INTERSECTING BELTS OF POST-TECTONIC "ALKALINE" INTRUSIONS IN NEW ENGLAND

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ABSTRACT.—Magmatic central complexes and plutons of "alkaline" nature, emplaced post-tectonically, largely by stoping, are widespread in New England and southern Quebec. They are concentrated within two principal belts. A north-northwest belt is composed largely of intrusions of the White Mountain magma series in New Hampshire and the Monteregian Hills of Quebec. The northeast belt is represented by intrusions along the eastern half of the Maine coast. Petrographic, structural, and geochemical evidence indicate that the northeast belt of plutons, together with the Bays-of-Maine igneous complex, extends southwestward into Connecticut and is transected in eastern Massachusetts by the north-northwest intrusion belt. Such a relation, if correct, may account for the two rather distinct sets of ages (180 and 320 m.y.) obtained for the "alkaline" intrusions in central and southern New England.

Plutonic bodies ranging in age probably from Ordovician to Cretaceous and in composition from gabbro to syenite and granite are abundant and widely distributed over New England and southern Quebec. For convenience they are divided into three groups: pretectonic, syntectonic, and post-tectonic. Although we will be concerned in this paper with bodies of the last group, it is recognized that all gradations occur between the syntectonic and post-tectonic types. To define our group here more precisely, we will consider those bodies which on the whole show no apparent effects of orogeny, are mildly alkaline in character, and generally constitute magmatic central complexes emplaced in the observable portion of the crust by ring-fracture stoping. For simplicity these "alkaline" intrusions are considered to belong principally to two geographic belts, one trending north-northwest and the other northeast (Figure 1).

THE NORTHEAST INTRUSION BELT

The northeast belt is located along the eastern half of the Maine Coast and coincides, at least in part, with a gigantic assemblage of mafic and felsic rocks known as the Bays-of-Maine igneous complex (Chapman, 1962). The complex, at least 175 miles long, extends well into New Brunswick in one direction and across Penobscot Bay, in south-central Maine, in the other. It was emplaced largely within and beneath a thick pile of volcanic and associated sedimentary rocks (Silurian and Devonian) in the late stage of Acadian orogeny. This may account for its trend parallel to tectonic strike. An early phase of the complex is represented by gabbroic and dioritic rocks with both visible and cryptic layering. More or less on top of the mafic phase and beneath a roof of volcanic rocks is an extensive sheet or capping of the younger, gianitic-granophyric phase.

Cutting through both phases of the complex are at least 14 granitic plu-

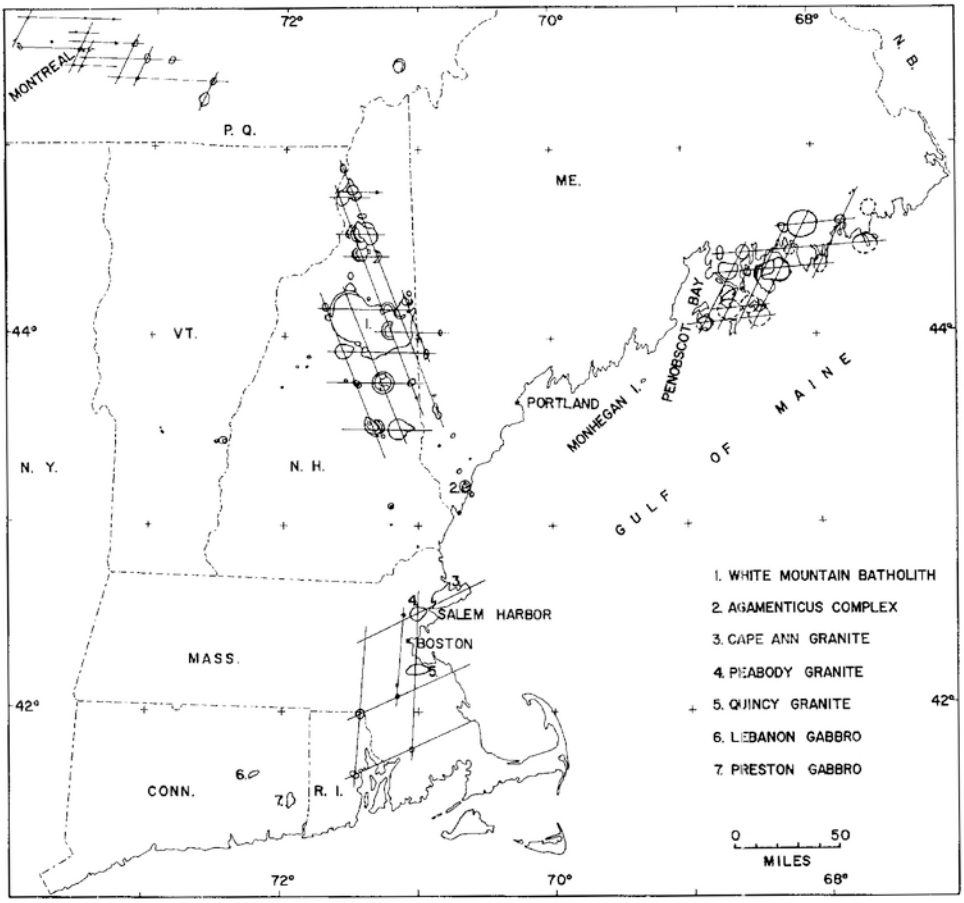

FIGURE 1. Distribution of post-tectonic "alkaline" intrusions in New England and southern Quebec.

tons, which in many respects resemble the granitic bodies of the north- northwest belt. They form a belt at least 25 miles wide and 80 miles long. These dimensions are limited by the Gulf of Maine, which undoubtedly covers numerous other plutons. Previously (Chapman, 1962) these granites were referred to as the "younger granites" and were separated from the Bays-of-Maine igneous complex. As study in the area progresses if may appear more logical to group the "younger granites" with the great complex as a third and later phase.

For the most part the plutons are roughly circular, 5-10 miles in diameter, and stock-like in form. A few ring-dikes are known. Granite and quartz monzonite are virtually the only rock types observed. Volcanic rocks genetically related to the granites have not yet been recognized. The plutons are disposed in a reticulate pattern in which two directions of linear arrangement (N30°E and N85°E) intersect at 55° (Chapman, 1967).

The mafic phase of the Bays-of-Maine igneous complex was emplaced in stratified rocks of Silurian and Devonian age, and it shows some effects of Acadian orogeny. The younger granitic-granophyric phase is overlain unconformably by the Upper Devonian, Perry Formation in eastern Maine (Bastin and Williams, 1914). Here, Faul et al (1963) date this phase as 404 m.y. It appears then that the Bays-of-Maine igneous complex in eastern Maine is roughly of Early Devonian age.

To the southwest toward Penobscot Bay the "younger granites" are abundant and appear to cut clearly through the great complex. An upper geologic age limit for these intrustions has not been established. Several age determinations (Faul et al, 1963), however, indicate a wide range for these bodies from 354-399 m.y. (Early to Late Devonian).

The North - northwest Intrusion Belt

The north - northwest belt extends across New Hampshire and is constituted by intrusions of the White Mountain magma series (Billings, 1956). It is roughly 40 miles wide and 150 miles long. The igneous rocks are principally plutonic and include mostly granite with subordinate syenite and quartz syenite and minor amounts of gabbroic and intermediate types. The intrusions of this series exhibit a striking bilaterally symmetrical distribution along the belt relative to size, shape and composition; and several features should be noted.

1. In the central part of the belt are large contiguous masses of plutonic rocks forming the White Mountain batholith (Billings, 1956). These plutons are stock-like in outline, but a few poorly formed ring-dikes are recognized. Compositionally the rocks are predominantly granite; only a small percenage is quartz syenite and syenite. Mafic types are essentially absent.

2. Both to the north-northeast and south-southwest, away from the batholith, are smaller but discretely disposed intrusive complexes. Here we find the large, well-formed ring-dikes of quartz syenite, syenite, and less commonly granite as well as numerous various-sized stocks mostly of granite. Mafic masses are important only locally.

3. Beyond the large discrete complexes are smaller complexes and plutons. In southern New Hampshire and southwestern Maine the series appears to be represented by small stocks, plug-like bodies, and perhaps funnel-shaped masses (Hussey, 1962). Excepting the Agamenticus complex here, the rocks are dominantly gabbroic and intermediate in composition. Toward the other end of the belt, in northern New Hampshire and Vermont, small plug-like and funnel-like masses do not appear.

4. As was true of the Maine coastal plutons, the intrusions of the White Mountain magma series are disposed along two well-defined lines (22°W and E-W), which intersect (at approximately 68°) to form a reticulate pattern (Chapman, 1963).

5. Changes along the intrusion belt appear more striking and systematic than changes across the belt. In a very general way, however, intrusive bodies are smaller toward either flank of the belt.

6. A central zone of intense metamorphism and plutonism (Late Devonian) in New Hampshire gives way northwestward and southeastward to successively less intense zones (Billings, 1956). This bilaterally symmetrical pattern, furthermore, is roughly coincidental with the bilaterally symmetrical pattern of the White Mountain magma series already described.

7. The northeasterly trending regional structure and metamorphic zones in New Hampshire are transected by the north-northwest intrusion belt at about 50°.

8. Lyons and Faul (in press) give the age for the White Mountain magma series as 180 m.y. (Early Jurassic).

From these observations it now appears that the post-tectonic "alkaline" instrusions of New Hampshire and neighboring parts of Maine and Vermont constitute a distinct and symmetrically disposed group set apart spatially, temporally, petrographically, and structurally from other plutons in New England.

To the extreme northwest the intrusion belt appears to pass into the belt of Monteregian Hills intrusions in southern Quebec (Dresser, 1906). These northern intrusions resemble in some respects those of southeastern New Hampshire and southwestern Maine for they also are small stock-like and plug-like bodies (some volcanic necks) composed predominantly of mafic and intermediate rocks. Small diatremes are abundant and some ultramafic rocks are represented. Northwestward, from the international boundary to Montreal (100 miles), the intrusions generally become smaller and more mafic. In a general way this group of small bodies fits the symmetrical pattern already described for the White Mountains magma series, and it might be considered the counterpart of the group in southeastern New Hampshire and southwestern Maine.

Three important differences, however, are to be noted. (1) Certain rocks of the Monteregian Hills have been dated (Fairbairn et al, 1962) as approximately 120 m.y. (Early Cretaceous). (2) The rocks are distinctly more alkalic than the White Mountain magma series as a whole; and in the more southeastern bodies, foidal syenites are moderately abundant. To the northwest essexite becomes increasingly more dominant. (3) The shape and disposition of bodies suggests a tectonic pattern with lattice lines trending N25°E and E-W. A northwesterly trend, however, does not appear as prominent or consistent. These differences, though very definite, are not in the least detrimental to the idea that the Monteregian Hills intrusions are very closely linked genetically to those of the White Mountain magma series. Both groups of intrusions may be considered as belonging to a single belt.

Extending southeast from eastern Massachusetts for roughly 900 miles is the colinear belt of Calvin seamounts, considered of volcanic origin and Late Cretaceous age (Northrop et al, 1962). These features may represent a later and more southeasterly extension of the north-northwest intrusion belt.

Returning to the main belt we find the bilaterally symmetrical distribution of intrusions (relative to size, shape, and composition) on either side of the White Mountain batholith appears to break down in eastern Massachusetts where large stock-like bodies of "alkaline" granite appear again. This might suggest that the "alkaline" plutons of Massachusetts and Rhode Island do not belong strictly to the north-northwest belt.

The age of these "alkaline" rocks is of particular importance in this regard. Emerson (1917, p. 188) demonstrated the pre-Pennsylvanian age for the Quincy Granite (Near Boston); and Williams and Billings (1938, p. 1025) assuming the New England "alkaline" rocks to be contemporaneous, tentatively concluded a pre-Pennsylvanian age for the White Mountain magma series. Since then there has been a tendency to think of all "alkaline" rocks in New England as correlatives of the White Mountain magma series. More recent studies, summarized by Lyons et al (1957) and Toulmin (1961), indicate an age of 260-270 m.y. for the "alkaline" rocks in eastern Massachusetts as compared with 180 m.y. for the White Mountain magma series. Lyons and Faul (in press) now give the geochemical age of the Massachusetts rocks as 320 ± 20 m.y.

Intersection of the Intrusion Belts

If we assume that the somewhat older northeast belt of the Bays-of-Maine igneous complex and associated "younger granites" extends southwestward across eastern Massachusetts and into Connecticut, then the apparent, great discrepancy in rock ages indicated above may be reconciled.

The writer has already suggested (Chapman, 1962, p. 887) that the Bays-of-Maine igneous complex, which extends from central New Brunswick to Penobscot Bay in Maine (175 miles), may disappear ". . . beneath the Gulf of Maine only to emerge again in eastern Massachusetts, 125 miles beyond." The gabbroic rocks of Monhegan Island (Lord, 1900) may represent a portion of the mafic phase; and therefore, the great complex may be definitely extended 25 miles nearer the Massachusetts coast. The writer has long suspected that the mafic phase of the great complex may be represented in eastern Massachusetts by such units as the Salem Gabbro-Diorite, Newburyport Quartz Diorite, and gabbro at Nahant (Emerson, 1917; Toulmin, 1964). Perhaps much of the Dedham Granodiorite represents the felsic phase. In eastern Connecticut the gabbros at Preston (Sclar, 1958) and Lebanon (Foy, 1949) may belong to this belt. It should be noted that bodies of mafic plutonic rock are larger and relatively much more common in the northeast belt than in the north-northwest belt in New England. It is suggested further that the coastal strip of positive gravity anomalies in the Boston-Portland area (Joyner, 1963) may be largely an expression of an unexposed portion of the gabbroic phase of the Bays-of-Maine igneous complex. The "alkaline" granites in eastern Massachusetts and Rhode Island, which can not belong to the White Mountain magma series, therefore, may represent the "younger granites" of the northeast belt.

Geologic observations by Toulmin (1961) and geophysical studies by Joyner (1963) suggest the shape and mechanics of intrusion of the Peabody and Cape Ann plutons resemble in certain respects those features of the Maine coastal plutons. The high gravity anomaly over the northeastern part of the Cape Ann granite may be due to a huge subsided block of the mafic phase of the Bays-of-Maine igneous complex (Salem Gabbro-Diorite). Furthermore, the overlap of the gravity high on the Cape Ann Granite just north of Salem Harbor may be due to a down-tilted portion of the mafic rock here. This inward tilt, which would provide a gently dipping shelf upon which feldspar presumably collected (Toulmin, 1964) to form the syenite here, is reminiscent of the external centripetal dip patterns formed around some of the Maine coastal plutons (Chapman, in press). From Joyner's anomaly map it appears to the present writer that something more than a shelf is indicated by the gravity high. Apparently an extensive portion of the Cape Ann Granite is underlain by the mafic rock. This granite may have consolidated, therefore, from a melt which occupied a nearly completely floored chamber.

Just as we found a difference in the geochemical age (ca 50 m.y.) of igneous activity along the north-northwest belt, from the White Mountain magma series of New Hampshire to the Monteregian Hills in one direction and the Calvin seamounts in the other, so might we expect an age difference in the intrusions along the northeast belt. The "alkaline" rocks of eastern Massachusetts and Rhode Island, therefore, may represent activity along the northeast belt that was somewhat later (ca 40 m.y.) than that in the Maine coastal region. Geochemical data, therefore, are in reasonable agreement with the idea that the northeast belt may be extended southwestward through Massachusetts.

Further evidence may be found in the tectonic pattern of instrusions. The Massachusetts - Rhode Island intrusion centers show fair alignment in N3°E and N65°E directions to form an acute lattice angle of 62°. This value is close to that (55°) determined for the Maine coastal plutons. In both areas, furthermore, the acute bisectrix of the lattice pattern roughly parallels the regional tectonic strike.

Significance of Pluton Distribution

A distinctive worldwide characteristic of post-tectonic plutons and magmatic central complexes appears to be their reticulate arrangement (Chapman, 1963, 1967, and in press). A great many of the younger igneous intrusions of New England and southern Quebec form large groups within which the bodies are arranged in two linear directions that intersect to produce a lattice pattern. Four such groups include the intrusions of the Monteregian Hills, White Mountain magma series, Maine coastal region, and eastern Massachusetts and Rhode Island. These reticulate patterns are considered to be controlled by two intersecting sets of deep-seated fractures, or sufaces of low pressure, that initiated the magmatic activity (Chapman, 1963, 1967).

Although the magmatic central complexes and younger plutons are widely spread over the New England region, they appear to be heavily concentrated within two belts. A northeast belt parallels the tectonic trend in New England; a younger, north-northwest belt transects this trend at roughly 50°. This suggests a still grander scale structural control of deep-seated nature.

Different ages may be assigned to magmatic activity in these two belts, and it appears that within either belt intrusive bodies may range widely in age. Eruption spanned a significantly greater period of time in the northeast belt. It began in the early Paleozoic with extensive volcanism (largely Silurian). During the Late Silurian and Early Devonian and somewhat overlapping Acadian orogeny, the mafic and felsic phases of the Bays-of-Maine igneous complex developed along the Maine coast. The time of formation of this great complex in the Massachusetts area is not clear, but it may have been roughly the same. In Early and Middle Devonian time granitic plutons and central complexes formed in the Maine coastal region; but the development of their counterparts to the southwest, in eastern Massachusetts and Rhode Island, appears not to have taken place until Mississippian time.

In the younger, north-northwest intrusion belt igneous activity appears to have passed in time and space from the White Mountain magma series (Early Jurassic) of New Hampshire to the Monteregian Hills intrusions (Early Cretaceous) in one direction and the Calvin seamounts (Late Cretaceous) in the other.

The pronounced shift in igneous activity from the northeast belt along the Maine coast, which parallels tectonic trend, to the north-northwest belt in New Hampshire, which transects the tectonic strike at approximately 50°, appears to reflect changes in the nature and behavior of the crust and subcrustal material beneath New England and southern Quebec. There appears to be nearly complete continuity in the space-time-environment relationship of igneous activity from at least the tectonically older (roughly Middle Devonian) calc-alkalic plutons, so abundant throughout the New England region, to the younger intrusions of the north-northwest belt. The writer (Chapman, 1967) has indicated this continuity by analogy with the Newer Granites of the Scottish Caledonian belt. The general picture developed there by Read (1961) fits admirably the Devonian counterparts of the Acadian belt in New England.

The coincidence of the symmetrical pattern of metamorphism and plutonism with that of "alkaline" intrusive activity in the north-northwest belt may be considerably more than fortuitous. It may indicate the control of crustal thickness, composition, and physical nature on igneous activity along a major tectonic zone. Presumably the disposition of intrusions in a contiguous fashion in the White Mountain batholith as compared with a discrete arrangement further away is principally an expression of differences in eruptive intensity or "eruptive density". Perhaps the greater abundance and proportion of granite in the batholith is due to a thicker and more sialic, and perhaps even warmer, crustal layer in this part of the belt. Some differences along the belt may be attributed to differences in levels of observation.

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