unbent into New Hampshire as stream valleys, becomes the southwestern edge of Lake Winnipesaukee, and runs into the northern part of Great Bay near Portsmouth (Figures 1 and 3). This lineament coincides with the remarkably straight northeastern border of the middle Jurassic Belknap plutonic complex of New Hampshire, separating the pluton from a ring dike that underlines southern Lake

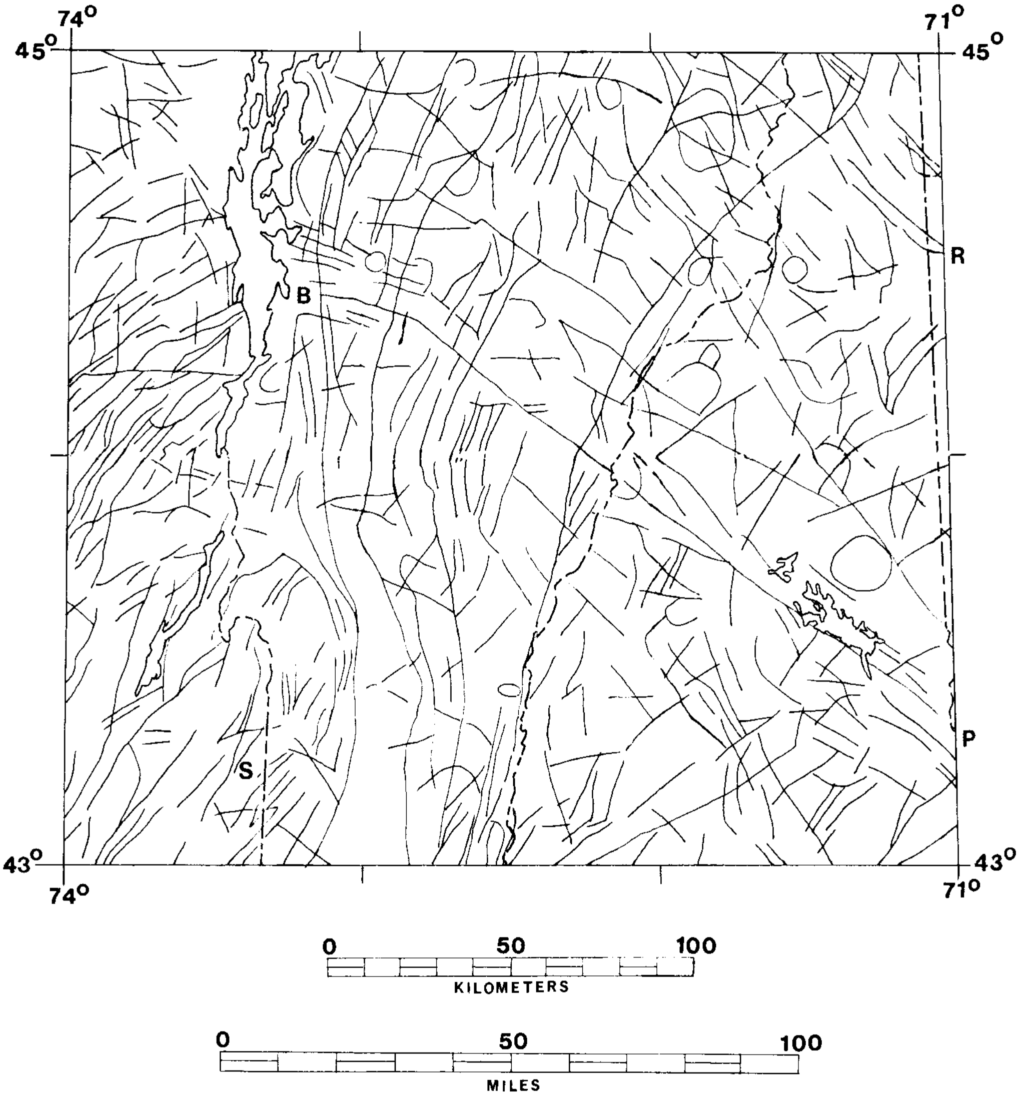

FIGURE 3. Topographic lineaments greater than 20 km long in part of central New England, as observed on a LANDSAT-1 image. B and P mark ends of the Burlington-Portsmouth lineament, and S and R mark the Salem-Rangeley lineament (also shown on Figure 1). Adapted from Figure 6 of Shake and McHone (1987).

Winnipesaukee (Billings, 1956). Intrusive breccias are present along the Burlington-Portsmouth lineament near its end-member cities (McHone and Williams, 1985). Geophysical anomalies and intensive zones of fracturing are known along the lineament in New Hampshire (F. Birch, pers. comm. 1983).

The Burlington-Portsmouth lineament is co-linear with geophysical lineament E (Figure 1) of Diment and others (1980) to the northwest of Vermont. Similar geophysical and topographic cross-trending lineaments have been described elsewhere in the Appalachians by Wheeler (1980), Parrish and Lavin (1982), Bevis (1983), Palmquist and Pees (1984), and others. The cross-lineaments are generally zones of intense fracturing ("cross-strike structural discontinuities"), perhaps caused by deep breaks in the Appalachian basement that propagated upward through the crust and allochthonous terranes, and also horizontally across the mountain belts.

The second major lineament is a less distinct topographic line of valleys and abrupt changes in relief between Salem, New York and northeast across Vermont at least to Rangeley, Maine (Figure 1). The line is shown as a zone of shorter segments in the satellite image (Figure 3) and with various levels of continuity in observations of radar and plastic relief maps. In Vermont, the line includes stream valleys and part of the Ottauquechee River Valley, bends more northward at the Connecticut River Valley for about 15 km, and continues across New Hampshire as the northwesterly topographic break of the White Mountains and Mahoosuc Range. Igneous breccias are found at two sites in Vermont along the Salem-Rangeley lineament (Figure 1), including the mantle xenolith-rich North Hartland dike (Williams and McHone, 1984). Mesozoic high-angle faults occur along the lineament in New Hampshire, creating mineralized zones (Cox, 1970) and offsetting a dolerite dike recently dated as 175 +/- 6 Ma (McHone, 1984).

As shown in Figure 3, NE-trending lineaments are rare northwest of the Salem-Rangeley lineament in northern Vermont and New Hampshire, but are relatively common southeast of the line. Early Jurassic dolerite dikes are extremely abundant along and southeast of the lineament in New Hampshire, and are uncommon to the northwest of the line in Vermont and northern New Hampshire. In addition, early Cretaceous lamprophyre dikes change trend across a narrow zone along this lineament, from WNW and E-W in southern Quebec and northwestern Vermont, to NE along and southeast of the lineament in southern Vermont and most of the rest of New England (McHone, 1984). These trends are generalized in Figure 1. The Salem-Rangeley lineament therefore marks a tectonic strain boundary for extension of NE-trending fractures during both Jurassic and Cretaceous magmatic events. It may also have acted as a physical boundary for part of the early Jurassic White Mountain batholith.

TECTONIC MODEL

Tectonic and magmatic patterns in New England, although a complex picture, provide important information about the Mesozoic history of the region. This study supports a model in which ancient vertical boundaries, fractures, or other inhomogeneities in the basement crust of New England were reactivated by extension and/or minor shearing during early Jurassic and early Cretaceous rifting of the central and northern North Atlantic basin (McHone and Butler, 1984). Fracturing of the upper crust over these tectonic zones produced jointing and subsequent erosion that formed topographic lineaments. Dike orientations and pluton arrangements in eastern and southern New England appear to be controlled by NE-trending fractures and N-S-trending structures underlying lineaments, especially for the early Jurassic intrusions. The early Cretaceous intrusions of northwestern New England and southern Quebec are aligned with E-W to WNW faults and lineaments.

As the first mid-Atlantic Ocean divergent ridges formed along Appalachian-parallel structures in the lithosphere, new (early Jurassic) crust accreted onto the eastern margin of the North American plate. Preexisting cross-trending fracture zones became terminations of new ridge transforms and ocean fracture zones, a process of lateral inheritance. NW-SE extension during rifting of the Northern Appalachians produced dike swarms east of the Appalachian gravity lineament and also southeast of the Salem-Rangeley lineament in New England. Structural basins and WMMS plutons, however, formed along deep north-south crustal structures that were activated in combination with the NE-trending fractures that paralleled the dikes.

The younger NEQ and New England seamount magmas intruded in response to plate motions and attendant shifts in stress patterns, activating the NW-trending cross fractures at deep levels of the lithosphere. Plutons and breccia dikes formed along fractures and intersections of faults and fracture zones that are partly expressed as topographic lineaments. Rather than being the relicts of an independent mantle plume, the New England seamounts were produced along fracture zones that gradually propagated into the ocean crust from parental fractures in the continental basement rocks.

REFERENCES

Barosh, P.J., 1986, 'Structural interpretation of magnetic and gravity data of New England -case histories.' In: *Proceedings of the 5th International Conference on Basement Tectonics.* S. Riad, D.L. Barrs (eds.). Salt Lake City, International Basement Tectonics Association, p. 245-257.

Billings, M.P., 1956, 'The geology of New Hampshire. Part II. Bedrock geology.' *New Hampshire State Planning and Development Commission,* 203 p.

Bevis, M., 1983, 'Megafracture systems and the allochthonous nature of mountain belts.' EOS, *Transactions of the American Geophysical Union,* v.**64**, p. 318.

Chapman, C.A., 1968, 'A comparison of the Maine coastal plutons and the magmatic complexes of New Hampshire.' In: *Studies of Appalachian geology: Northern and maritime.* E-an Zen and others (eds.), New York, Interscience, p. 385-398.

Cook, F.A. and J.E. Oliver, 1981, 'The Late Precambrian - Early Paleozoic continental edge in the Appalachian orogen.' *American Journal of Science,* v. **281**, p. 993-1008.

Cox, D.P., 1970, 'Lead-zinc-silver deposits related to the White Mountain plutonic series in New Hampshire and Maine.' *U.S. Geological Survey Bulletin,* v. **1312 D**, 18 p.

Crough, S.T., 1981, 'Mesozoic hotspot epeirogeny in eastern North America.' *Geology,* v. **9**, p. 2-6.

de Boer, J.Z., 1967, 'Paleomagnetic-tectonic study of Mesozoic dike swarms in the Appalachians.' *Journal of Geophysical Research,* v. **72**, p. 2237-2250.

Diment, W.H., 1968, 'Gravity anomalies in northwestern New England.' In: *Studies of Appalachian geology: Northern and maritime.* E-an Zen and others (eds.), New York , Interscience. p. 399-414.

Diment, W.H., O.H. Muller and P.M. Lavin, 1980,'Basement tectonics of New York and Pennsylvania as revealed by gravity and magnetic studies.' In: *Proceedings "The Caledonides in the USA", IGCP Project 27: Virginia Polytechnic Institute Memoir 2.* D.R. Wones, (ed). p. 221-228.

Duncan, R.A., 1984, 'Age progressive volcanism in the New England Seamounts and the opening of the central Atlantic Ocean.' *Journal of Geophysical Research,* v. **89**, no. **B12**, p. 9980-9990.

Fakundiny, R.H., 1986, 'Trans-Adirondack Mountains structural discontinuities.' In: *Proceedings of the 6th International Conference on Basement Tectonics.* M.J. Aldrich, and A.W. Laughlin (eds.), Salt Lake City, International Basement Tectonics Association. p. 64-75.

Foland, K.A. and H. Faul, 1977, 'Ages of the White Mountain intrusives - New Hampshire, Vermont and Maine.' *American Journal of Science,* v. **277**, p. 888-904.

Green, J.W., 1977, 'The relevance of linear features found on LANDSAT imagery of New Hampshire. (M.A. thesis), Hanover, Dartmouth College, 70 p.

Haggerty, S.E., 1982, 'Kimberlites in western Liberia: An overview of the geological setting in a plate tectonic framework.' *Journal of Geophysical Research,* v. **87**, p. 10,811-10,826.

Haworth, R.T., D.L. Daniels, H. Williams and I. Zeitz, compilers, 1980, 'Bouguer gravity anomaly map of the Appalachian orogen.' St. John's, Memorial University of Newfoundland, Scale 1;1,000,000.

Hurtubise, D.O., J.H. Puffer and H.L. Cousminer, 1987, 'An offshore Mesozoic igneous sequence, Georges Bank basin, North Atlantic.' *Geological Society of America Bulletin,* v. **98**, p. 430-438.

Isachsen, Y.W., 1975, 'Possible evidence for contemporary doming of the Adirondack Mountains, New York.' *Tectonophysics.* v. **29**, p. 169-181.

Isachsen, Y.W., E.P. Geraghty and R.W. Wiener, 1983, 'Fracture domains associated with a neotectonic, basement-cored dome - the Adirondack Mountains, New York.' In: *Proceedings of the 4th International Conference on Basement Tectonics.* R.H. Gabrielson, and others (eds.), Salt Lake City, International Basement Tectonics Association, p. 287-306.

King, P.B., 1971, 'Systematic pattern of Triassic dikes in the Appalachian region: Second report.' *U.S. Geological Society Professional Paper,* no. **750-d**, p. 84-88.

King, E.R. and I. Zietz, 1978, 'The New York - Alabama lineament: Geophysical evidence for a major crustal break in the basement beneath the Appalachian basin.' *Geology,* v. **6**, p. 312-318.

Kumarapeli, P.S. and V.A. Saull, 1966, 'The St. Lawrence Valley system: A North American equivalent of the East African rift system.' *Canadian Journal of Earth Science,* v. **3**, p. 639-658.

Lindholm, R.C., 1978, 'Triassic-Jurassic faulting in eastern North America: A model based on pre-Triassic structures.' *Geology,* v. **6**, p. 365-368.

Lyons, J.B. and J. Snellenburg, 1971, 'Dating faults.' *Geological Society of America Bulletin,* v. **82**, p. 1749-1752.

MacIntyre, R.M., 1977, 'Anorogenic magmatism, plate motion, and Atlantic evolution.' *Journal of the Geological Society of London,* v.**133**, p. 375-384.

May, P.R., 1971, 'Pattern of Triassic-Jurassic diabase dikes around the North Atlantic in context of predrift position of the continents.' *Geological Society of America Bulletin,* v. **82**, p. 1285-1291.

McHone, J.G., 1978, 'Distribution, orientations, and ages of mafic dikes in central New England.' *Geological Society of America Bulletin,* v. **89**, p. 1645-1655.

____, 1982, 'Mesozoic rifting in northern New England.' *Geological Society of America Abstracts with Programs,* v. **14**, p. 40.

____, 1984, 'Mesozoic igneous rocks of northern New England and adjacent Quebec.' *Geological Society of America Map and Chart Series,* **MC-49**, map with 5 p. text.

____, 1987, 'Mesozoic intrusions and rift features in the Champlain Valley of Vermont.' *Montpelier, New England Intercollegiate Geological Conference Field Guide,* In press.

McHone, J.G. and J.R. Butler, 1984, 'Mesozoic igneous provinces of New England and the opening of the North Atlantic Ocean.' *Geological Society of America Bulletin,* v. **95**, p. 757-765.

McHone, J.G. and J.C. Trygstad, 1982, 'Mesozoic mafic dykes of Southern Maine.' *Maine Geology,* Bull. **2**, p. 16-32.

McHone, J.G., M.E. Ross and J.D. Greenough, 1987, 'Mesozoic dyke swarms of eastern North America.' In: *Mafic dyke swarms: Geological Association of Canada Special Paper,* no. **33**, in press.

McHone, J.G. and N.A. Williams, 1985, 'Tectonic setting of xenolith-rich alkalic intrusions in New England and southern Quebec.' *Geological Society of America Abstracts with Programs,* v. **17**, p. 167.

Morgan, W.J., 1981, 'Hotspot tracks and the opening of the Atlantic and Indian Oceans.' *The Sea,* v. **7**, p. 443-488.

Palmquist, J.C. and S.T. Pees, 1984, 'Lineaments from LANDSAT imagery and topographic maps in the northern Appalachian basin.' *Northeastern Geology,* v. **6**, p. 65-69.

Parrish, J.B. and P.M. Lavin, 1982, 'Tectonic model for kimberlite emplacement in the Appalachian Plateau of Pennsylvania.' *Geology,* v. **10**, p. 344-347.

Philpotts, A.R., 1970, 'Mechanism of emplacement of the Monteregian intrusions.' *Canadian Mineralogist,* v. **10**, p. 395-410.

Rankin, D.W., 1976, 'Appalachian salients and recesses: Late Precambrian continental breakup and opening of the Iapetus Ocean.' *Journal of Geophysical Research,* v. **81**, p. 5606-5619.

Sanders, J.E., 1963, 'Late Triassic tectonic history of northeastern United States.' *American Journal of Science,* v. **261**, p. 501-524.

Shake, S.N. and J.G. McHone, 1987, 'Topographic lineaments and their geologic significance in central New England and adjacent New York.' *Northeastern Geology,* v. **9**, in press.

Stanley, R.S., 1974, 'Environment of deformation, Monkton Quartzite, Shelburne Bay, western Vermont.' *Geological Society of America Bulletin,* v. **85**, p. 233-246.

_____, 1980, 'Mesozoic faults and their environmental significance in western Vermont.' *Vermont Geology,* v. **1**, p. 22-32.

Stanley, R.S. and N.M. Ratcliff, 1985, 'Tectonic synthesis of the Taconian orogeny in western New England.' *Geological Society of America Bulletin,* v. **96**, p. 1227-1250.

Thomas, W.A., 1983, 'Continental margins, orogenic belts and intracratonic structures.' *Geology,* v. **11**, p. 270-272.

Vogt, P.R. and B.E. Tucholke, 1978, 'The New England seamounts: Testing origins.' *Initial Reports of the Deep Sea Drilling Project,* v. **43**, U.S. Government Printing Office, p. 847-856.

Weigand, P.W. and P.C. Ragland, 1970, 'Geochemistry of Mesozoic dolerite dikes from eastern North America.' *Contributions to Mineralogy and Petrology,* v. **29**, p. 195-214.

Wheeler, R.L., 1980, 'Cross-strike structural discontinuities: Possible exploration tool for natural gas in Appalachian overthrust belt.' *American Association of Petroleum Geologists Bulletin,* v. **64**, p. 2166-2178.

Willems, H.X., W. Bosworth and G.W. Putnam, 1983, 'Evidence for complex strain history of the MacGregor fault, eastern Adirondacks: A possible reactivated Late Precambrian rift structure.' *Geological Society of America Abstracts with Programs,* v. **15**, p. 124.

Williams, N.A. and J.G. McHone, 1984, 'Mantle and crustal xenoliths from the North Hartland dike, Vermont.' *Geological Society of America Abstracts with Programs,* v. **16**, p. 71.

Wise, D.U., 1982, 'New fault and fracture domains of southwestern New England: Hints on localization of the Mesozoic basins.' In: *Geotechnology in Massachusetts,* Farquhar, O.C. (ed.), Amherst, University of Massachusetts Graduate School. p. 447-454.

____, 1976, 'Sub-continental sized fracture systems etched into the topography of New England.' In: *Proceedings of the First International Conference on the New Basement Tectonics,* R.A. Hodgson and others (eds.). Salt Lake City, International Basement Tectonics Association. p. 416-422.

Zietz, I., F.P. Gilbert and J.R. Kirby, J.R., 1980, 'Aeromagnetic map of Connecticut, Massachusetts, New Hampshire, Vermont, Rhode Island and part of New York.' *U.S. Geological Survey Map GP-928.* Scale 1:1,000,000.