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Mesozoic mafic dikes of southern Maine

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ABSTRACT

Approximately 60 lamprophyre and dolerite dikes in southern Maine were mapped and examined as part of a regional study of post-metamorphic dikes in New England. The Maine dikes trend mainly around N30E, with a secondary maximum near N60E. The dolerite dikes are Early Jurassic and older, while both Early Jurassic and Early Cretaceous lamprophyre dikes are present.

The dolerite dikes are the more abundant type present. Minerals and textures vary, but the dolerites are predominantly fine-grained, porphyritic rocks consisting of labradorite, augite (+/- bronzite), olivine and opaque minerals. They are chemically and mineralogically more like alkali olivine basalts than like the quartz tholeiites common in southern New England. The dolerites are often altered, in contrast with the usually fresh textures which characterize the camptonite or the more rare monchiquite lamprophyres. The camptonite dikes are basanitic rocks which contain plagioclase, augite, olivine or kaersutite, analcime, calcite, and opaque minerals. The monchiquites are more nephelinitic, nearly lacking feldspar, but otherwise have mineralogies similar to camptonite.

The dikes represent basaltic magmas derived by partial melting of the mantle during Atlantic rifting events. Their compositional variations are due to different depths and degrees of partial melting, and to magmatic differentiation during their rapid intrusion into shallow crustal fractures.

INTRODUCTION

Few persons walk along the rock-bound coast of Maine without noting the dark bands of igneous dikes crossing the generally light-colored country rocks. Geologists in the late 1800's described some of the varieties of dikes present, but they were unable to make firm conclusions concerning the origins, ages, and genetic relationships of the magmas.

New ideas connecting plate tectonics with the origins of magmas have stimulated some wide-ranging studies of magma provinces in eastern North America by de Boer (1967, 1968), Weigand and Ragland (1970), May (1971), Foland and Faul (1977), McHone (1978b), and Crough (1981). Our graduate work (McHone, 1978a; Trygstad, 1979) surveyed the Mesozoic dikes of a large part of New England. We attempted to fill in some of the substantial gaps in the literature data, and then develop the most reasonable model for the origins of the New England magma suites. Our model is not yet complete, but we shall describe in this paper some of the varieties, ages, physical characteristics, petrography, and chemistry of southern Maine dikes, and follow with a suggestion for their origin.

DISTRIBUTION

Dikes are more prolific along the coastal area of Maine than in most of inland New England. The number of coastal examples must certainly exceed 1000, and several hundred others can be found in roadcuts, quarries, and natural exposures in the rest of Maine. The true variations in dike abundance across the region is masked by the uneven pattern of bedrock exposures, with outcrops more extensive along the shore than inland.

We visited dikes mentioned in the geologic literature of southern Maine, and we also located many other occurrences along the coast, Interstate 95, and state highways. A total of 59 dikes were measured and sampled. A much more comprehensive sampling program is needed before definitive statements can be made concerning all of the varieties and orientations of southern Maine dikes. However, we feel secure in our characterizations of the major groups present, especially in comparison with dikes elsewhere in northern New England. Figure 1 shows the locations and orientations (where measured) of the sampled dikes.

Dolerites make up 42 of the samples, and lamprophyres the other 17. We estimate that dolerites are actually 5 to 8 times more common than lamprophyres in southern Maine, based on our cursory reconnaissance and on descriptions in the literature. Felsic dikes are rare and were not studied. Mafic dikes are also abundant to the south along coastal areas of New Hampshire and Massachusetts, and are common inland throughout New Hampshire and Vermont (McHone, 1978b). Post-metamorphic dikes are less numerous along I-95 northeast of Lewiston, and also may be somewhat less abundant along the shoreline north of Portland. The dike groups of southern Maine are subsets of magma provinces which sweep across much of New England and adjacent Quebec.

APPEARANCE

Most dikes in southern Maine are between 0.5 m and 2 m in width (although a few range to greater than 7 m), and are dark gray to rusty-brown in color. Although the dike exteriors may be rusty, the interiors are usually unweathered because most of the exposures result from recent excavations or are in highly-eroded seashore and glaciated outcrops. Deuteric alteration of the dike minerals sometimes creates a slightly greenish cast to the rocks; feldspar-rich examples generally exhibit gray-green plagioclase phenocrysts which weather to a buff-white color.

Coastal dikes often differentially erode to form narrow gulleys or trenches (Figure 2). Some develop underwater pockets or caves which may connect with "blow-holes" as at Kennebunkport. The coastal dikes commonly have a very rough, black surface which is not seen on inland dikes, apparently the result of a chemical reaction produced by marine organisms

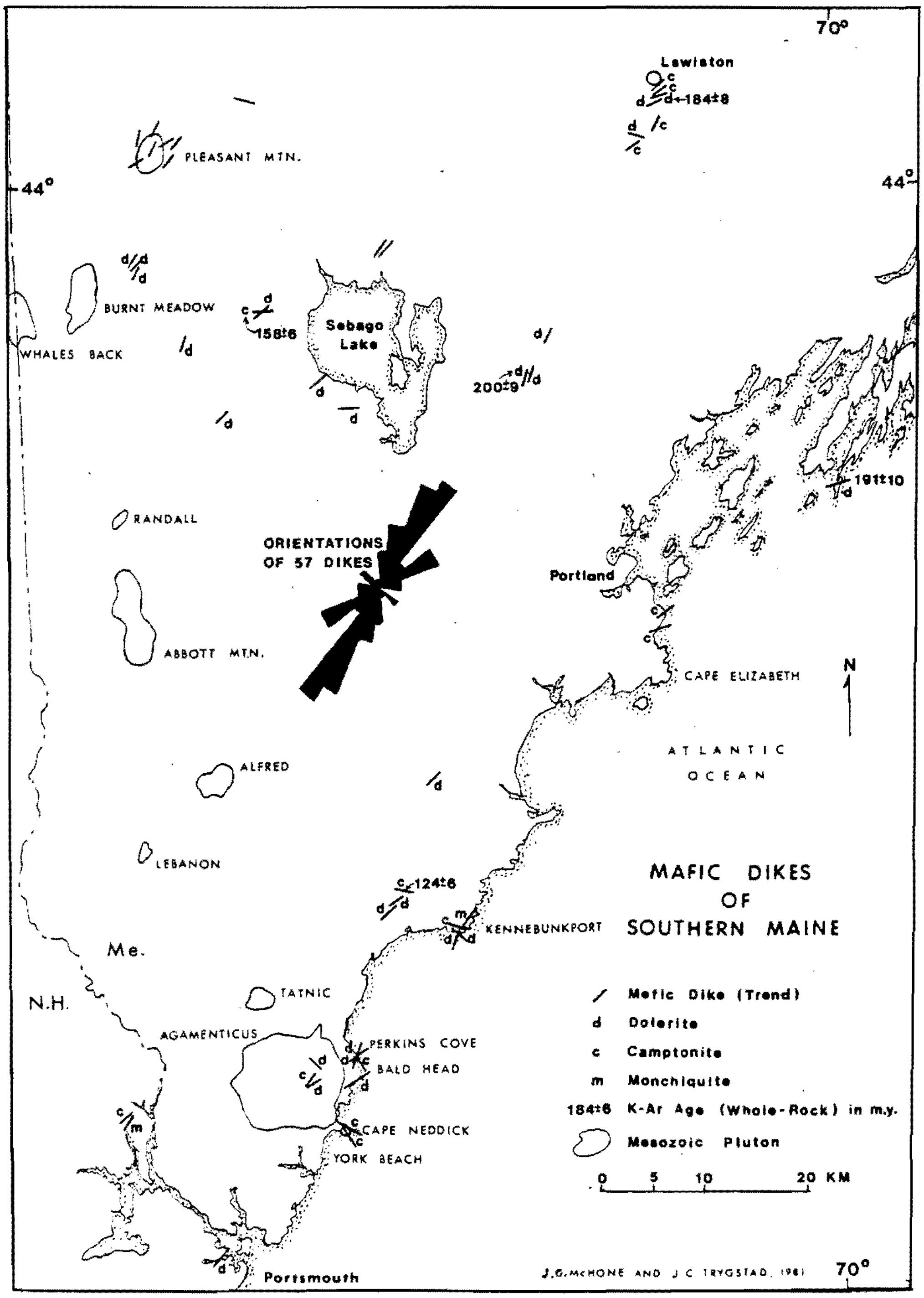

Figure 1. Locations of mafic dikes in southern Maine.

or seawater.

Many of the dikes are so fine-grained that their classification can only be made via thin section. Even then, altered samples may lack recognizable primary minerals, inhibiting our principle means of identification. In general, hand samples with phenocrysts of plagioclase are classified as dolerites, and samples with only mafic phenocrysts (augite or amphibole) are called lamprophyres. Both groups commonly contain calcite-filled amygdules, but only lamprophyres may display the pink globules of felsic material called ocelli. Many lamprophyres weather to an earthy-brown surface, while dolerites commonly appear smooth, gray, and flinty. However, we often found it necessary to reclassify field samples after observation (and discussion) of their petrographic characteristics.

ORIENTATIONS AND AGES

Most of the dikes measured have trends within 10^0 of N30E, and a smaller group trends N60E. The measurements are plotted as a rose diagram in Figure 1. Northeasterly trends are very common for dolerite dikes all across New England, but most lamprophyre dikes in northwestern Vermont and adjacent Quebec have east-west to west-northwest trends. Because they follow local fracture sets, individual dikes may be observed in almost any orientation (usually with high dip angles), but the major northeasterly trend in Maine is apparent even with our limited sample population.

Because lamprophyres in northwestern Vermont have Early Cretaceous ages and trend east-west, McHone (1977) suggested that Early Cretaceous lamprophyres across New England might all belong to a unified, east-west dike province. The northeast-trending dikes were expected to mainly represent an Early Jurassic dolerite province, similar to the basaltic dikes of the Triassic-Jurassic basin in Massachusetts and Connecticut (King, 1961).

Our subsequent correlations of trends with dike types show that most lamprophyre dikes in New Hampshire and Maine also trend northeasterly. The relatively small number of dated lamprophyres have unfortunately been selected from those examples which do trend east-west, and they yield Late Jurassic to Early Cretaceous ages. The dated dolerites are dikes with northeasterly trends, and they all have Early Jurassic or Triassic ages (McHone, 1978b). Dated dike localities in southern Maine are shown in Figure 1.

Dikes at the Lewiston city quarry (described by Merrill, 1892 and Fisher, 1941) are particularly helpful in that they represent a single series of intrusions with members gradational between lamprophyre (camptonite) and olivine dolerite, with both types well represented. The dikes are northeast-trending. One of the dolerites has been dated as 184 ± 8 m.y. old (McHone, 1978b), and Fisher (1941) mentioned another date of 170 ± 8 m.y. for a Lewiston dike, so in this area it seems likely that lamprophyres as well as dolerites have the Early Jurassic ages expected of northeasterly dikes.

If east-west lamprophyres are an Early Cretaceous generation, they apparently are a very minor group in Maine. Until more radiometric analyses are available, we will not know whether the Early Cretaceous magmas include northeast-trending dikes. However, because of their radiometric ages and because dolerite dikes are rarely (never?) found crosscutting Early Cretaceous plutons or lamprophyre dikes in New England, it is likely that the dolerite dikes of Maine are confined to Early Jurassic or older magmatic episodes.

PETROGRAPHY OF THE DOLERITES

Dolerite dikes in southern Maine are most commonly fine-grained, intergranular to isogranular, porphyritic rocks with varying amounts of small-to-medium sized plagioclase, pyroxene, and olivine phenocrysts. Approximately one-third of the dikes are characterized by olivine and plagioclase phenocrysts. Euhedral and subhedral labradorite (identified by microprobe analysis) tends to be zoned. This zoning is occasionally truncated (Figure 3), implying sudden decrease in confining pressure caused by rapid injection of dike magma. Olivine phenocrysts are typically, although not universally, altered, and skeletal (resorbed?) grains of olivine are often found in the same dike with euhedral olivine. Microprobe analyses of two fresh olivine grains show compositions around Fo80-84 (Table 1, nos. 3 and 4).

Phenocrysts tend to increase in abundance from dike contacts to centers. Overall, the dikes range from 3% to 26% phenocrysts (visual estimate). Groundmass minerals include labradorite, colorless-to-pink titaniferous augite with some ferroaugite possible, olivine (?), opaque minerals (probably magnetite or ilmenite, often replaced by iron sulfide), and very minor (less than 1%) brown hornblende.

Most of the dikes are amygdaloidal, with rounded to subrounded amygdules averaging 0.7 mm in diameter. They are filled with carbonate and often rimmed with green chlorite, which in turn may be surrounded by a red-brown phyllosilicate mineral. An epidote-group mineral, possibly zoisite, is often present. The vesicles, the epidote, and the carbonate and phyllosilicate minerals are probably associated with deuteric processes. Microfractures in the dikes are filled with carbonate, and we believe these, too, have been formed by deuteric processes.

Another third of the dolerite samples contain pyroxene as well as olivine and plagioclase phenocrysts. Typically, phenocrysts make up 10% to 20% of the volume of these dikes, increasing from dike edge to center. Labradorite is sometimes seen with truncated zoning, and is occasionally "jacketed" by augite. Orthopyroxene phenocrysts (bronzite according to microprobe analysis no. 2 in Table 1) are relatively abundant, although they have not been identified previously in modern studies of eastern North American dolerites. Fresh bronzite phenocrysts occur in three Kezar Falls dikes (Figure 4), and are probably present in dikes at York Beach. The "enstatite porphyry diabase" from Cape Elizabeth, described by Lord (1898), may represent another dike of this group. Additional dikes with similar-looking but heavily altered grains are suspected to have had bronzite phenocrysts. The alteration appears to have progressed along grain boundaries and fractures. The alteration mineral may be antigorite, but it

TABLE 1. MICROPROBE ANALYSES OF MAINE DIKE MINERALS

	1	2	3	4	5	6	7	8	9
					WEIGHT PER CENT				
SiO_2	51.09	43.25	40.23	39.17	55.38	51.54	47.13	38.18	54.73
TiO_2	0.81	0.54	0.09	0.10	0.11	0.16	2.28	5.54	0.03
Al_2O_3	1.50	2.30	0.00	0.00	27.83	29.78	6.95	12.19	21.22
FeO*	14.49	13.13	14.98	18.70	0.52	0.50	7.22	14.90	0.00
MnO	0.47	0.29	0.18	0.16	0.01	0.00	0.27	0.23	0.01
MgO	10.91	28.94	43.74	40.83	0.09	0.12	13.04	9.56	0.00
CaO	20.55	2.45	0.17	0.19	11.33	14.26	22.23	12.09	0.02
Na_2O	0.52	0.00	0.00	0.01	4.67	3.63	0.74	2.41	14.46
K_2O	0.00	0.00	0.00	0.00	0.30	0.26	0.00	1.14	0.11
Total	100.34	100.90	99.39	99.16	100.24	100.27	99.86	96.24**	90.58**
					CATIONS PER ( ) OXYGENS				
	(6)	(6)	(4)	(4)	(8)	(8)	(6)	(23)	(6)
Si	1.948	1.898	1.014	1.008	2.495	2.349	1.765	5.887	2.038
Ti	0.067	0.097	0.002	0.000	0.004	0.006	0.307	0.642	0.001
Al	0.023	0.014	0.000	0.002	1.478	1.599	0.064	2.215	0.931
Fe^{+2}	0.462	0.391	0.316	0.403	0.019	0.019	0.226	1.921	0.000
Mn	0.015	0.009	0.004	0.004	0.000	0.000	0.008	0.030	0.000
Mg	0.620	1.537	1.649	1.567	0.006	0.008	0.728	2.196	0.000
Ca	0.840	0.094	0.004	0.005	0.547	0.696	0.894	1.998	0.001
Na	0.038	0.000	0.000	0.000	0.408	0.321	0.054	0.721	1.044
K	0.000	0.000	0.000	0.000	0.017	0.015	0.000	0.224	0.005
Total	4.013	4.040	2.984	2.989	4.974	5.013	4.044	15.834	4.020

* total Fe as FeO ** less volatiles

1. Augite, center of phenocryst, dolerite dike KP-9, Kennebunk.
2. Bronzite, center of phenocryst, dolerite dike KF-3K, Brownfield.
3. Olivine, center of phenocryst, dolerite dike LW-6, Lewiston.
4. Olivine, edge of phenocryst, dolerite dike LW-6, Lewiston.
5. Labradorite, center of phenocryst, dolerite dike KF-3B, Brownfield.
6. Labradorite, matrix grain, camptonite dike KP-3, Kennebunkport.
7. Augite, edge of phenocryst, camptonite dike KP-3, Kennebunkport.
8. Kaersutite, center of phenocryst, camptonite dike KP-3, Kennebunkport.
9. Analcime, grain in ocellus, camptonite dike KP-3, Kennebunkport.

was not positively identified.

Glomerophenocrysts are common in this group of dikes, with diverse combinations including all augite, all olivine, augite plus olivine, augite plus labradorite, and augite plus olivine plus labradorite. Although the augite phenocrysts are colorless, augite in the groundmass is quite pink. The groundmass mineralogy of this group closely resembles that described above, with the following exceptions: traces of brown biotite may occur with the minor brown hornblende; olivine (altered) is present; and groundmass orthopyroxene may be present (at Kezar Falls localities).

Amygdules are common. One dike, from the Lewiston city quarry, is unusually amygdaloidal (up to 50% by volume). Only 31 cm wide, the dike is either a multiple injection or exhibits extensive flow banding. Euhedral phenocrysts are mutually aligned and amygdules occur in bands parallel to this alignment. Other dikes in this dolerite group do not commonly exhibit flow banding. The same deuteric minerals are present regardless of presence or absence of flow banding.

The two groups described above comprise about two-thirds of the dolerites examined in this study. A smaller group of dikes is characterized by phenocrysts of only olivine and pyroxene. This group tends to have dikes trending more northerly than other dike groups, but we are uncertain as to its genetic distinction. As discussed in another section, such dikes may be transitional between dolerite and camptonite in southern Maine. Except for the phenocryst minerals, the mineralogy and textures of this group resemble those described for the first two groups.

One texture quite common for all of the above dike groups suggests two episodes of alteration in the olivine grains. A high-temperature (magmatic) alteration is proposed for the generation of dark-brown to opaque minerals replacing the outer portions of olivine grains: the centers remain fresh. A lower-temperature, more deuteric-like alteration has resulted in the complete replacement of olivine by a greenish phyllosilicate mineral or sometimes by a carbonate mineral. Both alteration types are shown in Figure 5.

The last dolerite group is represented by only four dikes. The dikes contain only plagioclase phenocrysts. While New Hampshire examples in this group exhibit some unique textures (Trygstad, 1979), the Maine examples have minerals and textures similar to those already described.

PETROGRAPHY OF THE LAMPROPHYRES

Lamprophyre dikes in southern Maine are predominantly camptonite and more rarely, monchiquite. In thin section, camptonite normally shows plagioclase only in the groundmass and never as phenocrysts, although some xenocrystic grains are observed. Blocky phenocrysts of augite up to several mm across are common, often mixed with or even subordinate to laths of kaersutite (a basaltic hornblende). Small olivine phenocrysts are generally present, in variable but minor amounts. The groundmass is commonly a mixture of plagioclase, augite, kaersutite, analcime, and calcite. Assessories include titaniferous magnetite, pyrite, sphene, and nearly ubiquitous needles of apatite. Biotite or phlogopite is present in the matrix of a few examples.

Other characteristics of camptonite (in Maine as elsewhere) include abundant amygdules up to several cm across, often 5% to 20% of the rock by volume depending upon flow segregations. The amygdules are filled with calcite, or more rarely analcime or other zeolites. Some dikes exhibit ocelli, small rounded segregations of analcime, feldspar, kaersutite, zeolites, calcite, and apatite. Most lamprophyres are porphyritic, with idiomorphic grains of both the phenocrysts and groundmass minerals. Good examples of ocelli and other lamprophyre characteristics can be found in dikes at the base of Walker's Point, Kennebunkport (Kemp, 1890).

Monchiquite is uncommon in Maine, but is identical to monchiquite from Vermont (McHone and Corneille, 1980) and elsewhere in New England. A good example is present at the base of Walker's Point in Kennebunkport, a dike which Kemp (1890) called camptonite. The rock is rich in kaersutite (as phenocrysts and groundmass minerals), and analcime is clearly more abundant than plagioclase, an important criterion. The mineralogy and textures are otherwise like camptonite.

Many camptonite dikes, including several at the Lewiston city quarry, have only minor amounts of hydrous minerals, or contain a fairly noticeable proportion of feldspar phenocrysts. Where the rocks clearly lack ocelli and primary amphibole, biotite, and/or analcime, they are classed as dolerite. Maine has many examples of dikes which appear to grade between dolerite and camptonite, a point which will be discussed in the next section.

In general, the high water and carbon dioxide contents in lamprophyre magmas have retarded the crystallization of feldspar, allowing euhedral crystals of mafic minerals to dominate the textures. Recognizable olivine grains are usually partially resorbed, or altered to chlorite, calcite, epidote, and other secondary minerals. Otherwise, the minerals of the lamprophyres appear to be primary, magmatic phases.

Electron microprobe analyses were made for minerals of only one Maine lamprophyre, a small camptonite dike which cuts across the Blow-Hole dolerite dike at Kennebunkport. The analyses (Table 1, nos. 6, 7, 8, and 9) are similar to others from lamprophyres elsewhere in New England (McHone, 1978a), and are also typical of mineral compositions from basanites and alkali basalts around the world.

Many of the camptonite dikes have plagioclase with optical characteristics close to andesine, but the available microprobe analyses show slightly more calcic compositions of labradorite (Table 1, no. 6). Augite in the dike is characterized by oscillatory zoning, becoming more Ti- and Al-rich from grain center to grain edge (Table 2, no. 7). Often the Ti imparts a rosy tint to the augite. The augite is actually very similar to augite in most of the alkali dolerites discussed above. The fact that there are more than four cations per six anionic oxygens in the unit formula indicates the presence of Fe^{+3} as well as Fe^{+2} in the crystal structures. Such an oxidizing environment probably reflects the late stages of crystallization of the dike magmas.

Amphiboles in the lamprophyres (Table 1, no. 8) easily fit Leake's (1968) classification of kaersutite, with more than 0.5 Ti atoms per formula unit, and an Mg/Mg+Fe+Mn ratio also greater than 0.5. Kaersutite is a relatively K-rich amphibole, and is ideal for K-Ar radiometric analysis. The mineral has a straw-yellow to reddish-brown pleochroism, and, like augite, crystallizes as both phenocrysts and later matrix grains.

Analcime in the lamprophyre groundmass is often mistaken for glass, but its cubic crystal form may rarely be seen in amygdules and ocelli. Devitrified glass is also present, but is confined to narrow borders along the dike margins. Analcime is easily destroyed by the electron beam in most microprobes, but number 9 in Table 1 shows a reasonable chemistry, assuming about 9% water (unanalyzed). It is one of the last minerals to crystallize and may actually form by a sub-solidus phase reaction rather than as a true liquidus precipitate.

GEOCHEMISTRY

Nine chemical analyses are available for mafic dike rocks in southern Maine (Table 2). Analyses 1, 4, 5, 6, and 8 of Table 2 were performed at the University of North Carolina as part of McHone's (1978a) dissertation work, while the other four are rather old literature analyses. Some of the literature values are of doubtful accuracy (such as MnO of nos. 2 and 3, Table 2), but in general, some useful comparisons can be made. We are not satisfied that all the varieties of mafic dikes are represented by these analyses: in particular, the more plagioclase-rich examples are missing.

Most of the analyses show compositions characteristic of alkali-olivine basalts (Table 2, no. 9), such as low SiO_2 and high K_2O, P_2O_5, and volatile contents. Although some petrologists relate high H_2O and CO_2 analyses of basalts to secondary alteration and contamination, we believe that the volatiles are mainly primary magmatic constituents when the petrology of the dike indicates no major post-magmatic alteration. We are still investigating this, however. The low volatile contents of most basalt analyses reported in the literature are the result of dehydration during volcanic extrusion, and so do not reflect true magmatic compositions (Moore, 1970). The dikes are intrusions which were sealed by glassy margins and thus retained their original volatiles.

Classified by CIPW normative mineralogies (Yoder and Tilley, 1962), the monchiquite dike (Table 2, no. 1) is an alkali basalt because it is nepheline normative, numbers 5, 8, and 9 of Table 2 are quartz tholeiites because they are quartz normative, and the other camptonite and dolerite dikes in Table 2 are olivine tholeiites (olivine-hypersthene normative). This is a common and practical system used widely in petrology, and it is valuable for comparisons among basaltic magma suites. However, analyses 2 through 8 of Table 2 are clearly alkali-rich and silica-poor relative to most tholeiites, and in fact are much like Nockold's "average alkali basalt and dolerite" (Table 2, no. 10). The analyses (except for number 9, Lord's "diabase" dike) are also clearly "alkaline" rather than "subalkaline" according to Chaye's (1975) basalt discriminant function.

TABLE 2. WHOLE-ROCK ANALYSES OF MAFIC DIKES FROM SOUTHERN MAINE

	1	2	3	4	5	6	7	8	9	10
					MAJOR OXIDES (WT. %)					
SiO_2	45.1	41.15	39.32	43.79	43.18	46.23	45.20	44.05	50.76	45.78
TiO_2	2.94	1.60	1.70	3.00	3.03	1.85	0.68	2.86	-	2.63
Al_2O_3	15.1	13.51	14.48	15.34	11.89	13.50	17.12	15.30	12.83	14.64
Fe_2O_3	3.20	2.32	2.01	-	-	-	5.98	-	4.98	3.16
FeO	6.48	8.68	8.73	10.77*	10.09*	10.64*	6.55	10.99*	10.09	8.73
MnO	0.18	1.28	0.71	0.19	0.16	0.18	-	0.31	-	0.20
MgO	6.30	10.09	11.11	5.82	8.14	7.37	5.29	5.93	6.67	9.39
CaO	7.48	8.75	8.30	9.29	9.83	9.30	7.89	6.84	9.88	10.74
Na_2O	4.36	3.21	3.76	2.99	2.19	3.04	4.23	3.46	3.52	2.63
K_2O	2.65	1.22	0.87	1.67	0.97	1.03	2.31	2.46	0.62	0.95
P_2O_5	0.81	0.61	0.61	0.65	0.46	0.38	-	0.60	-	0.39
H_2O^+	2.68	3.05	2.57	2.82	3.66	3.16	5.35	2.31	0.87	0.76
H_2O^-	0.31	-	-	0.40	1.63	0.76	-	0.41	-	-
CO_2	2.20	5.54	5.25	3.07	3.90	1.69	-	3.94	-	-
Total	99.79	100.96	99.42	99.80	99.13	99.13	100.60	99.46	100.22	100.00
					TRACE ELEMENTS (ppm)					
Rb	71	-	-	47.3	71.0	17.7	-	60.7	-	-
Sr	1244	-	-	789	515	251	-	665	-	-
Zr	416	-	-	186	203	182	-	212	-	-
Y	-	-	-	25.8	23.7	21.4	-	23.7	-	-
V	-	-	-	254	199	207	-	162	-	-
Cr	-	-	-	178	385	302	-	246	-	-
Ni	-	-	-	106	236	198	-	89	-	-
Ba	-	-	-	543	263	198	-	797	-	-

* total iron as FeO

1. Monchiquite dike, Walker's Point, Kennebunkport.
2. "Lamprophyre" dike, Lewiston city quarry (Merrill, 1892).
3. "Lamprophyre" dike, Maine Central R.R. cut, Auburn (Merrill, 1892).
4. Olivine dolerite dike, Lewiston city quarry, dated 184 ± 8 m.y.
5. Olivine dolerite dike, Rte. 115 roadcut, Gray, dated 200 ± 9 m.y.
6. Camptonite dike, I-95 roadcut, Kennebunk, dated 124 ± 6 m.y.
7. Camptonite dike, Portland Head Light, Cape Elizabeth (Lord, 1898).
8. Camptonite dike, Pond Cove, Cape Elizabeth.
9. "Enstatite porphyry diabase" dike, Cape Elizabeth (Lord, 1898).
10. "Average alkali basalt and dolerite" (Nockolds, 1954).

Lord's quartz tholeiitic dike (Table 2, no. 9) is chemically like basalts and dolerites from the Connecticut Basin in southern New England (Weigand and Ragland, 1970), a magma group which is also present in the northern New England states (McHone, 1978a). We refer to the camptonite and olivine dolerite dikes of southern Maine as members of an alkali basalt series because they appear to be chemically distinct from the quartz and olivine tholeiite dikes of Weigand and Ragland's (1970) Eastern North America (ENA) series.

Analysis 1 of Table 2 is relatively silicic for monchiquite, a type which averages closer to 40% SiO_2 in New England (McHone, 1978a). Although some are of camptonite and others of olivine dolerite, analyses 2 through 8 of Table 2 have enough variation to mask any significant differences between the two types. Camptonite dikes throughout the rest of New England are chemically similar to the camptonites and olivine dolerites of Table 2, despite age differences of 80 m.y. or more among the dikes.

The available analyses for Lewiston city quarry dikes (Table 2, nos. 2 and 4) support the petrographic evidence that at this locality, camptonite and olivine dolerite are varieties of a single magma series. Our regional studies indicate that this series is spread over much of southern Maine, New Hampshire, and eastern Massachusetts as well, and is an abundant or even predominant Early Jurassic dike group. The Early Cretaceous series apparently contains camptonite and monchiquite dikes, but not dolerites, and becomes more abundant westward into Vermont and adjacent Quebec (McHone, 1978b). Quartz tholeiitic dikes of Early Jurassic (?) age are also present, but are not as common in Maine as they are in southern New England.

DISCUSSION

The mafic dike groups of southern Maine represent magmas created during post-orogenic rifting episodes along eastern North America. The sequence of Early Jurassic alkali dolerite and camptonite followed by Early Cretaceous camptonite and monchiquite in southern Maine is paralleled by dike and plutonic intrusions across northern New England. An episode of Early Jurassic syenite-granite plutonism in New Hampshire (the classic White Mountain magma series; Foland and Faul, 1977) was followed by more widespread Early Cretaceous gabbro-syenite plutonism across northern New England and adjacent Quebec (including the Monteregian Hills). McHone (1981) proposes that the latter group of lamprophyre dikes and alkalic plutons be called the New England - Quebec (NEQ) series.

The Triassic-Early Jurassic tholeiites of New England (part of the ENA series), best known in the Connecticut Basin, apparently have no cogenetic plutonic associates. In New Hampshire and Maine, at least some of the alkali dolerites overlap in both time and space with the Mesozoic plutons, creating one of several problems facing the development of a successful model for the Maine dikes. Some important constraints are provided by the structural and chemical data available for the Maine dikes, data which must be integrated with other regional studies. Several models for the history and origins of New England Mesozoic intrusions have been discussed by Foland and Faul (1977), McHone (1978b), McHone and Corneille (1980), and Crough (1981).

The model which we are developing does not utilize a system of extensive crystal fractionation in one or a few magma chambers at some depth in the New England crust, nor does it rely on movement across a "hotspot" or mantle plume. Rather, we propose that the variety of dike types resulted from the generation of local "partial melt" magmas which rapidly ascended from their mantle sources, often as multiple intrusions. Minor gravity and flowage differentiation could be expected during their migration into the uppermost crust, and recent studies indicate that immiscible separation of liquids was not unlikely (Philpotts, 1976; 1979). Each pulse of magma resulted in the emplacement of a small swarm of dikes with a uniform trend and definite range of compositions. Eventually, a regional pattern emerged, consisting of overlapping dike swarms which may or may not be distinquishable from one another.

The initial, or "primary" compositions of the dike magmas may have varied because of heterogeneity in the mantle source rocks, different depths and temperatures at which melting occurred, and the degree of melting of the source rocks (Yoder, 1976). The tectonic environment of the lithosphere not only stimulated the production of the magmas, but also controlled their locations (via fracture zones) and their orientations (via stress patterns interacting with local fracture sets). In the southern Maine region, the predominant northeasterly dike trend indicates a northwest-southeast direction for extensional stresses during the Early Jurassic. This stress orientation may also have been present in Maine during Early Cretaceous time, unlike the more north-south extension implied for lamprophyres in Vermont and Quebec by McHone (1978b).

During Mesozoic time in New England, lithospheric rifting which initiated the opening of the adjacent Atlantic Ocean basin produced the Early Jurassic magmas, as well as fractures, faults, and structural basins along eastern North America. This activity diminished in New England by mid-Jurassic time, continuing farther east in the new ocean basin with the production of seamounts post-dating the ocean-floor basalts (Baragan and others, 1977). Atlantic rifting north from Newfoundland was initiated in Early Cretaceous time (Lapoint, 1979), and was accompanied by alkalic magmatism in Maine (part of the NEQ series) as well as in many other places around the northern ocean basin. Renewed faulting and basin formation in the New England region may also have occurred (McHone, 1982).

The close association of the magmas with rifting events does not support their origin via an independent "hotspot" or mantle plume under the moving lithosphere (the model of Crough, 1981). More widespread studies of the chemical variations in the tholeiitic ENA magmas have been conducted by Weigand and Ragland (1970), Ragland and others (1971), and Bryan and others (1977). Their model explains the ENA magmas as the forebears of the present mid-Atlantic Ridge basalts. Such basalts are recognized to be relatively large-volume, shallow-mantle melts (Yoder, 1976) that are characteristic of all diverging plate boundaries.

In contrast, the alkalic magmas of New England (producing the Maine lamprophyres, alkali dolerites, and Mesozoic plutons) are typical of intraplate rift magmas throughout the world. Such magmas are not necessarily associated with new ocean basins. In the New England area, the alkalic magmas were produced well inland of the new continental margin, but correlate with the major initiations of plate-spreading which created the present North Atlantic Ocean. The New England intrusions and the volcanic seamounts farther east are localities where magmas could be formed and released from mantle sources deeper than those for tholeiites, perhaps in lesser volumes, and/or with the source less depleted in elements which characterize alakali basalts (such as K_2O, P_2O_5, and volatiles).

The above model probably requires some mechanism for the localization of the intrusions, such as a lithospheric "weak zone", or an extended transform fault (the Kelvin fracture zone?). Such a zone must extend through southern Maine and may be represented by some of the faults and fracture sets so common in the area. Studies of Mesozoic features other than igneous rocks are rare for northern New England, but additional work underway by ourselves and other geologists will certainly result in a much more comprehensive Mesozoic history of the region.

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Figure 2. Mafic dikes near Perkins Cove, Maine. A multiple dolerite intrusion around 2.2 m wide has eroded to form a gully, cross-cut by a camptonite dike.

Figure 3. Photomicrograph of a dolerite dike from York Beach, showing euhedral labradorite phenocrysts with a truncated zoning. Crossed nicols. Scale bar = 0.5 mm.

Figure 4. Photomicrograph of a dolerite dike from the Kezar Falls Quadrangle showing euhedral bronzite phenocrysts, partly altered along fractures. Plagioclase lies adjacent to the bronzite grains. Crossed nicols. Scale bar = 0.5 mm.

Figure 5. Photomicrograph of a dolerite multiple-intrusion dike from the Kezar Falls Quadrangle. The glassy chill margin of the later intrusion lies at the bottom of the picture, and contains olivine phenocrysts altered by relatively low-temperature, deuteric processes. Olivine in the older, coarser intrusion toward the top of the picture has been altered around the margins by a higher-temperature replacement phase. Crossed nicols. Scale bar = 5 mm.


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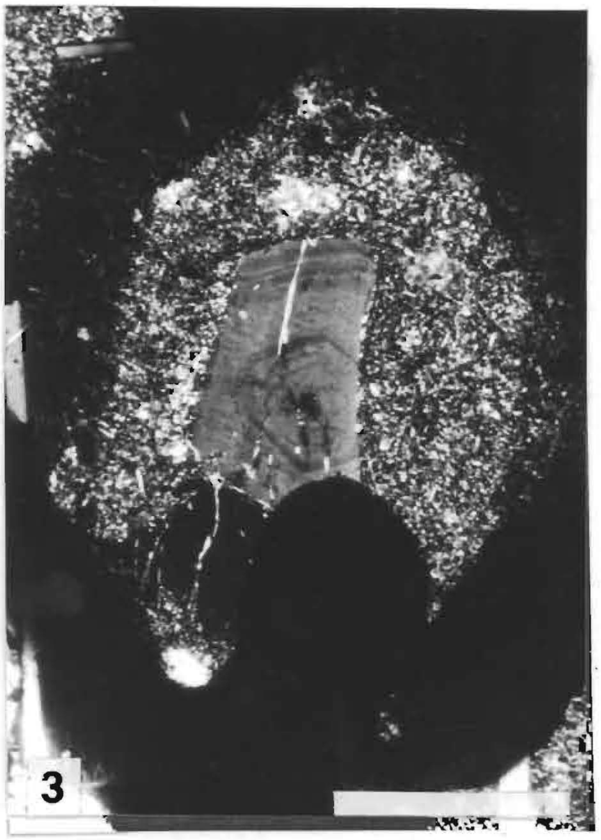
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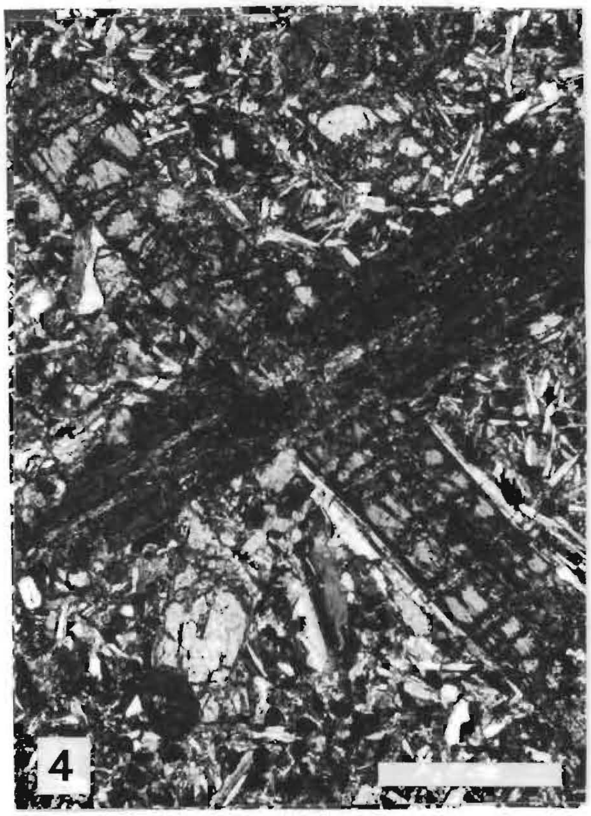
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