

DISCOVERY OF A LATE TRIASSIC BASIN
NORTH OF BOSTON AND SOME IMPLICATIONS
AS TO POST-PALEOZOIC TECTONICS
IN NORTHEASTERN MASSACHUSETTS

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ABSTRACT. Red conglomerate, arkose, and micaceous red sandy shale bearing plant fossils of the Newark Group (Late Triassic and Lower Jurassic) are exposed in a quarry in Peabody, 17 km north of Boston. Except for this exposure, these beds are everywhere buried by glacial drift. As deduced from various data, this Triassic-Jurassic basin—herein named the Middleton basin—trends northeast and is probably about 5.7 km in length and no greater than 0.5 km in width. In the quarry, the small exposure of red beds is cut by three faults, one of which is the border fault that drops the basin down against thick mylonite of Paleozoic age, another is a strike-slip fault trending north-northeast. There are many faults with the same attitude and sense of faulting in the region. Some, if not all, of these faults may be Mesozoic in origin. Support of this idea is provided by two sets of dikes which have been K/Ar dated as Late Triassic-Early Jurassic and which have the same north-northeast strikes as the strike-slip faults. There are indications that a tectonic event of some importance may have occurred in Middle Mesozoic time.

INTRODUCTION

Marine seismic investigations of the New England Continental Shelf (Ballard and Uchupi, 1975) have identified a large number of fault basins containing sedimentary rocks and associated basalts of the Newark Group (Upper Triassic and Lower Jurassic). Onshore in New England, similar fault basins are much less numerous, consisting of the Connecticut Valley (comprising the Hartford and Deerfield Basins), the Pomperaug Valley, and the very small basin at Canton Center, all of which are in western Connecticut and adjoining Massachusetts (fig. 1). In addition to these three basins, two offshore basins were shown by Ballard and Uchupi (1975) to extend onshore, under Cape Cod and Nantucket. The presence of the latter was proved by a deep borehole (Kohout and others, 1977).

This paper describes a small basin about 17 km north of Boston which was first revealed when its southern end was exposed in an active rock quarry. The basin's existence was deduced some years ago by Oldale (1962a) from pebbles of Triassic-like rock that he found nearby in the drift.

MIDDLETON BASIN

Quarry of the Essex Bituminous Concrete Corporation.—The quarry of the Essex Bituminous Concrete Corporation, which is being worked at the present time, is about 17 km north of Boston in the western part of the town of Peabody at lat 42°34' N, long 71°01' W (fig. 2). It is near the

eastern margin of the Reading 7½-minute topographic quadrangle and is 0.2 km south of the narrow, meandering Ipswich River. The quarry is roughly circular, about 350 m in diameter, and approx 35 m deep. It is producing cataclastic rock (mylonite) for use as crushed aggregate.

The quarry presents a spectacular exposure of a very wide zone of intense cataclasis, shearing, and faulting. Except for the Upper Triassic, all the rock in the quarry consists of well-indurated mylonite (which includes various grain-sizes ranging from breccias to pseudotachylite). It is deduced from fragments of primary rock in the mass and from thin-section study that the main contributors to the mylonite were gabbro-diorites and amphibolites of the "Salem Gabbro-Diorite Complex" (see below).

The quarry is located near the northeastern margin of a large, complex zone of mylonite and intact primary rock which has an estimated north-south width of about 4 km at the quarry location (fig. 2), and which extends in an arcuate course to the west-southwest for a distance of about 40 km. This mylonitic belt was described by Castle and others (1976) as

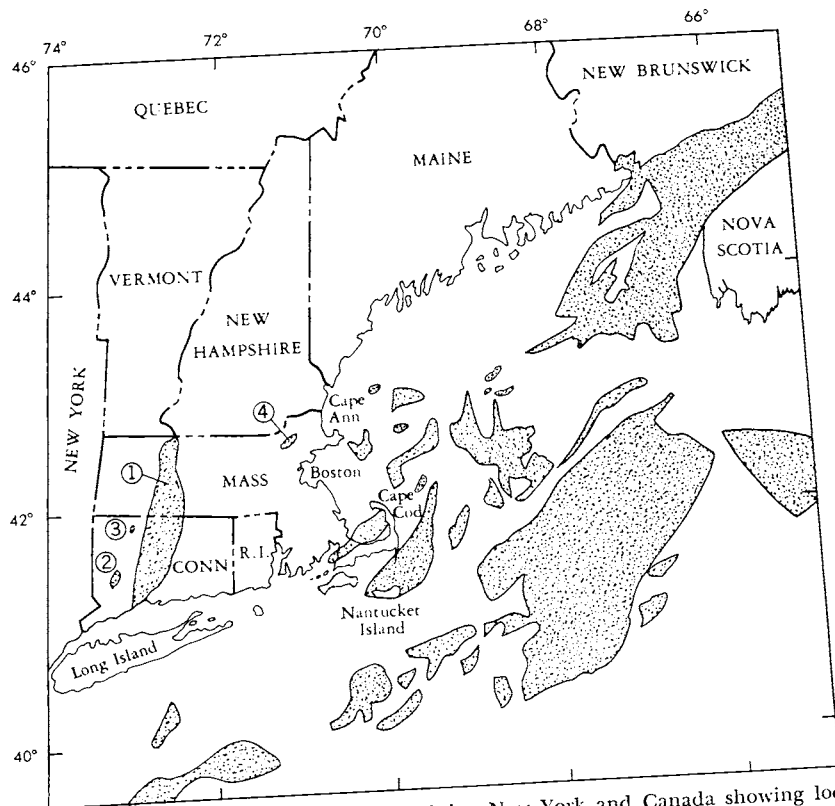


Fig. 1. Map of New England and adjoining New York and Canada showing locations of basins containing Newark Group (stippled). Offshore basins are the Ballard and Uchupi (1975). Onshore basins are the Connecticut Valley basin (1), Pomperaug Valley basin (2), Canton Center basin (3), and Middleton basin (4).

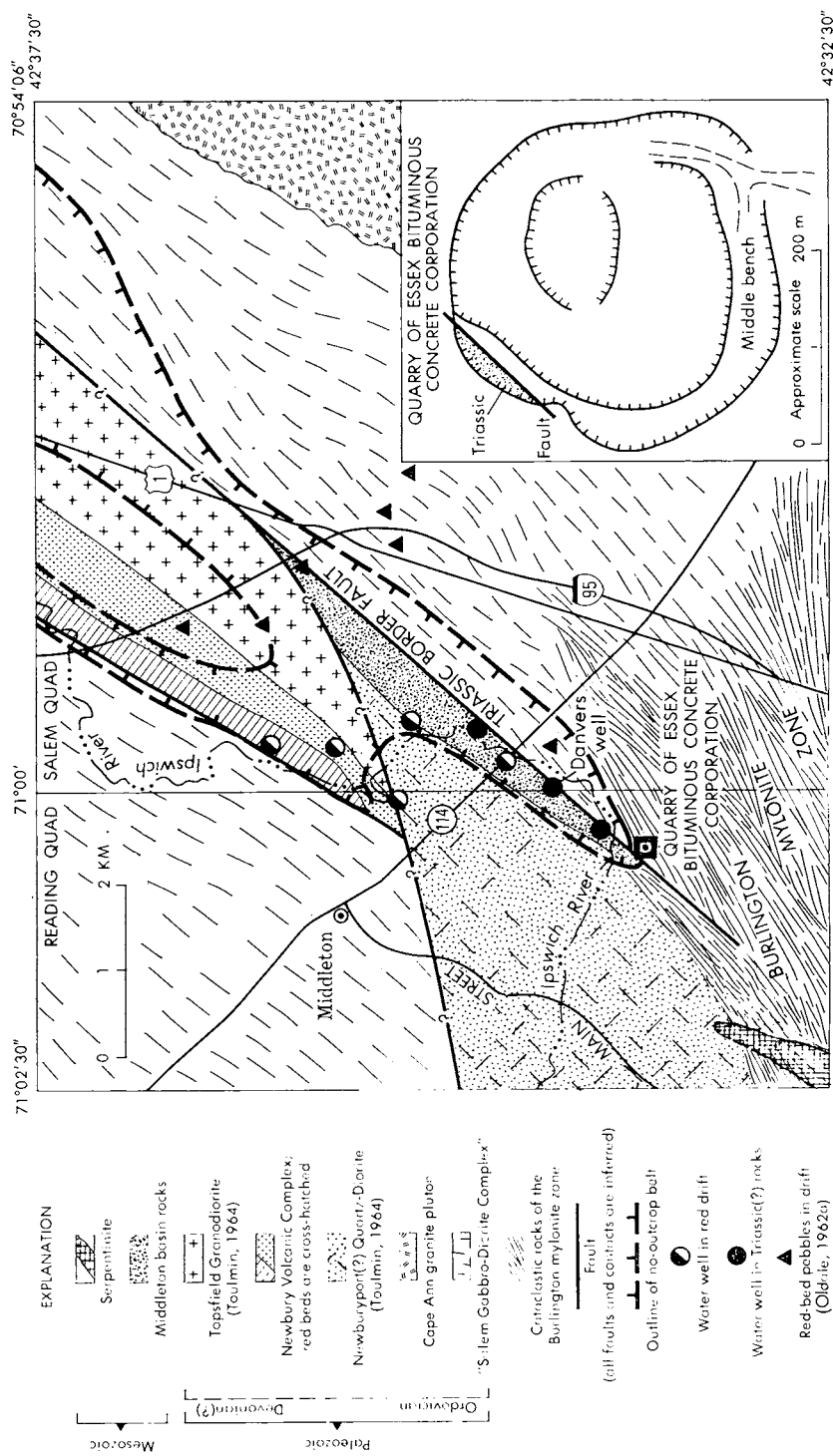


Fig. 2. Geologic map of northwestern part of Salem quadrangle and northeastern part of Reading quadrangle, Massachusetts, showing location of the quarry of the Essex Bituminous Concrete Corporation, the probable extent of Middleton basin, and the data used to determine this. Inset map shows quarry and the location of Triassic rocks. Geology by Clifford A. Kaye.

the Burlington mylonite zone. It forms, however, just one element of a well-defined zone of faults that extends across southeastern New England in an arc from the Cape Ann area to southeastern Connecticut (fig. 3). This Southeastern New England fault zone has been discussed by many authors, including: Wilson (1966), Dixon and Lundgren (1968), Lundgren and Eblin (1972), Skehan (1968, 1969, 1973a, 1973b), Castle and others (1976), Harwood and Zietz (1976), Rast (1980), Simpson, Bothner, and Shride (1980), and Goldstein (1982).

The quarry reveals that faulting took place at three or more intervals. The mylonite represents the earliest, but it in turn is much broken by shear-faults characterized by horizontally striated curved fault planes. These shears strike mostly north to northeast. This family of faults occurs widely in the area, exceeding the limits of the southeastern New England fault zone, but it is developed to an unusual degree in the quarry. A third episode of faulting is represented by the down faulting of the Newark Group beds. These faults will be discussed further below.

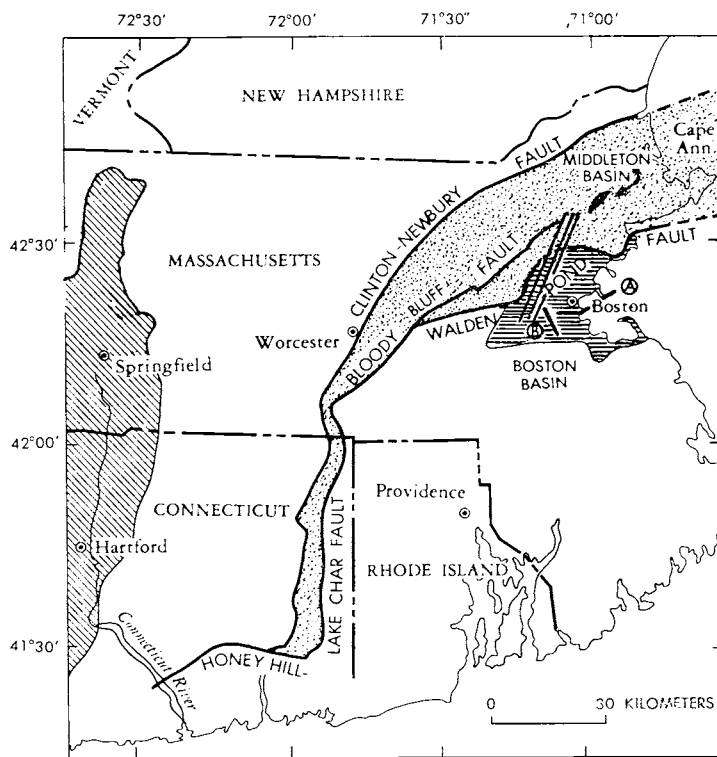


Fig. 3. Southeastern New England showing: Middleton basin (black), Southeastern New England fault zone (stippled), Boston Basin (horizontal hatch), Connecticut Valley Triassic-Jurassic basin (diagonal hatch); in the Boston Basin: Main sewer tunnel (A), Dorchester water tunnel (B), zone of northerly shear-faults (triple line).

Description.—The red beds are exposed for about 75 m along the upper part of the quarry wall on the northwest side, above a wide bench that encircles the western part of the quarry perimeter at about mid-height (fig. 2). Viewed from the entry of the quarry on the south side, the red beds are in sharp contrast to the greenish-gray mylonite and have the aspect of a shallow syncline resting on the latter rocks. Overlying the red beds in the quarry is about 13 m of glacial drift, consisting of interbedded silt and sand in the lower part, and till, both reddish and buff, in the upper part.

Closer up, the greenish-gray cataclastic rock and the red beds are seen to be separated by a high-angle, normal fault, striking N 40° E and dipping 72° NW, or into the quarry wall (pl. 1-A). This fault — the border fault of the Triassic basin — cuts longitudinally across the quarry bench, from quarry wall to quarry wall, as a result of the curvature of the quarry side (fig. 2). The fault contains 2 to 3 cm of gray, clayey gouge on the foot wall that is overlain by a breccia of broken red beds, averaging 2 m in thickness. About 4.5 m to the north, there is a second fault, probably a minor offshoot of the border fault. It strikes N 25° E and dips 30° NW (fig. 1A). A third, striking N 20° E, and having a curved, though essentially vertical, fault plane with horizontal slickensides, can be seen in the quarry wall about 20 m to the east. This fault, which probably is of small displacement, is truncated by the border fault.

A stratigraphic thickness of about 9 m of red beds is exposed. These consist largely of a poorly stratified, badly sorted conglomerate with sub-angular to subrounded pebbles up to 60 cm. There is a zone of gritty, fine- to coarse-grained arkose and a lenticular bed, up to 0.5 m in thickness, of deep red, fissile micaceous, sandy shale (pl. 1-B).

The rock types represented in the conglomerate pebbles are of a wide variety but consist dominantly of granitic rocks that crop out today in the vicinity (fig. 2), most conspicuously, fine- to coarse-grained, red and pink granites that intrude the Salem Gabbro-Diorite (using this formation name as originally defined by Clapp, ms and 1921), muscovite-bearing Andover Granite, and the volcanic and sedimentary rock of the Newbury Volcanic Complex. The finer grained component of the conglomerate is mostly angular granitic arkose.

The color of the conglomerate and arkose is pink to light hematite red, the shale is deep red (1 YR 4/2, Munsell Color System). The cementing materials are hematite and, in places in the conglomerate, white coarsely crystalline calcite. Cementation of the red beds is variable. In a zone within about 8 m of the boundary fault, all rocks are very friable. Pebbles, for example, can be readily picked out of the conglomerate, the point of a pick can be easily driven a centimeter or more into the arkose, and a gentle blow of the blunt end of a pick will disaggregate the rock. In the vertical quarry face, just a few meters away, however, these same beds are well-indurated, as is shown by the fact that this near-vertical face has been standing with little erosion since it was first exposed in quarrying about 12 yrs ago (John Drislane, quarry owner, oral commun.).

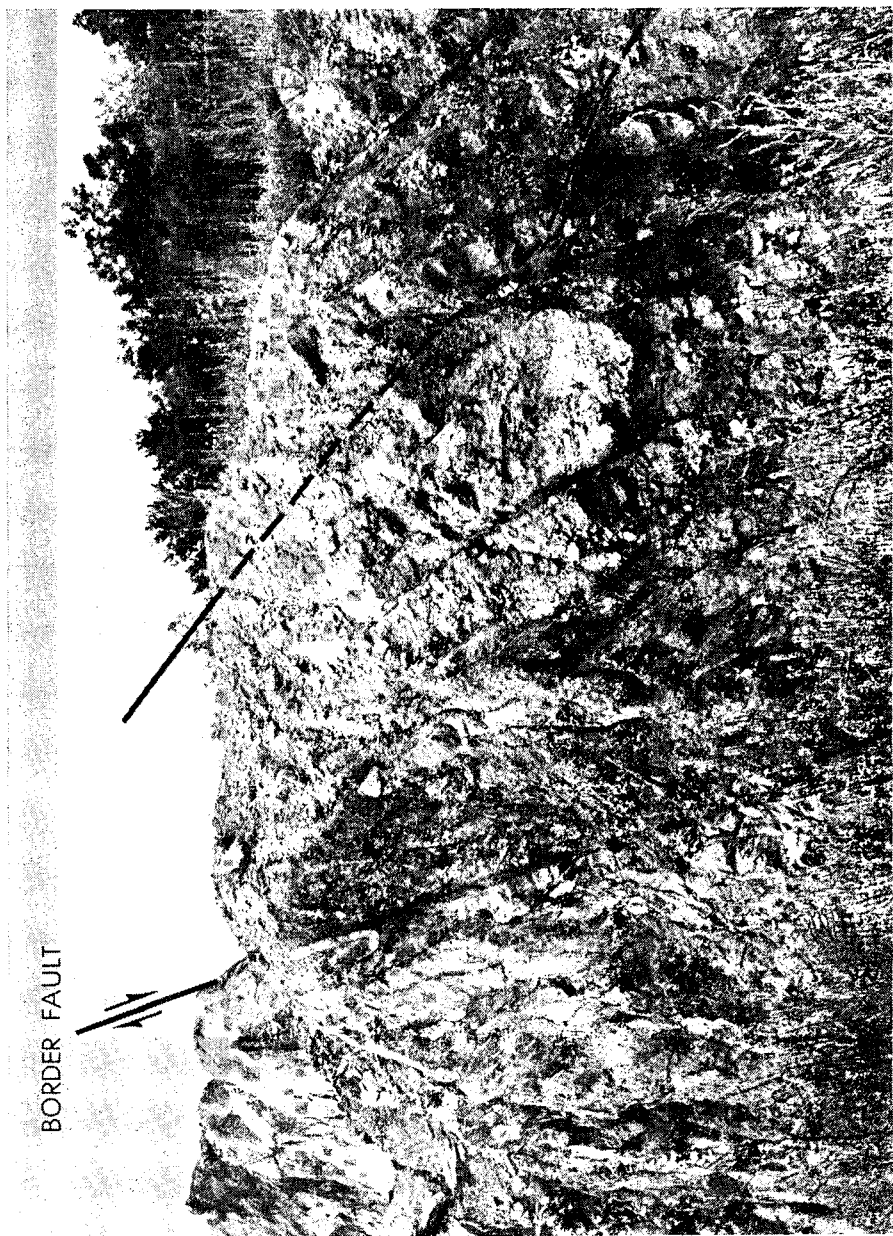
The red beds have evidently been dragged by the border fault separating them from the mylonite. Adjacent to the fault, the poorly developed bedding in the red beds strikes parallel to the fault and dips 62° NW; whereas, in the quarry wall some 8 m away, these same beds lie almost flat. If this body of Triassic rock conforms to the structure of other Triassic basins (Ballard and Uchupi, 1975), the unexposed beds north of the quarry probably dip southeast.

Fossils.—Plant fossils, discovered and collected by Peter Robinson, University of Massachusetts, and associates, in the dark hematite-red, fissile, sandy shale (pl. 1-B), consisted of sparse, detached fragments — mostly long narrow impressions and carbonized remains of stems and leaves, longitudinally striated or grooved. These were shown to Elso S. Barghoorn, Harvard University, who reported that the assemblage “resembles the collections at Harvard University of Late Triassic flora from the Connecticut Valley and the Richmond coal basin, Virginia. Among the typical Triassic plants present are *Equisitites* sp. (pl. 2-A-C), *Baiera* sp., and cycadophyte leaves (pinnae). These last are not clearly assignable generically but have the characteristic venation of certain cycadophyte foliar organs known from the Triassic and Jurassic. Comparable cycadophyte leaves occur in the Santa Clara Formation (uppermost Triassic), Sonora, Mexico.”

Confusion with Newbury Volcanic Complex.—The Triassic red beds can be easily confused with red beds in the Newbury Volcanic Complex of Silurian and Devonian (?) age (Shride, 1976), particularly because the two formations are in close proximity (fig. 2). The latter formation contains a red-bed member whose only known outcrop is about 15 km northeast of the quarry, in the Georgetown quadrangle (Shride, 1976, p. 164). The exposure there is in an artificial cut about 100 m east of U.S. Route 1, approx 400 m north of the intersection of this highway with Linebrook Road. Here fissile red shale, ranging from the same color and physical properties as the Triassic rock to a somewhat more purplish red color, is interbedded with drab greenish gray, well-cemented, arkosic sandstone containing red shale flakes, with two thin andesite flows, and with a thin lenticular sill of micrographic rhyolite (Shride, 1976, member 11). This unusual sequence of interbedded rocks is about 50 m thick, strikes N 20° E, and dips steeply northwest. Seen by themselves, the red sediments could be mistaken for the Triassic red shales, just as the Triassic red shales of the quarry could be mistaken for these beds if the Triassic units did not contain the diagnostic plant fossils. The association, however, of the red shales of the Georgetown quadrangle with the unusual suite of other rocks that are characteristic of the Newbury Volcanic Complex (Shride, 1976) clearly identifies them as belonging to that formation. One must admit, however, it would be difficult to classify isolated outcrops of pure red beds in this area as either Triassic or Silurian-Devonian (?) without additional data.

Extent of the Middleton basin.—We can assume that the quarry of the Essex Bituminous Concrete Corporation just nicked the edge of a sizable body of Triassic rock, and that this body of sedimentary rocks of

PLATE I
Quarry of the Essex Bituminous Corporation.



A. Border fault of Middleton basin and secondary fault (dashed). Ultramylonite to left of border fault, red beds to right.



B. Fossiliferous, deep-red, fissile, sandy micaceous shale; underlain by thin-bedded arkose (lower left) and overlain by poorly sorted conglomerate (upper right).

PLATE 2

Fossil plants from red micaceous sandy shale in the quarry of the Essex Bituminous Concrete Corporation. Scale is 5 mm.

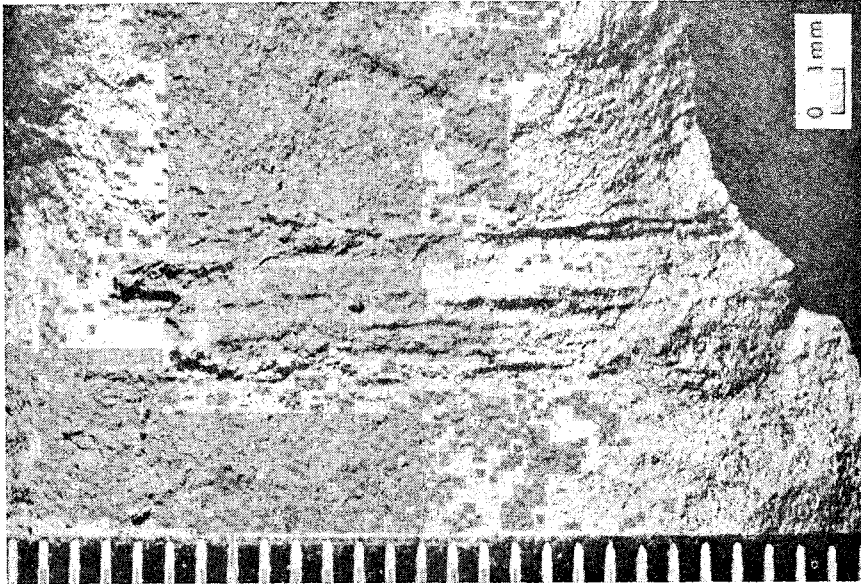


A. Cast of compressed stem of *Equisitites* sp.

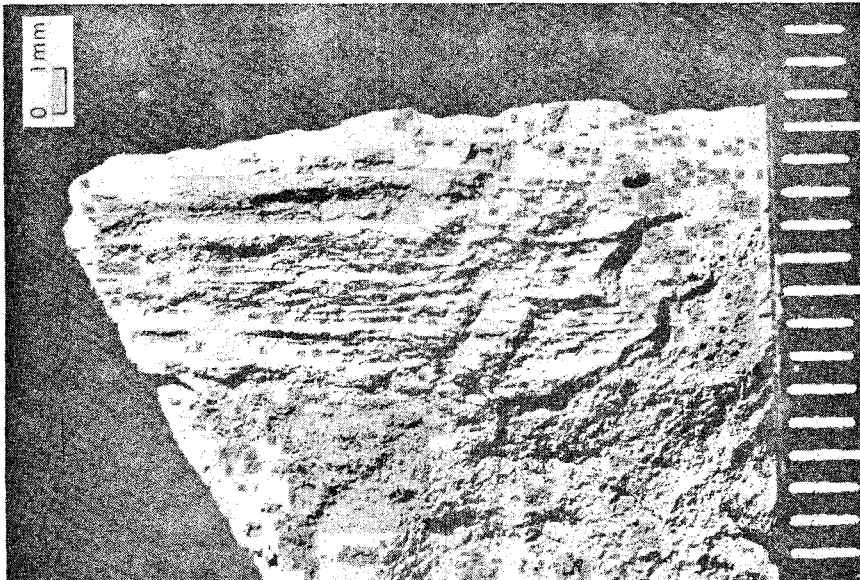
the Newark Group has the form and structure of other such bodies — that is, a basin or syncline dropped down on one side along a normal fault (Ballard and Uchupi, 1975). In spite of the absence of outcrops to guide us, the probable outline of this basin can be roughly deduced from several lines of evidence, although the problem is complicated by the proximity of red beds belonging to the Newbury Volcanic Complex.

In a reconstruction, we can start by assuming that the northeast-striking border fault in the quarry is the border fault of the entire basin. The fault, therefore, is projected rectilinearly in both directions. Then, as no natural outcrops of red beds have been reported in the vicinity of the quarry, we can assume that the basin underlies areas lacking outcrops within this northeasterly trend. Such areas can be outlined (fig. 2) by making use of the outcrops shown on the maps of Toulmin (1964) and Oldale (1962b, 1964). Other broad areas lack outcrops in the region, particularly in the Reading quadrangle; but these were not considered and, in consequence, are not shown in figure 2 because we have no evidence that they are underlain by red beds. The southeast border fault exposed in the quarry, when extended to the northeast, fits into this no-outcrop zone. Just how far the basin itself — as distinct from the fault — extends

B.



C.



B. and C. Fragments of branches of *Equisitites* showing node and portions of two internodes.

TABLE 1
Quality of water from selected public water-supply wells for

Town	Turbidity	Color*	pH	Alkalinity
Danvers**	1	23	7.0	69
Topsfield	0	2	6.8	38
Groveland	1	3	7.1	39
Georgetown	0	1.3	6.2	19

Source: Massachusetts Department of Public Health, Division of Environmental Health "Report of routine chemical and physical analyses of public water supplies in Massachusetts, 1970." Analyses are in milligrams per liter except as indicated.

in that direction, and whether or not it bends or ramifies to fit the entire no-outcrop zone, are questions to be considered.

Southwest of the quarry, the presence of many outcrops of cataclastic rocks seems to imply that the red beds disappear within a short distance from the quarry. Possibly, the basin has been cut off on the south by one of the many planar faults seen in the quarry.

A search was made for subsurface data indicating the presence of Triassic rock. The drillers' logs of several water wells in the valley of the Ipswich River recorded red sediment at depth (Sammel and Baker, 1962; data filed at the Massachusetts Department of Environmental Quality Engineering, Water Supply Division). These wells were separated into those that gave evidence of having penetrated red bedrock and those that seemed to be bottomed in red drift (fig. 2). Further confirmation of a red-bed aquifer was provided by water-quality data. Water coming from a well bottomed in red rock had an unusually high mineral content when compared with water from various other aquifers in the area (table 1).

The pebbles of red beds in the drift, and particularly in till, reported by Oldale (1962a) were used further to define the extent of the basin, taking into account the fact that these pebbles had been glacially transported in a southeasterly direction. Another factor borne in mind here is that red bed pebbles travel badly in glacial ice. These soft pebbles disappear in till within about a kilometer of their outcrops. Thus, the cluster of four eastern localities (fig. 2) might well have been derived from a basin immediately west of the border fault. The two northern pebble localities, however, point to the existence of red beds in the western branch of the no-outcrop zone. Their presence suggests several possibilities: (1) The Triassic basin branches into two, following the shape of the no-outcrop zone; (2) the basin consists of a single trunk but bends sharply; (3) the basin, which originally was a single elongated structure, has been severed in two by a cross-fault; (4) there are two separate basins; and (5) the red beds in the western no-outcrop arm are not Triassic at all but belong to the Newbury Volcanic Complex.

Several reasons support the last of these possibilities. First, the western no-outcrop arm is adjacent to outcrops of sedimentary rocks of the Newbury Volcanic Complex (fig. 2; and Toulmin, 1964). Second, the strike of the rocks in these outcrops is northeast, parallel to the elongation of the

Danvers, Mass., and adjoining towns, to illustrate the effects of a
Middleton basin aquifer

Hardness	Iron	Manganese	Ammonia as N	Nitrate as N	Chloride	Sodium
99	0.90	0.64	0.13	0.2	32.0	18
57	0.01	0.01	0.00	0.9	19.0	5.5
66	0.27	0.02	0.00	0.4	6.8	5.2
35	0.19	0.05	0.01	0.2	14.0	6.0

* Platinum-Cobalt scale of Hazen (1892).

** Triassic (Middleton basin) aquifer; location of well shown in figure 2.

no-outcrop arm, and the dip is steeply west. This is also the attitude of the red beds in the Georgetown quadrangle, already described, and both of these areas are on strike. If the red shales of the Georgetown quadrangle were projected to the southwest along their strike, they would fit exactly into the western arm of the no-outcrop zone. The conclusion is hard to escape, therefore, that the western no-outcrop arm is underlain by Silurian-Devonian (?) red beds and the eastern no-outcrop zone is underlain by Triassic red beds. Considering that these arms are probably less than 1 km apart, this coincidence is remarkable. The coincidence seems further compounded by the possibility that a single northeast-trending cross-fault cuts off the southern end of the Newbury Volcanic Complex and the northern end of the Triassic basin, as shown on figure 2 — that is, possibility (3) but in somewhat modified form. In any case, the indicated shape of the Triassic basin is a body approx 5.7 km in length, 0.5 km or less in width, faulted on its southeast side and possibly its northeast and southwest ends (fig. 2).

Basin name.—Several possible names could be assigned this small Triassic basin. It could be named after the Ipswich River, which follows it for several kilometers, but “Ipswich River basin” can be confused with the hydrologic basin of that river. Of the towns in which the basin falls (Peabody, Middleton, Danvers), Middleton seems the least equivocal as the center of Peabody, as people understand it, is too far to the east of the basin, and some question exists about how much of the basin extends into the town of Danvers. Middleton basin is, therefore, proposed.

Rock association.—The Middleton basin is surrounded by rocks of Ordovician (?) to Devonian (?) age. Most of the rock bodies are probably separated by faults, although the absence of critical exposures makes contact relationships uncertain. The closest outcrops to the west of the basin (fig. 2) are of a fine-grained, much-altered granodiorite which closely resembles rock cropping out on the north side of the Boston Basin (Kaye, 1980, shown as “Gtg”) and on the north side of the Merrimac River, north of Newburyport (Newburyport Quartz Diorite, as used by Toulmin, 1964). On the south, this rock gets lost in the mylonite zone, and its western margin is probably also a fault. To the north and northeast of the Middleton basin, one finds outcrops of the Newbury Volcanic Complex and

the Topsfield granodiorite (Toulmin, 1964) — the latter a coarse-grained quartz monzonite, hematite-stained in this area, probably from Newark Group rock that once overlay it.

To the southeast of the Middleton basin, there are many exposures of a very distinctive suite of dark rocks, rich in green hornblende and lesser biotite; these include well-foliated amphibolites (characteristically impregnated and cut by red microcline granite) and fine to medium-grained diorite and gabbro. These latter rocks are lenticular bodies with margins conforming to the foliation of the surrounding amphibolite. The general direction of foliation of the amphibolite is indicated in figure 2 and suggests some genetic relationship between the direction of streaking in the mylonite and the foliation of the rocks to the northeast.

The dark amphibolitic rocks are classified in figure 2 as the "Salem Gabbro-Diorite Complex," a modification of the name Salem Gabbro-Diorite given to them originally by Clapp (ms and 1921), who, in turn, was influenced by W. O. Crosby's (1880) mapping in which they were lumped as a single rock unit under the name "Huronian diorites." Later authors have reclassified them variously in this area, for example: Marlboro (?) Formation, in part, (Toulmin, 1964); Sharpners Pond Tonalite (Castle, 1965); and Boxford Member of the Nashoba Formation (Dennen, 1978). It seems preferable to retain Clapp's original formational name here for it has the virtue of unifying a group of rocks that are mineralogically related and may have formed from a common parent rock or magma.

Farther to the east (fig. 2), the western end of the Cape Ann Granite pluton crops out. It is the easternmost of a series of petrologically distinct granite bodies intruded into the Salem Gabbro-Diorite Complex (Castle and others, 1976). In the southeastern corner of figure 2 is the northern end of the Lynnfield Center serpentinite body. This relatively unstudied body was first noted by Sears (1905), and later by Clapp (1921), both of whom saw outcrops on the east side of the village of Lynnfield Center. The present writer extended the known outcrop about 1.75 km farther north by finding an ephemeral exposure (new house foundation), thereby indicating a dike-like form. For reasons briefly noted below, it is suggested that this serpentinite body was a "cold" intrusion of Middle Mesozoic date.

POST-PALEOZOIC TECTONICS

The three faults cutting the red beds within the small compass of the quarry-exposure show not only that post-Paleozoic faults exist in the region but, also, that they probably exist beyond the limits of the Middleton basin, in the terrane of the Paleozoic. This, in turn, raises such questions as: How can they be recognized and distinguished from Paleozoic faults? Are they common? Widespread? What types of faults are they?

Unfortunately, to answer the above questions, our sample of post-Paleozoic faults is too small to permit more than the following speculative analysis. We can, for example, match the small sample of post-Paleozoic faults with faults in the Paleozoic terrane having the same attitudes, sense of fault movement, and other characteristics. Agreement in these few

parameters would not, of itself, constitute proof of age-correlation; a better case could be made if an independent, though related, factor were introduced into the analysis. There is such a factor available: two sets of dikes that have been K/Ar-dated as Late Triassic-Early Jurassic in age and whose attitudes agree with one of the fault systems of possible post-Paleozoic age.

Let us consider the oldest structure first — the N 20°E strike-slip fault with curved fault surface (pl. 3-A). This fault, because it is cut by the border fault, clearly predates that structure. This is the most distinctively marked of the red-bed faults and is strikingly like many faults in the older terrane in attitude, displacement, and fault-plane characteristics. These faults strike northerly (N 10° E ± 15°), dip steeply east or west, and commonly have somewhat curved fault surfaces. They generally lack cataclastics, and the fault surface may be coated with highly polished epidote. Fault surfaces are invariably striated, showing dominant strike-slip movement. Displacements on these faults range from < 1 m to > 100 m, with the large majority probably characterized by very small displacements. These shear-faults are among the youngest structures in the Paleozoic terrane, cutting most other features, including most of the dikes.

The faults are both abundant and widespread in the region and, because of their striated surfaces, are easily recognized in the field. They tend to concentrate in linear zones that trend north-northeast, parallel to the strike of the individual faults. One of these zones extends from the quarry area south through the Boston Basin (fig. 3) and was intersected by the southwestern portion of the City Tunnel Extension, one of the rock tunnels of the Greater Boston water system. Some of the individual faults are shown on the geologic map of that tunnel (Billings and Tierney, 1964).

Many of the faults cutting the mylonite in the quarry belong to this system, having the typical attitude and striations (pl. 3-B). However, they contrast to the single fault in the red beds by being much more strongly marked, probably resulting from greater fault displacements. They, like the fault in the red beds, are cut by the Triassic border fault. Because of the more clearly marked fault planes, the impression is conveyed, on first viewing, that the faults in the mylonite are probably Paleozoic in age. However, before coming to this conclusion and dismissing the similarities of these faults and the red-bed fault as coincidental, one must consider two factors that may have been responsible for this. The first is that vertical displacement on the border fault was large (probably > 500 m) and that the mylonite, when the shear-faulting occurred, lay at deeper levels in the crust than the red beds. In consequence, one would expect these faults to be much attenuated in the red beds if they reached greatest displacements at crustal levels well below the surface. The second factor is the bias of our samples. We see and know so little of the Triassic rocks and the structures in them. In fact, all we know is what we see in the quarry, which is a mere sliver. By contrast, everything else we see in the region is the preMesozoic terrane, and all the structures therein we have

PLATE 3

Faults in quarry of the Essex Bituminous Corporation.

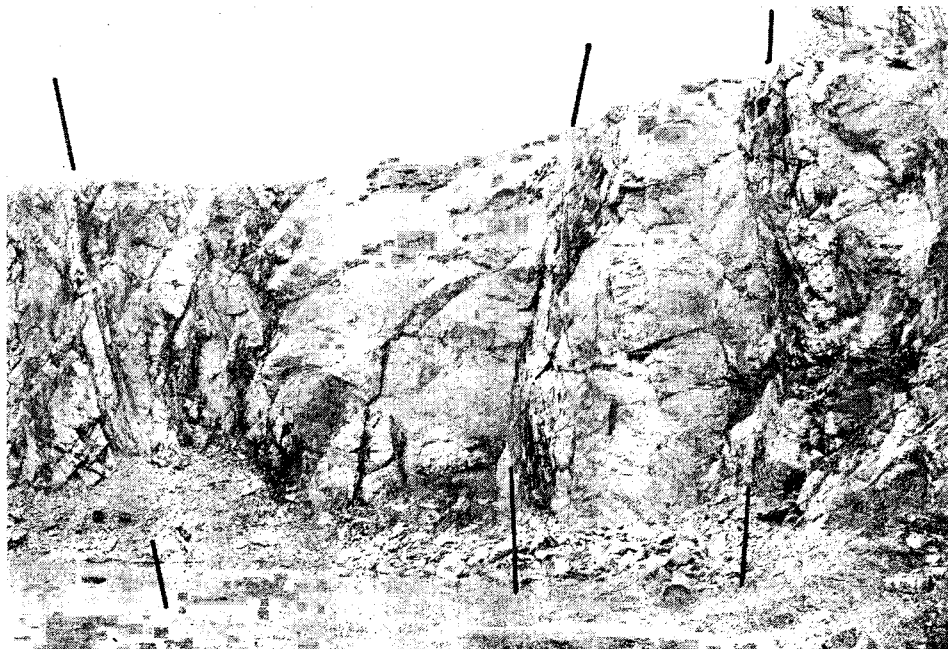


A. Shear fault cutting coarse red arkose of the Middleton basin. Shallow, horizontal grooving of fault surface not visible on photo. Triassic border-fault crosses quarry bench obliquely in foreground.

quite naturally placed in the same time frame. The possibility should be considered, therefore, that if the Middleton basin were better known, the shear faults would be seen to be as well-developed in them as they are in the Paleozoic rocks.

Two petrographically distinct sets of dikes in the Boston Basin have been K/Ar-dated as Late Triassic-Early Jurassic in age. They seem to be closely tied to the northerly striking shear faults. These are the coarse-grained, biotitic diabases (Medford Diabase; LaForge, 1932) and the porphyritic lamprophyres; the former rocks yielded an age of $202 \pm 8 \times 10^6$

PLATE 3 (continued)



B. Three steeply dipping shear faults in mylonite; about 75 m south of (A). Quarry face above bench about 10 m high.

ys, the latter, $190 \pm 6 \times 10^6$ yrs (both dates by Harold W. Krueger, personal commun.). Interestingly, these dates confirm LaForge's (1932, p. 75) deduction as to the ages of these two sets of dikes ("... end of the Triassic or the beginning of the Jurassic...").

The Medford Diabase is known from 11 separate intrusions in the Boston Basin (LaForge, 1932; Kaye, 1980) and includes pipe-shaped bodies as well as dikes. The dikes range in size from the large Medford dike (length: 4 km; maximum width: 0.25 km) to the smaller Powderhouse Hill dike, Somerville, and The Country Club dike, Brookline, both of which are approx 450 m in length and 75 m in maximum width. The porphyritic lamprophyre dikes are smaller and more abundant and are not known to exceed 150 m in length and 3 m in width.

A factor thought to be significant is that both sets of dikes strike northerly, within the same narrow range as the northerly shear faults. Moreover, the Medford Diabase dikes seem to be confined to the narrow zone of concentration of the shear faults mentioned earlier and shown in figure 3.

An unusual feature shared by both sets of dikes (although known from only a few examples) are breccias made up of large to small fragments of many types of rock that are mostly unknown in the region. Among the exotic xenoliths are garnetiferous quartzites and coarse-grained

basic and ultrabasic igneous rocks, including pebbles of serpentinite (Kaye, in preparation; Ross, 1981). These must represent fragments of wall rock carried up by the dike magma from considerable depths in the crust. The fracture system up which these dikes ascended was either the shear faults or else fractures produced by the same crustal stress field.

The breccia has been found in three lamprophyre dikes and in one Medford Diabase dike. The latter occurrence is no longer exposed but was described from the south end of the Powderhouse Hill dike by LaForge (1932, p. 48), whose description is sufficiently detailed to show that it was very like the breccias in the nearby lamprophyre dikes.

The serpentinite pebbles in the breccias immediately bring to mind the only body of serpentinite in the area, the Lynnfield Center serpentinite dike (fig. 2). Interestingly, the Lynnfield Center dike has the same north-northeast-strike as the dikes in the Boston Basin. In fact, if the axis of the large Medford Diabase dike is prolonged 12 km to the north-northeast, it coincides with the axis of the Lynnfield Center serpentinite body. Moreover, all these dikes fall within the narrow zone of concentration of the northerly shear faults (fig. 3).

These similarities suggest that all the dikes, as well as the shear faults, have some genetic interconnection. The dikes seem to have ascended a single fracture system, which may have been either the shear faults or else a system of tensional fractures produced by a related crustal stress field. Furthermore, if the serpentinite fragments in the dike-breccias originated in a deep-seated body of ultrabasic rock, then it seems reasonable to suggest that the Lynnfield Center serpentinite originated in the same body and that it was squeezed up "cold" into the same fracture system as that utilized by the dikes in their ascent.

Younger than the shear faults and very different in its attributes is the N 40° E-striking normal fault with nonlithified cataclastics—the border fault of the Middleton basin. This fault may not be unique for there are many normal faults of similar orientation. It seems to the writer that its distinction lies rather in its unusually large displacement (> 500 m?)—a displacement sufficient to have dropped the Triassic-Jurassic sedimentary cover down to crustal levels below present topographic surface. Correlative faults of smaller displacement probably occur in the older rocks. Among the many structures of similar attitude that may qualify is the fault shown on figure 2 cutting the northwest side of the outcrop of the Newbury Volcanic Complex.

In the Boston Basin, faults striking N 30°-40° E, dipping steeply northwest, and with nonlithified cataclastics have been mapped in many places. For example, in the Main Drainage Tunnel—an 18-km long, essentially east-west tunnel, located about 26 km south of the Middleton basin (fig. 3)—Rahm (1962, fig. 13) mapped 45 such faults, comprising the largest single group of faults in the tunnel. In the Dorchester Tunnel—a northwest-trending, 16 km tunnel, about 31 km south of the Middleton basin (fig. 3)—Richardson (1977) noted that the eight faults having the largest measurable displacement fell into the same group. Some of these

faults and similar faults elsewhere may correlate in time with the border fault.

If the above interpretation of the age of the several dike and fault systems is correct, then we are seeing in these somewhat disparate observations evidence of tectonic events of some importance. The data suggest an earlier (Late Triassic-Early Jurassic) and a later (Middle or Late Jurassic) event, the earlier consisting of shear faulting and dike intrusion along openings structurally associated with the faulting. The stress field had the configuration of a horizontal shear-couple oriented N 15° E. The later event included the downfaulting (rifting?) of the Middleton Basin and associated faulting of lesser displacement. This was probably in response to regional tensional stresses oriented northwest-southeast.

SUMMARY

1. Red beds of the Newark Group, containing Late Triassic-Early Jurassic plant fossils, crop out in a quarry in Peabody, Mass., about 17 km north of Boston. Here, the red beds are downfaulted against mylonite of the Burlington mylonite zone.

2. The red beds are elsewhere covered by drift. From several lines of evidence, however, the red beds are deduced to form a narrow basin, elongated to the northeast, about 5.7 km in length and no greater than 0.5 km in width. The basin, named the Middleton basin, is downfaulted on its southeastern side and possibly also on its northern and southern ends.

3. From the faults cutting the red beds in the quarry of the Essex Bituminous Concrete Corporation, it becomes apparent that some, if not many, faults of the area may be post-Paleozoic in age, most notably, the well slickensided, strike-slip, shear faults of northerly orientation and northeasterly normal faults, analogous to the Triassic border faults. Several systems of dikes in the Boston area, that have been K/Ar dated as Late Triassic-Early Jurassic, are thought to have been intruded along these, or genetically related fractures.

4. The above data, viewed together, suggest that a tectonic event of special character and of some importance occurred in the Mid-Mesozoic.

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