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SUBDUCTION ZONE BETWEEN THE PALEO-AMERICAN AND THE PALEO-AFRICAN PLATES IN NEW ENGLAND

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RESUMEN

Las faunas cámbricas y tremadocianas de la provincia acado-báltica presentan grandes semejanzas en ambas orillas del Atlántico (Fig. 1). Existen ejemplares del Cámbrico inferior y medio para esta provincia en Massachusetts oriental, y por otra parte hay faunas de la Provincia del Pacífico en Nueva Inglaterra occidental y en el este del estado de Nueva York.

La falla Marginal de Boston y su probable continuación al sur marca el borde occidental de la Placa Paleoafricana que contiene las localidades de faunas acado-bálticas (Fig. 2). Adyacente a las localidades acado-bálticas de Massachusetts en dirección oeste, encontramos una secuencia de rocas que se interpretan como una secuencia ofiolítica (Figs. 3, 4 y 5), que marcarían una zona de subducción cuyo borde occidental sería la zona de la falla Clinton-Newbury (Fig. 3). La traza de esta falla presenta el lineamiento magnético más conspicuo del sureste de Nueva Inglaterra (Fig. 6), y puede interpretarse como el borde occidental de la Placa Paleo-Americana. Las formaciones Marlboro y Nashoba, y formaciones más recientes sin nombre (Figs. 3 y 4), cuyos protolitos consisten en rocas metavolcánicas y metasedimentarias marinas de la secuencia ofiolítica, representan una corteza ensimática que fue comprimida y deformada intensamente entre las dos placas. Por lo tanto, proponemos una frontera de colisión entre dos placas continentales (Fig. 7) para los Montes Apalachianos del Norte. Se infiere que los mecanismos de la tectónica de placas han estado activos por lo menos desde fines de la era precámbrica.

ABSTRACT

Cambrian and Tremadocian faunas of the Acado-Baltic Province have remarkable similarities on both sides of the Atlantic (Fig. 1). Lower and Middle Cambrian representatives of this

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province are present in eastern Massachusetts, whereas Pacific Province faunas are present in nearby western New England and eastern New York.

The Boston Border Fault and its presumed continuation to the south marks the western margin of the Paleo-African Plate which contains the Acado-Baltic faunal localities (Fig. 2). Immediately west of the Acado-Baltic localities in Massachusetts is a sequence of rocks interpreted as an ophiolite suite (Figs. 3, 4 and 5), marking a subduction zone whose western margin is marked by the Clinton-Newbury Fault Zone (Fig. 3). The trace of this fault is marked by the most conspicuous magnetic lineament in southeastern New England (Fig. 6) and is interpreted as the eastern margin of the Paleo-American Plate. The Marlboro and Nashoba Formations and younger Unnamed Formations (Figs. 3 and 4) whose protoliths consist of sea floor metavolcanics and metasediments of the ophiolite suite, represent ensimatic crust, squeezed and intensely deformed between the two paleo-plates.

Thus a collision boundary between two continental plates (Fig. 7) is hypothesized for the northern Appalachians. I infer that plate tectonic mechanisms have been operative since at least the end of Precambrian time.

EARLY CAMBRIAN OCEAN BASIN

It has long been known (Walcott, 1886; Foerste, *in* Shaler, Woodworth and Foerste, 1899; and Grabau, 1900) that a distinctive Lower and Middle Cambrian fauna, now referred to as Acado-Baltic or European, is present in a succession of strata near Boston, Massachusetts. Late Early Cambrian faunas (Theokritoff, 1968) are recognized at Hoppin Hill in North Attleboro (Fig. 2), at Weymouth and at Nahant. The Middle Cambrian, Paradoxides-bearing, Braintree Slate, cropping out in Quincy and Weymouth (Walcott 1884; Grabau, 1900; Howell, Shimer and Lord, 1936; Shaw, 1950 and 1961; and Theokritoff, 1968), contains two assemblages belonging to the Acado-Baltic Province. These have been correlated with the "Paradoxides bennetti" zone of southeastern Newfoundland (Howell, Shimer and Lord, 1936; Howell et al, 1944; Hutchinson, 1962; and Theokritoff 1968). Correlations have also been made between the above sequences in eastern Massachusetts and those in St. John, New Brunswick (Fig. 1); in Cape Breton Island, Nova Scotia; and in the Avalon Peninsula, Newfoundland (Walcott, 1890; Palmer, 1969; and Skehan, 1969). Moreover, it has been pointed out (Henningsmoen, 1969; Palmer, 1969) that the Cambrian and even Tremadocian sequences of the Acado-Baltic Province have remarkable similarities on both sides of the Atlantic. European localities of special importance in such correlations are in Wales, Central England, and Northern Spain (Fig.

1) (Palmer, 1969; Seilacher and Crimes, 1969; and Fairbairn et al, 1965):

COLLISION BOUNDARY AND SUBDUCTION ZONE

Such considerations as the above served as partial basis for Wilson's (1966) hypothesis which held that, as continents or plates collide, one block may override another and thus one plate may become attached to the other. During a later pull-apart phase a part of one plate may break off and remain attached to the other as an exotic fragment sutured in one way or another to a formerly foreign continent.

Basically, the somewhat oversimplified version of the paleontologic argument, so attractive to the plate tectonicist, though not fully satisfactory to all paleontologists, is that the Acado-Baltic and the Pacific faunas respectively are present in rocks lying now within 100 to 200 miles of each other laterally with only minor intermingling of related forms. At the same time each of these faunal units is traceable on strike for hundreds of miles on either side of the Atlantic and in each case lying in much the same relative position.

In his interesting paper in the introductory session of this Symposium, C. L. Drake (1973) correctly pointed out that to date our studies have not revealed how long the presently active plate tectonic mechanisms have been operative.

Elliott (1973) has recently noted that although subduction zones may be extinguished when pieces of continental crust collide, some sort of discontinuity or suture within the continental crust should mark these extinct subduction zones. He then asks "Can sutures be found within continental crust of the American plate? " and "Was plate tectonics operating in Archean time? "

The present paper, addressing itself to the points made by Drake and Elliott, will present a line of reasoning leading to the hypothetical conclusion that such mechanisms have been operative at least as early as the end of Precambrian and the beginning of Cambrian time inasmuch as a substantial marine basin of as-yet-unspecified width already separated the Paleo-American Plate from the Paleo-Afro-European Plate by the beginning of Cambrian time.

Additionally, I conclude that the ophiolite suite, between the Clinton-Newbury and the Boston Border Faults, the eastern and western margins respectively of the Paleo-American and of the Paleo-African Plates, may comprise a "fossilized" subduction zone.

PLATE BOUNDARIES AND THE OPHIOLITE SUITE

Earlier I theorized (Skehan, 1973) that the eastern boundary of the Paleo-American Plate in southern New England is marked by the westerly-dipping Clinton-Newbury Thrust Fault (Fig. 2), which I interpret as the collision boundary between the Paleo-American block to the west and the modified ophiolite suite of the paleo-ocean floor immediately to the east. I interpret this latter sequence of rocks as comprising ensimatic crust of a subduction zone, squeezed and preserved between the Paleo-American and the Paleo-African blocks. A fragment of the latter now underlies southeastern Massachusetts and Rhode Island and its western boundary is probably the westerly-dipping Boston Border Fault Zone and its presumed continuation to the south.

An analogous situation prevails in Newfoundland where mafic and ultramafic rocks of the central area (the paleo-ocean floor) separate the Acado-Baltic sequence of the Avalon Peninsula from that referred to as the Pacific fauna-bearing sequence of western Newfoundland.

The 8 mile long Wachusett-Marlborough Tunnel (Fig. 3) penetrates the Clinton-Newbury Fault Zone (Skehan, 1968 and 1969) and that part of the sequence of intensely deformed metasediments and metaigneous rocks lying northwest of the Bloody Bluff Fault. In spite of being cut into a mosaic of fault blocks, the 25 000 foot thick sequence of the Wachusett-Marlborough Tunnel seems to be chiefly a coherent stratigraphic succession. It is intensely intruded by igneous rocks of considerable variety, both as regards age and rock type, and is cut by several fault systems both pre-and post-metamorphic (Fig. 3). The Clinton-Newbury Thrust Fault has an important component of right lateral motion and the structural data derived from the deformed stratigraphic units southeast of the Fault indicate that the tectonic transport directions of the forces producing the deformation were easterly directed (Fig. 3) consistent with underthrusting of the subduction zone.

The stratigraphic sequence is metamorphosed as high as the sillimanite zone and is partially altered by post-metamorphic processes. The protolith of these rocks is interpreted as being chiefly a modified ophiolite suite. I refer to it as such since, as is commonly the case in many parts of the world, certain component parts of the suite are adequately represented while others are not well represented.

The protolith of the lower part of the sequence, the Marlboro Formation, (Figs. 3 and 4), is dominantly comprised of basaltic volcanics with abundant interbedded cherts (MC), as well as arenaceous carbonate muds with minor but distinctive limestone beds (M). The Nashoba Formation (Figs. 3 and 4), consisting dominantly of volcanogenic metasediments of keratophyric composition, contains far less extrusive rock than the Marlboro as well as only minor chert. Additionally, minor altered ultramafics (U) of as-yet-uncertain origin are present in some parts of the Nashoba Formation. The uppermost Unnamed Formation, the 1700 foot-thick, ultramafic hornblendite, a layered pyroclastic volcanic whose western margin is cut by the Clinton-Newbury Fault, may have been thrust into its present higher tectonic position by being caught up in easterly-directed thrusting. This and a related sequence lying between the Bloody Bluff and the Boston Border Fault comprise the ophiolite suite between the two continental plates (Fig. 5).

MAGNETIC LINEAMENT

Zietz et al (1971) of the United States Geological Survey have prepared a map of the airborne magnetics for southern New England, eastern New York and adjacent offshore areas (Fig. 6). Barosh (1972) points out that the trace of the Clinton-Newbury Fault Zone (Figs 2 and 6) is marked by a pronounced magnetic low of 800 γ, and that therefore, this fault is the most conspicuous magnetic lineament in southeastern New England. The magnetic gradient rises sharply to the east of the Clinton-Newbury as well as east of the Bloody Bluff Faults with maxima of approximately 2 000 γ over the Beverly Syenite of eastern Massachusetts and over the Preston Gabbro of southeastern Connecticut (Fig. 2).

This magnetic lineament (Fig. 6), following the trace of the Clinton-Newbury Fault Zone, is particularly well developed as it passes in a southwesterly direction from a point near Lowell, to Clinton, Worcester, into eastern Connecticut as the Lake Char Fault (Fig. 2) to a location just west of the Preston Gabbro, and southwestward across Long Island Sound near the eastern margin of the Connecticut Valley. The ophiolite sequence east of these two faults (Figs. 5 and 6) is highly magnetic and thus provides the contrast required for the geophysical recognition fo the Clinton-Newbury and the Bloody Bluff Fault Zones.

CONCLUSION

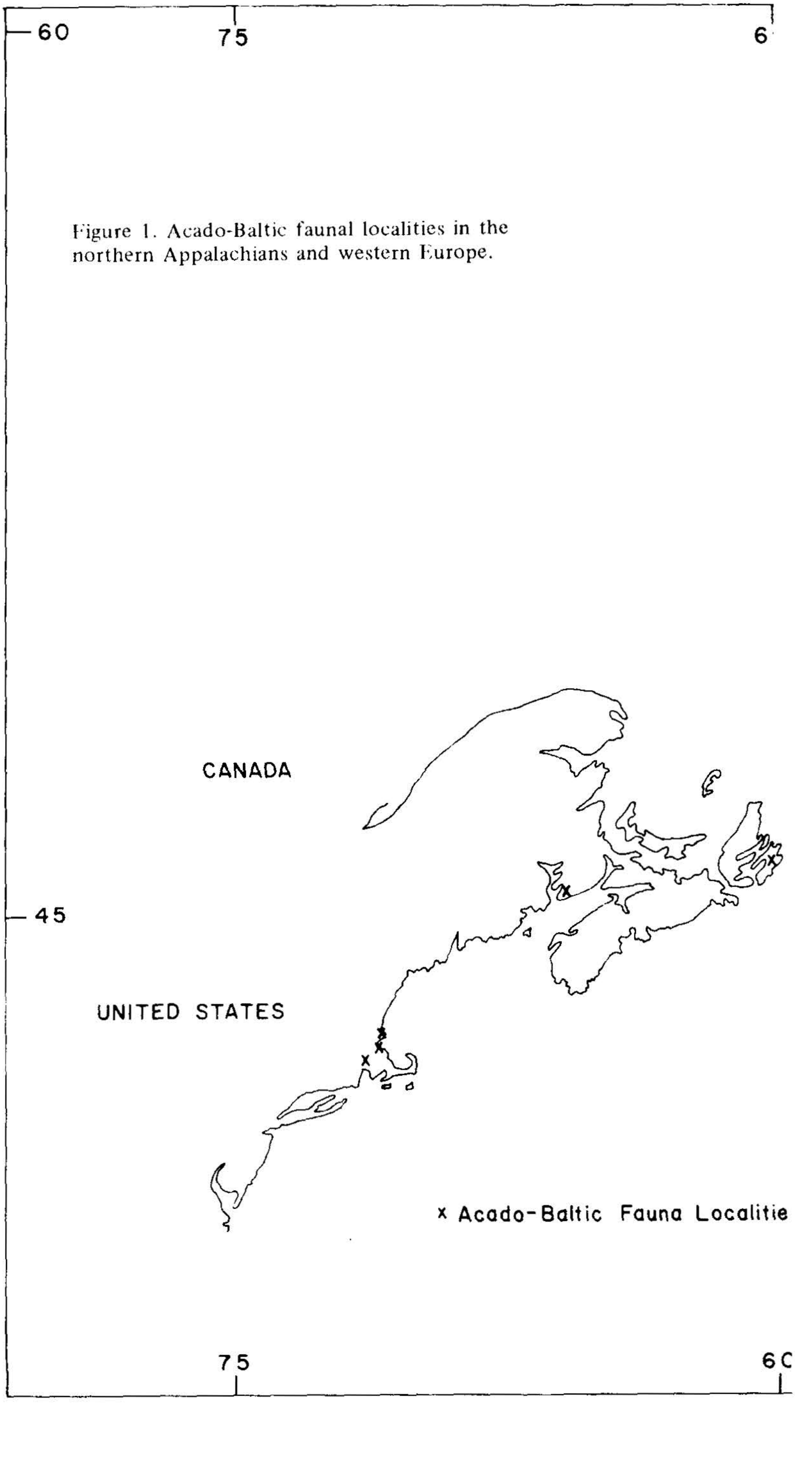
In southeastern New England as well as in Newfoundland a relatively narrow expanse of ocean-floor rocks are squeezed and shattered between blocks whose respective Cambrian faunas suggest that they are part of early Paleozoic American and African Plates. This implies that any protocontinental mass such as Pangaea, must have been breaking up by latest Precambrian or earliest Cambrian time rather than during Triassic time as is generally stated (Dietz and Holden, 1970). The pronounced differences in Cambrian and Tremadocian faunas from western New England to eastern Massachusetts and the lack of such differences later in the Ordovician suggests that the Paleo-American and Paleo-Eurafrican plates were separated until at least Middle Ordovician time when they moved closer together and may have collided, possibly more than once, as for example, during the Taconic, the Acadian (Naylor, 1971), and perhaps also during the Alleghenian orogenic episodes. The Marlboro and Nashoba Formations are probably no younger than Cambro-Ordovician age whereas the sequence above the Nashoba Formations may be of Siluro-Devonian age.

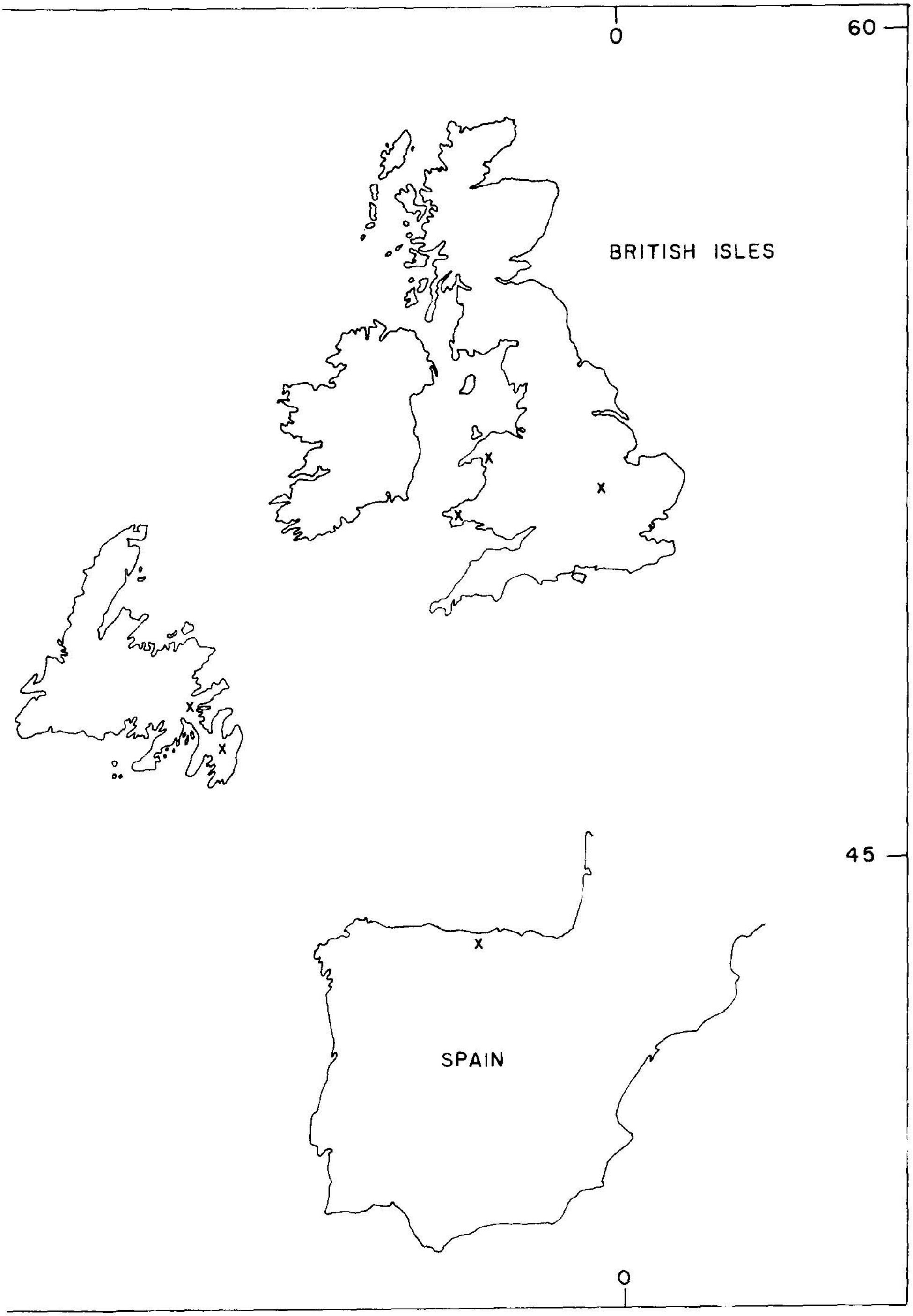
The Clinton-Newbury Fault Zone, as the most pronounced magnetic lineament in southeastern New England, may represent the eastern margin of the Paleo-American Plate. The western margin of the Paleo-African Plate which contains the Acado-Baltic fauna is marked by the Boston Border Fault. The ophiolite sequence between these two faults (Fig. 5), perhaps 10 miles thick, and consisting dominantly of basaltic rocks and cherts with minor ultramafics, and thickened 25 percent by intrusives and having a complex structural development is dominated by westerly-dipping thrust and reverse faults. This sequence may represent part of an ensimatic subduction zone squeezed between the two continental plates (Figs. 5 and 7).

Remnants of the Paleo-African Plate east of the Boston Border Fault, as well as those of the eastern margin of the Appalachians in the Maritime Provinces of Canada (Fig. 1), must have remained sutured to the American Plate when the collided plates were separated by being pulled apart in Triassic and Jurassic time (Fig. 7).

I conclude that there is a growing body of paleontologic, petrologic, structural and geophysical data which provides a solid basis for hypothesizing the existence of a collision boundary between the Paleo-American and the Paleo-African Plates, marked by a relatively narrow outcrop belt of rocks representing a "fossilized" subduction zone. Moreover, I propose that plate tectonic mechanisms have been operative since at least the end of Precambrian and probably earlier than that time.

Figure 1. Acado-Baltic faunal localities in the northern Appalachians and western Europe.

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SPAIN
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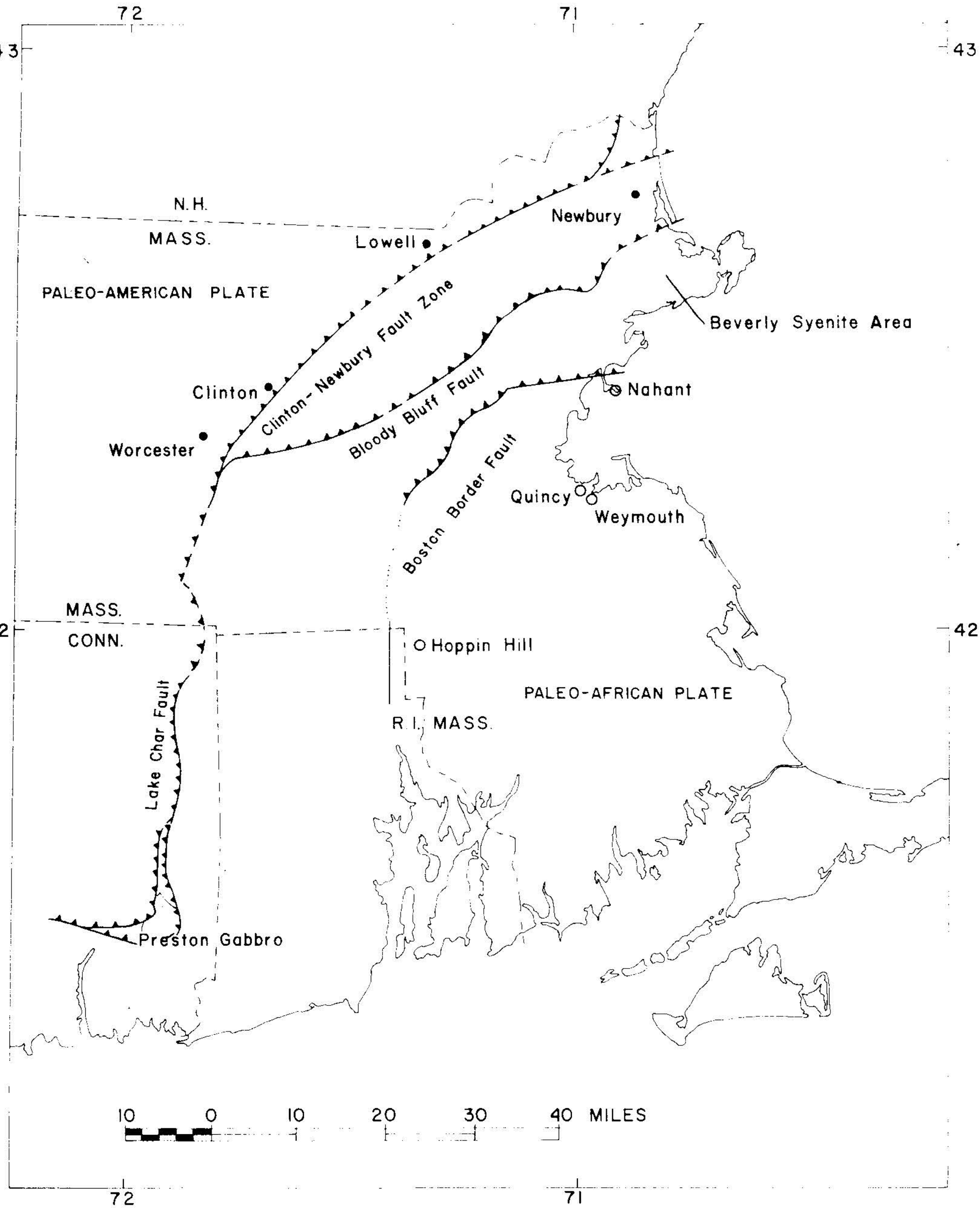


Figure 2. Acado-Baltic faunal localities, major plate boundary faults, and localities of eastern Massachusetts mentioned in the text.

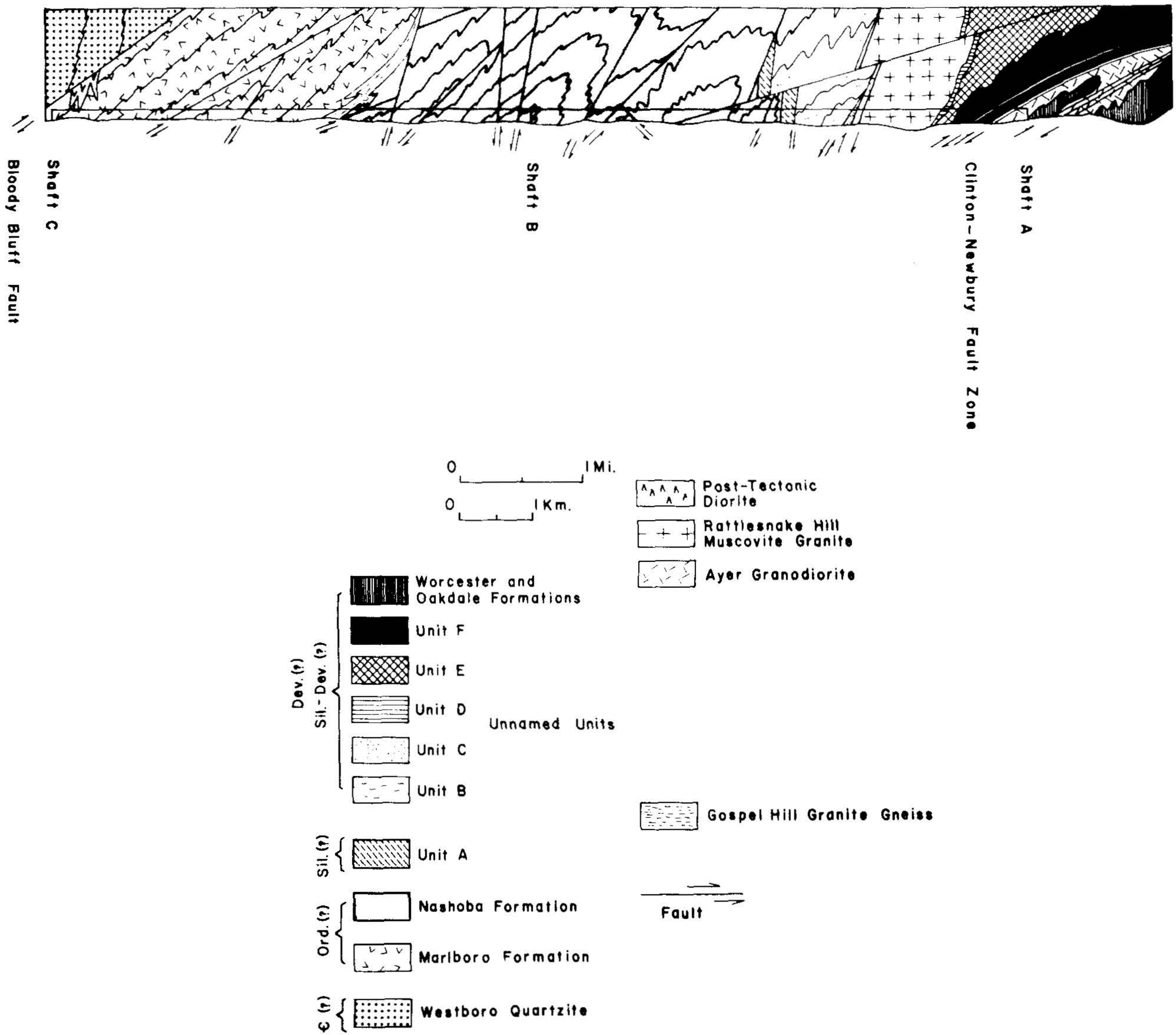


Figure 3. Cross section of the Wachusett-Marlborough Tunnel.

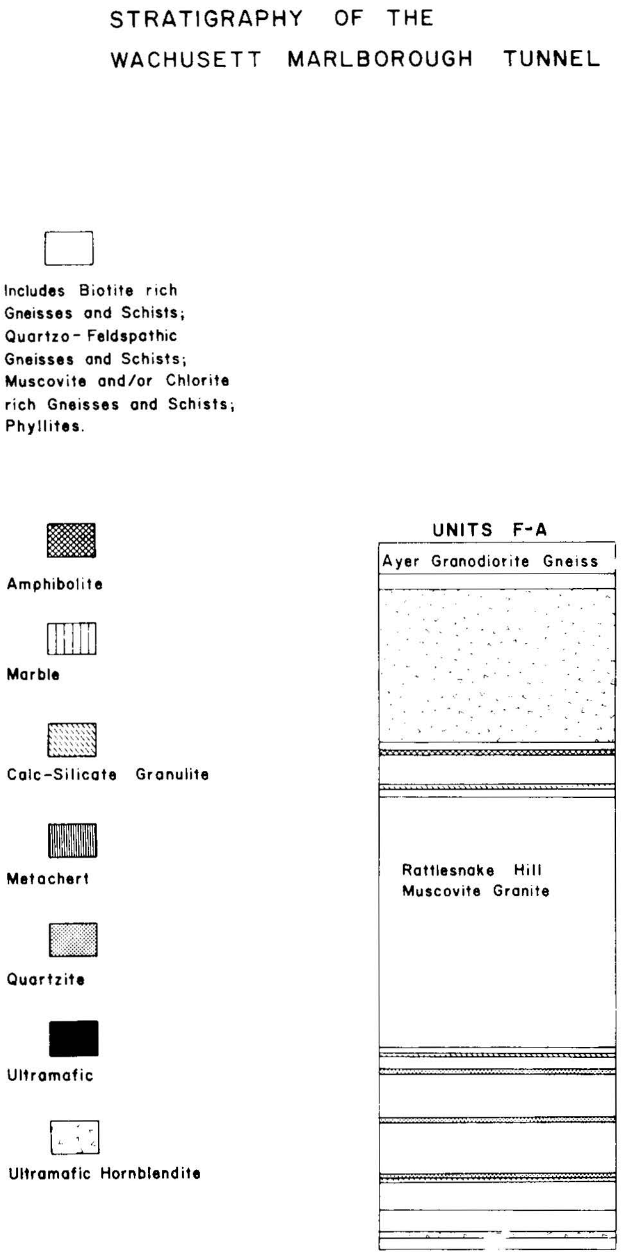
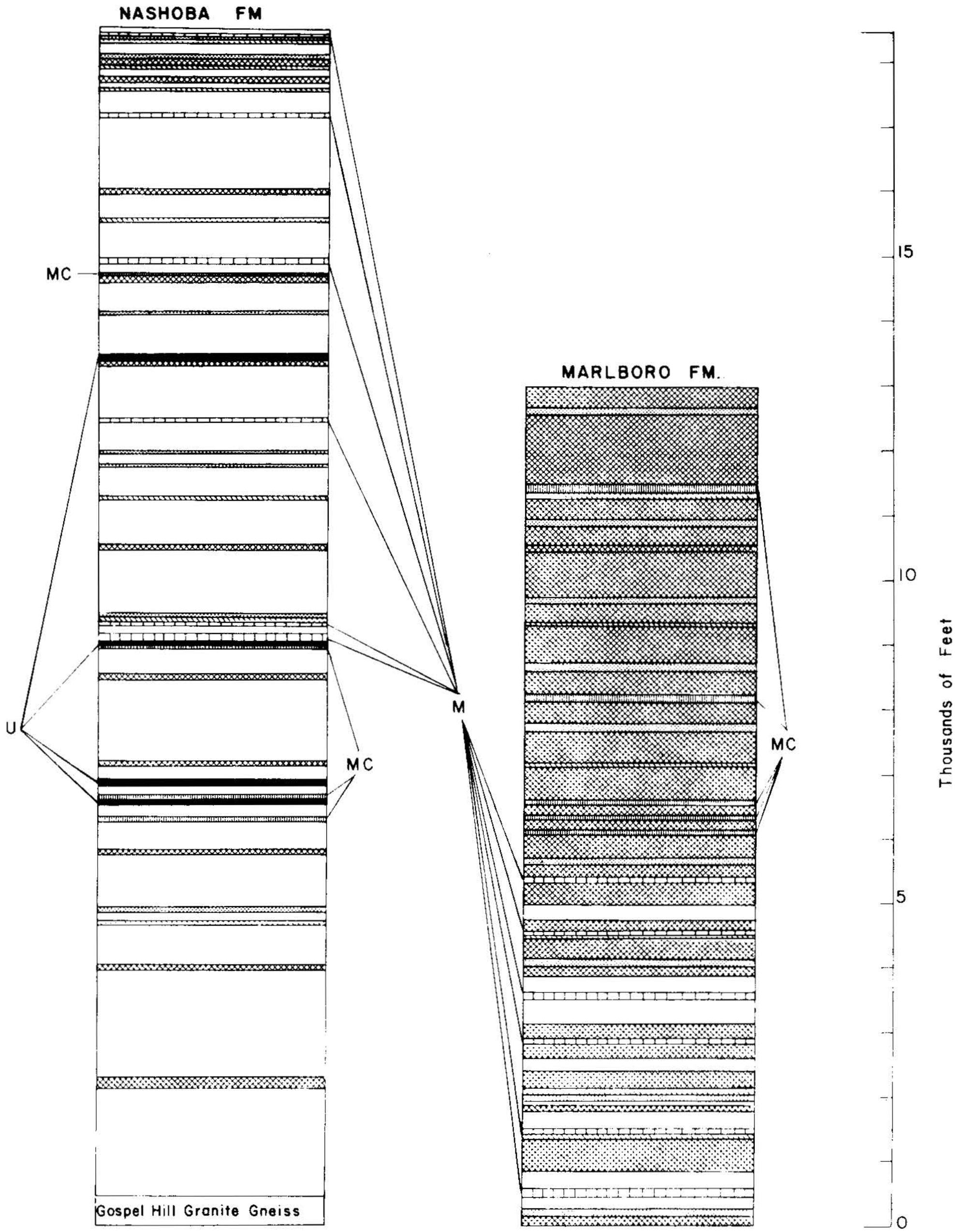


Figure 4. Stratigraphic column of the Marlboro, the Nashoba and the unnamed formations of the



wachusett-Marlborough tunnel.

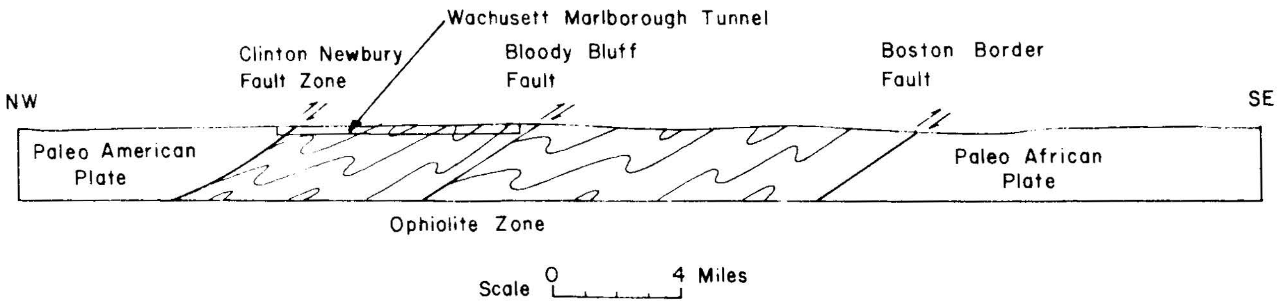


Figure 5. Cross section showing relation of paleo-plates to major faults and to the modified ophiolite suite.

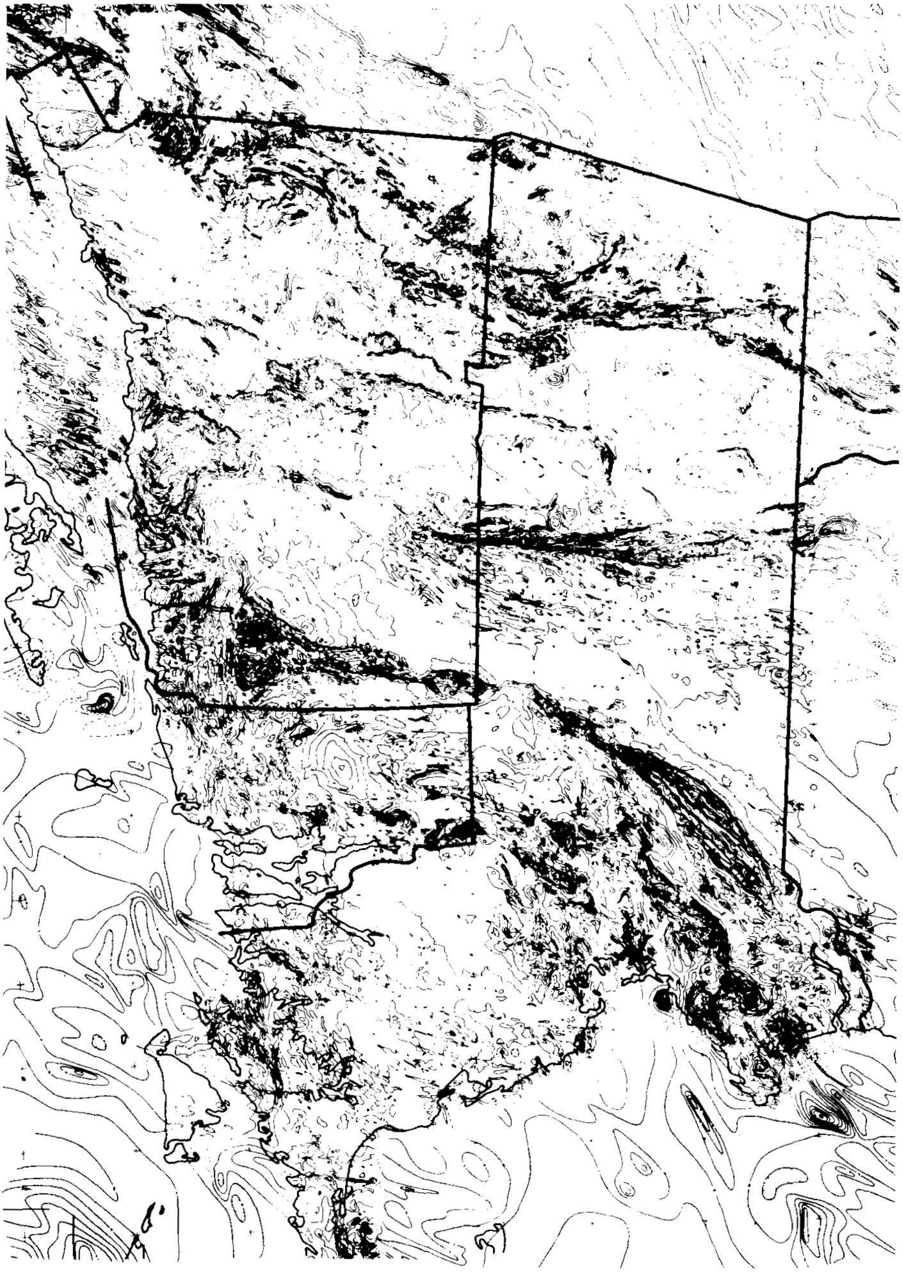


Figure 6. Magnetic Map of southeastern New England (Zietz et al, 1971).

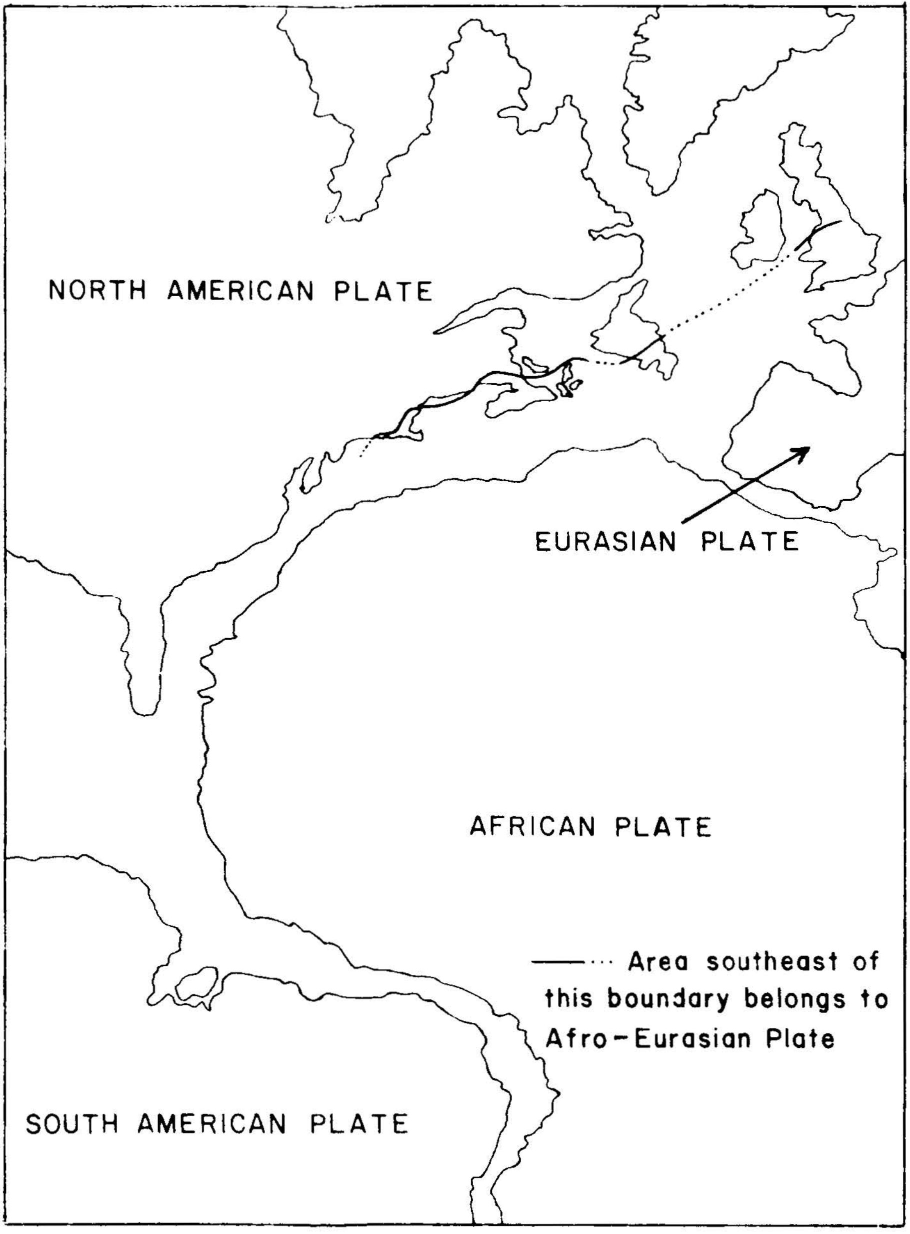


Figure 7. Reconstruction showing the relative positions of the American, African and South American plates during the time immediately preceding the earliest Paleozoic collision (after Bullard, 1969).

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