STATE GEOLOGICAL AND
NATURAL HISTORY SURVEY
OF CONNECTICUT

THE BEDROCK GEOLOGY
OF THE
GLASTONBURY QUADRANGLE

With Map

Open Map

By

NORMAN HERZ, PH. D.

QUADRANGLE REPORT NO. 5

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U.S. Geological Survey

Manuscript Received, March, 1954

STORRS

Printed by the State Geological and Natural History Survey

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ABSTRACT

The lithology and structure of the Glastonbury quadrangle, Connecticut, are mapped and described. Triassic, arkosic sandstone, found in the northwest part, is equivalent to the Portland formation of the Newark group. The Middletown biotite and hornblende gneisses are bounded by the Triassic border fault to the west and the Bolton schist to the east. The Bolton biotite schist includes marble, quartzite, and mylonite facies. Both the Bolton and the Middletown appear to be overturned towards the east. The Glastonbury gneiss forms a dome, also overturned to the east, and separates the Bolton schist into two bands. Four distinct facies are recognized in the Glastonbury gneiss; a northwest schistose, a porphyroblastic, a flaser, and the eastern border facies. The schistose facies is fine grained and well foliated and may represent a gradation into the Bolton schist. The porphyroblastic facies has coarse metacrysts of potash feldspar, abundant mafic schlieren, aplitic and pegmatite intrusions. It seems to lie astride the Glastonbury migmatite axis. The flaser gneiss facies has coarse flaser, largely of quartz grains, and grades into the porphyroblastic. The eastern border facies is highly felsic and coarse grained, possibly an eastern transition into the Bolton schist. Its northern phase is well lineated, without foliation, and may indicate a fault contact between the Glastonbury and Bolton. Pegmatites of the area seem to be of two ages, an early syntectonic and a late syn- or post-tectonic. Commercial pegmatites are largely the latter and are restricted to the southwest corner. The Monson gneiss lies in the southeast corner. The direction of the Triassic border fault was determined early, for it is parallel to structures in the crystallines. The crystallines are structurally conformable, except where the Bolton and Glastonbury have a fault contact. This fault may also explain the disappearance of the Bolton quartzite around Great Hill Pond south of the quadrangle.

INTRODUCTION

Detailed mapping in the Glastonbury quadrangle was undertaken primarily to learn the lithology and structural relationships of the Glastonbury gneiss in its type locality, and its relationships to the Bolton schist and the Triassic border fault. The southwestern part of the quadrangle had already been mapped by Frederick Stugard, Jr. (1953), but his main interest was the pegmatites of the area and their relationships to the intruded country rock. His mapping in the Glastonbury quadrangle is incorporated into this present map. The major part of the field work was done in the summer of 1950 and finished in the spring of 1951. The U. S. Geological Survey 7½′ Glastonbury quadrangle sheet, 1946, 1/31,-680, was enlarged to 1/12,000 and served as a base for mapping.

The area was described by Foye (1950), but his report, actually written in 1934, covered too great an area, and is too general to serve as a guide to the Glastonbury quadrangle. Previous to that was Westgate's manuscript, "Crystalline Rocks of the Farmington Folio, East Side," published in part in Bulletin 6, 1906, of the Connecticut Geological and Natural History Survey. Neither contains a sufficiently detailed study of the various Glastonbury gneiss facies to indicate any sort of genetic relationships.

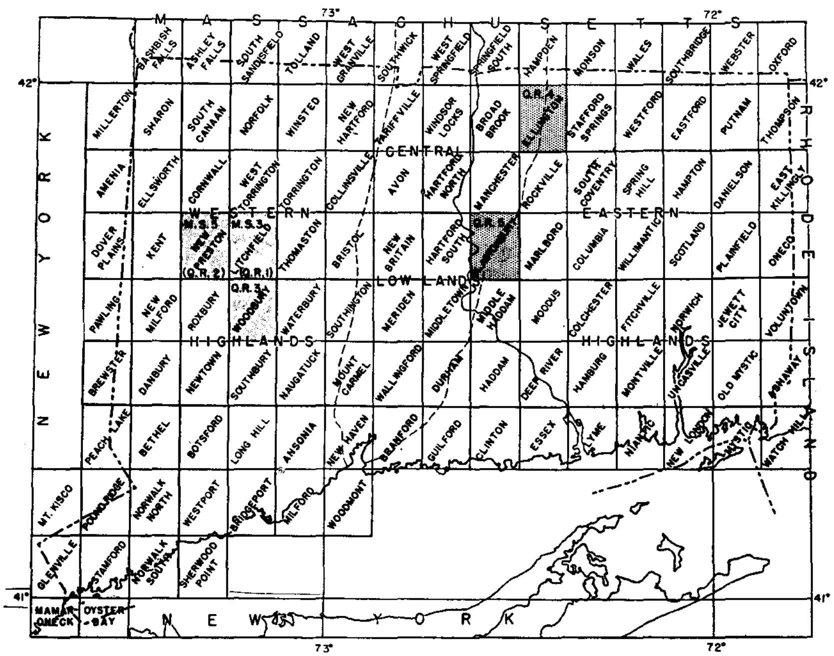

Figure 1: Index map of Connecticut, showing location of Glastonbury quadrangle.

I wish to express my indebtedness to the Connecticut Geological and Natural History Survey, and its former director, Dr. E. L. Troxell, for making this study possible. Further, I wish to thank Dr. Joe W. Peoples for his keen criticism and continued help and encouragement throughout the course of the study. Dr. Frederick Stugard, Jr., of the U. S. Geological Survey, and Dr. David Keppel kindly permitted some of their unpublished data to be incorporated into the map. Dr. C. R. Longwell, Dr. E. S. Larsen, Jr., and Dr. John Rodgers read and criticized the manuscript. My wife, Rhoda Herz, helped with the drafting and some of the laboratory work.

GEOLOGICAL SETTING

The Glastonbury quadrangle of central Connecticut includes within its bounds parts of the Triassic Lowland drained by the Connecticut River, and parts of the Eastern Highlands. Topographically, these are two distinct areas. The northwestern part, underlain by the easily eroded Triassic sandstones, is relatively flat except where drumlins rise 100 feet or more. This area supports the larger settlements of Glastonbury and South Glastonbury and is extensively cultivated, especially by tobacco farms. Sharply contrasting with this, and bounded by the Triassic border fault, is the rolling and forested crystalline upland. This area is underlain by resistant schists and gneisses and offers the greatest contrasts in topography. Meshomasic Mountain rises 897 feet above sea level; the ground drops 400 feet in less than half a mile to Buck Brook, flowing around the toe of its slope. Drumlins and drumloidal hills in this region are common, but aqueoglacial deposits are not nearly as well represented as ground moraine. Much more important than the glacier as a determinant of topography in the upland is bedrock. Many hills trend with the strike of the formations, that is, N-S or N 30°E, and the low dips of the Glastonbury gneiss in the central part of its outcrop area are reflected in the lack of direction of the central hills.

The lithologic units represented, from northwest to southeast, are: (1) the Triassic arkosic red sandstones which extend to the border fault; (2) the Middletown gneiss which can be correlated to the south; (3) the Bolton schist which loops southwards, turns in the area of Great Hill Pond on the Middle Haddam sheet, then appears again on the southeast part of this map; (4) the Glastonbury gneiss which covers most of the crystalline area and divides the two Bolton schist bands; (5) the Monson gneiss which outcrops only in the southeastern corner of the map; and (6) pegmatites which especially abound in the southwest.

LITHOLOGY

Triassic Sandstone

Extensive evidence from deep wells indicates that Triassic sandstone of the Newark group underlies the western and northern sections of the quadrangle (Cushman). Outcrops of this type, however, are decidely rare so conclusions based on field observations must be severely restricted.

Wherever it is seen, the sandstone is a coarse, reddish-brown arkosic variety with pebbles of schist, quartz and pegmatite up to 10 mm. It is badly sorted, and the pebbles are subrounded to subangular. True fanglomerates are not found, as they are to the south, but this may be due only to the lack of outcrops within 2000 feet of the Triassic border fault. Krynine (1950, p. 33) has found that the fanglomerates of central and southern Connecticut are not over 2000 feet wide in outcrop, from the Great Fault westward.

The Triassic sandstone formation of the Glastonbury sheet appears to be equivalent to the Portland arkose formation of Krynine (Upper sandstone of Davis and Eastern sandstone of Percival). Lithologically it is similar to the Portland as described by Krynine (p. 70), having up to 30 percent of rock fragments, showing great variation in grain size, and being, as a whole, more red than gray. The few dip and strike readings taken on the sandstone, plus a Connecticut Highway Department core 0.3

mile northwest of Williams school, seem to indicate an anticlinal structure. Just across the Connecticut River, at Rocky Hill, the uppermost Meriden formation (Posterior sandstones of Davis), as shown by the Upper lava flow (Davis' Posterior trap sheet), is also anticlinal. The fold axis of Rocky Hill anticline, however, appears to be offset about 3½ miles to the southwest of the Glastonbury anticline axis.

Middletown Gneiss

Between the western Bolton schist band and the Triassic border fault, in the southwestern part of the map, is a series of biotite and amphibole gneisses. They appear to be cut out just below South Glastonbury. Westgate (1899) mapped these gneisses as the northern continuation of a more or less elliptical intrusion into the Middletown gneiss centered about Maromas and Middle Haddam to the south. He called this formation the Maromas granite gneiss.

Westgate thought the Maromas an intrusive granite gneiss because of certain criteria best developed nearer the type localities. These criteria include contact phenomena such as a granulitic (aplite) texture developed in the intrusive, especially where it borders schist, inclusions of schist, schlieren of basic segregates, and pegmatitic dikes increasing in number towards the granite gneiss. It is possible, however, to explain these criteria without recourse to igneous processes. Thus granulitic structures can be produced in rocks merely by kinetic metamorphism, schist inclusions by original sedimentary compositional differences before metamorphism, and schlieren by metamorphic differentiation or diffusion (Turner, 1948, p. 137). Pegmatite dikes in the Glastonbury quadrangle, at any rate, are certainly more abundant in the Bolton schist than in either of the gneiss formations, proving merely that the Bolton was the best situated structurally to receive pegmatitic solutions, and not that it was a source for them.

Recent mapping by Stugard (1953) indicates that these biotite and amphibolite gneisses belong to the Middletown formation of variegated gneisses, generally hornblendic, and commonly with associated granulite. Since the biotite and amphibole gneisses of the Glastonbury sheet show no clear cut igneous relationships to the Bolton Schist, and are similar to published descriptions of the Middletown gneiss, they are called Middletown gneiss in this report, following Stugard.

There is also the very good possibility that these gneisses merely represent metamorphosed volcanics. Digman (1948) holds that similar beds around Killingworth are reworked tuffs and flows.

The gneisses are ordinarily very well banded, showing sharp differences in adjacent bands due to variation in volume of component minerals from band to band. They are commonly fine-grained, biotite-hornblende rocks with K-feldspar, plagioclase, and quartz. Amphibolite schlieren are well developed, as are augen gneisses with sub-porphyritic feldspar crystals. Granulite and mylonite are found along the western side of the outcrop area, adjacent to and probably the result of the Triassic border fault.

BOLTON SCHIST

The Bolton schist crops out in two bands in the Glastonbury quadrangle. One about 4 miles wide, in the southeastern part of the map, strikes N25°E. The other, one mile wide, in the western part, heads initially due north, then turns just above South Glastonbury, and follows the Triassic border fault NE. It is faulted off by the border fault to the north, probably just above Town Woods Hill. The two bands are separated by the Glastonbury gneiss; the Monson gneiss borders the eastern band on the east; and the Middletown borders the western on the west. The two bands join near Great Hill Pond, south of the quadrangle, where the western band loops east and the east band west.

The east band of the Bolton can be traced easily through to its type locality at Bolton Notch in the Rockville sheet, thence northwards into Massachusetts and Emerson's Amherst schist (1917, p. 75).

Stratigraphically, it appears to correspond to the Littleton formation of northern Massachusetts and New Hampshire (Hadley, 1949; Billings, 1937), and may even possess equivalents of the Clough formation in its quartzitic members.

Both the eastern and western Bolton bands have in common a biotite schist as their major rock type, though the eastern facies is coarser grained. A typical modal composition (Foye 1950) is biotite 50 percent, muscovite 30 percent, quartz 15 percent, oligoclase 3-4 percent, and 1 percent accessories, largely pyrite, staurolite, and garnet. Sericite schists, staurolite and garnet schists, quartzite, and marble are also found in the east. The staurolite is especially common towards the Glastonbury contact, reaching 1 inch in length. Garnet everywhere accompanies the staurolite and is present locally where staurolite is not. It reaches about ¼ inch in diameter. Quartzite is in contact with the Glastonbury. The quartzite has varying sericite content, and in fact becomes a quartz schist in places because of abundant included sericite. It has been described in other places as massive (Westgate, manuscript), but here it shows a fine foliation resulting from what may be reworked quartz pebble layers. These layers measure ¼ inch and less in thickness and must represent original bedding. Small boudin structures have resulted from the flow of finer layers around the fractured coarser and thicker ones. This quartzitic phase of the Bolton is a very resistant one and makes up a line of hills roughly delineated by the east side of Hollow Brook and the hills at the source of Fawn Hill Brook. Around Great Hill in the Middle Haddam sheet, it reaches its maximum thickness; in Glastonbury its outcrop area is not over ¼ mile in width.

Marble occurs as isolated, impure lenses. On the New London turnpike, near the Marlboro town line, it is a fine grained, micaceous gray rock with abundant, scattered grains of titanite and magnetite. This is similar to a facies found in the western area.

Mylonite is very common in the western phase. Under the microscope, a fine sericite mat is seen directed between remaining quartz, garnet, and feldspar porphyroblasts. Advanced alteration of biotite to chlorite and of feldspar to sericite is apparent; garnet porphyroblasts have well developed "snowball" structure, completely surrounded by a rim replaced by chlorite. The quartz porphyroblasts are the most interesting, having developed by the fusing of numerous small quartz grains that now show mutually sutured boundaries. The porphyroblasts and many of the small grains have an elongation in the direction of schistosity. Thus, a typical large porphyroblast is about 2 x 6 mm.; its component grains, 0.05 x 0.03 mm. Small grains, or remnants of orthoclase, sodic andesine, biotite, and quartz round out the slide. In each, however, mylonite comprises well over half. The proximity of the Triassic border fault and the lateness of the deformation, as indicated for example by garnet that has been deformed and altered to chlorite rather than biotite (Harker, 1939, p. 349), suggest a cataclastic origin in Triassic movement for this rock type.

Beds in the west, possibly analogous to the eastern impure marble beds, occur with different mineral assemblages. Northeast of South Glastonbury, a highly deformed epidote-tremolite rock may represent this type (plate I, figure 1). To the south, the marble develops diopside and garnet, graphite and amphiboles to a lesser degree, and grades into an amphibolite with major hornblende, or into a calcareous mica schist.

Glastonbury Gneiss

Introduction. The Glastonbury gneiss crops out in a band about 4 miles wide, trending N30°E. It can be traced northward through Connecticut and into southern Massachusetts, where it has been called the Monson granodiorite (Emerson, 1917, p. 241). Exact correlation with the well-known magma series of New Hampshire is highly tenuous, and pending further mapping to the north can be attempted only by comparison to published lithologic descriptions. However, on the basis of field relationships and Mississippian dated pegmatites, the Glastonbury probably represents either the late Devonian (?) New Hampshire magma series or the mid-Devonian (?) Oliverian (Billings, et al., 1952).*

The formation varies radically in appearance from place to place, both in amount of constituents and degree of foliation and lineation. The different facies have in common biotite as the primary mafic mineral. The biotite generally occurs in isolated knots, even where the foliation in the gneiss is developed to a marked degree. In some of the more massive types, the knots are so well developed that no foliation can be seen; in other types the knots are drawn out into a well-developed lineation without the presence of any planar structure. In the western border facies, the biotite is shredded through the rocks as discrete flakes and knots are completely missing.

Quartz is also omnipresent in all facies. The bulk percentage differs greatly from place to place, and locally, within a few hundred feet, the volume of quartz ranges from 20 to 60 percent. Most of the quartz is present as isolated, small grains, but in some rock types occurs as flaser-like aggregrates of relatively large porphyroblasts. In these flaser, the

* Since this manuscript went to press, Dr. J. B. Lyons ("Nuclear Geology" 1954, p. 268) determined both the New Hampshire and Oliverian as approximately lower Devonian.

quartz is strained, with an undulatory extinction pattern, and often shows a 2E of a few degrees. Its appearance is strongly suggestive of a derivation from sedimentary pebble beds: a coarse arkose, for example, where the quartz has persisted through changes in the other felsic minerals. This flaser facies is the most common of all, and occurs towards the southeast part of the Glastonbury outcrop area.

Potash feldspar and perthite are common in the different facies of the Glastonbury. They are present as discrete small grains, but also form augen and porphyroblasts, reminiscent of the quartz flaser. However, the feldspar is generally larger and most often consists of only one crystal rather than an aggregate. The porphyroblasts, usually discordant, reach dimensions of 10 mm. or more. Where the feldspar is present as a flaser structure, it consists of an aggregate of small grains, conformable to the gneissic foliation, and drawn out augen-like at the edges into the folia of the rock itself. It is impossible to delimit exactly the large potash feldspar porphyroblast facies. It appears most abundant around Hopewell, and thence northeast and east to East Glastonbury. It grades into a schistose augen type to the northwest, and into a mixed zone with the flaser facies to the southeast, where it finally disappears (plate I, figure 2).

Plagioclase occurs as small grains in the groundmass of the rock. It is rare as porphyroblasts, but more common as flaser, with other felsic minerals. Its composition is amazingly constant in all the facies; the total variation from the mafic biotite-rich forms to the more felsic ones is entirely in oligoclase, usually $Ab_{72\text{-}75}$. In highly felsic portions, and in the aplite that especially intrudes the central facies, its range is $Ab_{79\text{-}83}$.

Epidote is the most important accessory mineral. Although most often restricted to the biotite clusters, and under 3 percent in total volume, there are phases where the epidote may reach 15 percent or more. These seem restricted to the higher hills of the quadrangle, indicating that the phase is the most resistant one of the Glastonbury. Thus, it underlies the area around Kongscut Mountain (elevation 809 feet), Belltown Hill (600 feet), Clark Hill (714 feet), Hill 786 (one mile northeast of Clark), and Meshomasic Mountain (897 feet), and the foothills around Meshomasic. Epidote also appears as small subhedral crystals inside of large unaltered feldspar prophyroblasts (plate II, figure 4). This occurrence must be related to the instability of pre-metamorphic plagioclase with more than 25 percent anorthite content, and ties in very well with the constant anorthite content of all plagioclase in the Glastonbury. Thus conditions close to metamorphic equilibrium must have obtained throughout the formation.

As a rule muscovite is completely missing, though towards the southeast, nearer then Bolton contacts, it may be locally even more abundant than biotite. The flakes of the two micas are of the same size, and in some places appear almost intergrown, or at least restricted to the same areas in the rock. Sericite is developed in all the other facies, but through the alteration of feldspar, especially plagioclase.

Hornblende occurs in the northwest border facies; less commonly towards the southeast. It is, however, seen in mafic phases of the gneiss, together with biotite. It forms subhedral crystals which are restricted to the areas also occupied by the biotite clusters in the rock.

Chlorite derived from biotite alteration, apatite in small euhedral crystals, magnetite, sulphides, and titanite are occsionally present as minor accessories.

Schistose facies. The schistose facies is the westernmost and abuts upon the Triassic border fault where the Glastonbury is in contact with it. To the south, it forms a narrow zone against the western Bolton schist area. Two phases can be distinguished: a border and an interior one. The border phase is rich in plagioclase and has a lighter appearance than the inner phase, which is granitoid and rich in potash feldspar. The whole facies reaches a maximum width of about 3 miles at the northeast corner of the sheet; nearer the south edge, however, it is not over ¼ mile. Both phases have an excellent foliation caused by a planar elongation and orientation of both the felsic and mafic minerals. This facies is the finest grained of all, except for the aplites, and is entirely free of large porphyroblasts or flaser. Average grain-size of the groundmass crystals is about 0.3 x 0.2 mm., though larger grains reach about 0.8 x 0.3 mm. In many outcrops, however, transitional forms to other facies are seen with relatively small augen of potash feldspar and perthite or flaser.

This facies is easily spotted in the field. Its close foliation gives the rock a schistose appearance in many places, but it is much more compact than the Bolton schist. Biotite flakes are about as fine grained as the felsic minerals, and compared to its more common knotted appearance, in other facies of the Glastonbury, the biotite seems shredded. Because of this fine grain, the usual large speckled weathering of the coarser types is missing, and its place taken by a sort of pepper and salt arrangement.

The atypical, fine grain of this facies and its proximity to the Triassic border fault strongly suggest that cataclastic deformation may have played a strong role. This role seems evinced by the omnipresent elongated, strained, large quartz grains. These are not numerous, but they have a remarkable index of elongation; some typical grains showed 3.7 to 4.6 mm. x 0.9 to 1.1, with well-developed strain patterns, oriented bubble inclusions passing through several grains, and systematic fractures crossing the grains (plate II, figure 3). The undulatory extinction and the fractures seem to indicate an incipient cleavage development, although this is not evident in the hand specimen.

Other processes that may have played important roles in the making of the schistose facies should be mentioned here. The first is igneous differentiation; that is, a potash-feldspar-poor rock (tonalite or granodiorite) is normally expected about a granitic massif and is generally finer grained and better foliated than the interior granite itself. The second, granitization or migmatization, better preserves gross sedimentary features of the country rock being granitized, in the transition area from schist to completely granitized rock. Aitken (1951, p. 36) presents this latter explanation for the east and west border phases of the Hebron gneiss and gives a convincing argument for permeation of the Bolton by magmatic solutions.

Sericite, probably developing as an alteration of feldspar, is common in small flakes. Except for these small sericite flakes, plagioclase is generally unaltered. Its composition is calcic oligoclase, about Ab_{73}; in the associated granitic phases and felsic dikes, plagioclase is more sodic, about Ab_{80}. It nowhere forms large crystals, as do quartz and potash feldspars, but appears as part of the finer-grained groundmass. Albite and pericline twins are very common. Microcline is common as large and small grains; orthoclase is not seen here as frequently as it is in the interior facies. Perthites are abundant, especially as larger grains in the interior granitoid phase. Apparent evidence of a metasomatic origin for this granitoid phase is seen in small epidote or quartz grains completely enclosed in fresh-looking perthites. Most of the perthites are of the exsolution variety showing rods and blebs of plagioclase.

Biotite varies from about 3 percent to more than 20 percent, commonly shredded with patches running off between the boundaries of adjacent felsic grains. It occurs in elongate flakes, with an elongation index as high as 7. Pleochroism in the biotite varies with each different rock phase; thus in the lighter plagioclase-rich rocks, biotite shows a pale olive-dark greenish yellow = X (N.R.C. Rock Chart 10Y6/4) and a moderate olive brown gray (5Y4/2) = YZ. In the pinkish interior phase of the facies, the biotite has pale greenish yellow (10Y8/4) = X and olive gray (5Y3/2) = YZ. The change is probably indicative of a changing chemical composition.

Epidote and zoisite are commonly present, though rarely over 3 percent. Their crystals are smaller than those of the other minerals and commonly are completely enclosed by them. Biotite-epidote-rich layers, seen in the other facies, are not common here. The epidote grains in thin-section show a slight reddish tinge and a very high birefringence—both indicative of a fairly high iron content. Because of their small size, the grains are rarely deformed even where larger grains show crushing or strain. Their lack of correlation to shear planes and their enclosure in other minerals, however, rule out any late age assignment.

Garnet is rare. It is found, however, near pegmatites or other intrusives, developed as a contact reaction. Chlorite occasionally has developed as an alteration of biotite. Small euhedral apatite, magnetite, and rarer sulphide crystals occur, largely near the border fault. Since they do seem to occur between other grains, and not as chadacrysts, they must be fairly late in paragenesis. These latter minerals may have been introduced by mineralizing solutions, associated with faulting, which have left abundant evidence for their existence elsewhere.

Porphyroblastic facies. The facies is especially abundant towards the northwest part of the gneiss area. The schistose facies grades into it across a narrow zone, with the development of large, often discordant porphyroblasts of potash feldspar. Towards the east, it disappears into a flaser gneiss by very subtle degrees, since there are flaser, especially of quartz grains, in the porphyroblastic facies and porphyroblasts of potash and perthitic feldspar in the flaser facies. In hand specimens the best-developed phases of each are easily distinguished. The porphyroblastic facies has a very coarse grain and distinctly granitic appearance even where high in biotite and hornblende.The flaser facies has a much whiter appearance, rather than pink, but is also coarse grained.

Two phases of this facies can easily be distinguished, a mafic one where biotite patches, with some hornblende and epidote, comprise over 20 percent and up to 40 percent of the rock; and a felsic one where these patches are much below 15 percent. It is impossible, however, to delimit an area for each phase since they are commonly interbanded in the same outcrop, though the mafic facies seems to be more abundant. This may merely be a function of higher resistance to erosion, since epidote-rich facies, as has been pointed out, underlie the high points of the area.

The porphyroblasts are generally discordant to the foliation, except near the schistose facies where they are true augen and strictly concordant. In all thin-sections, however, biotite foliation is seen to wrap around the metacrysts. The larger elongated border augen average about 15 x 5 mm.; the equidimensional crystals are as large as 20 mm., but are mostly about 6 mm. The groundmass of the rock does not tend to be equigranular, but rather has a crude banding with finer-grained bands (0.5 mm. and less) alternating with coarser (0.7 mm. and larger). The larger crystals tend to be elongate; biotite knots and hornblende always are, whereas the smaller crystals show no such tendency.

Intimately associated with this facies are many pegmatites and aplites. Ordinarily, where the porphyroblasts of the gneiss are exceptionally coarse and abundant, an intrusion is usually found nearby. Mafic schlieren are also abundant, very narrow and plate-like, with harmonious foliation but discordant contacts. This harmonious foliation—discordant contact relationship is also shown by the aplites and some pegmatites (plate I, figures 2, 3). The whole picture is suggestive of a strong migmatization, with the migmatite axis for the Glastonbury gneiss centered in this facies.

Orthoclase (commonly as Carlsbad twins), microcline, and microcline-perthite form the metacrysts. They all have numerous small inclusions of epidote and zoisite, probably formed from the unstable anorthite-molecule of plagioclase during the metasomatic generation of the porphyroblasts. Potash feldspars are also abundant in the groundmass of the rock.

Larger quartz grains occur as elongate masses which have developed by the fusing of smaller grains, as shown in their sutured boundaries. Quartz is also abundant in the groundmass, rarely below 30 percent and in many places as high as 60 percent. Plagioclase varies considerably, from 15 percent or so in mafic phases to over 50 percent in felsic. It is restricted to the groundmass; its composition is oligoclase (Ab_{73}) in both varieties. Biotite also varies considerably, occurring as elongate flakes, with elongation indices up to about 10. Pleochroism is remarkably constant; X = a greenish or grayish yellow (10Y 8/4)and YZ = olive gray (5Y4/2). Hornblende is abundant in the mafic varieties, forming up to ¼ of the mafic bands, thus up to 10 percent of the rock, though it is generally under 5 percent. It is prismatic, with an elongation index close to 3, a yellowish-green pleochroism, and locally shows contact twins, with the composition plane (100). Epidote is seen as small, idiomorphic crystals restricted to the mafic layers, or enclosed by feldspar crystals. Muscovite and tourmaline are rare, except near intrusives; cordierite also is locally developed here.

Flaser gneiss facies. The facies grades into the porphyroblastic facies towards the northwest. The bulk of the flaser are quartz, but feldspars also occur in them. Their dimensions are roughly equivalent to the metacrysts, except that they are rarely greater than 12 mm., averaging closer to 6 mm.

Granitic intrusives are also common here, though not nearly as common as in the porphyroblastic facies. In other respects, the two facies are identical.

Eastern border facies. In the southeastern part of the Glastonbury quadrangle, the eastern border facies appears. South of the New London turnpike, it is highly felsic, with biotite nowhere over 3 percent. The grain of the rock here is coarse to medium and the biotite occurs in plates rather than in knots. North of the turnpike, the rock shows a better lineation and tends to be more mafic.

The greatest width, in the south, is about one mile, and it thins considerably north of the New London turnpike. Foliation in many places is difficult to see. In the felsic phases, this is mostly due to the scarcity of platy minerals, for under the microscope, finer-grained bands alternate with coarser ones giving the rock a decided foliation plane. This feature is emphasized by the biotite and muscovite flakes which parallel it. To the north, the facies lacks a foliation altogether. Biotite is somewhat more abundant, but still only about 5 percent. Along with all the felsic minerals, it is drawn out into long stringers, giving the rock a pronounced lineation whose direction is remarkably constant. Some of these elongate cylindrical stringers reach dimensions of 11 x 1 cm., but the average is closer to 7 x1 cm. Under the microscope, smaller biotite flakes are seen discordant to this major lineament.

The largest grains are generally quartz and the largest of these are made up of sutured smaller grains. They are elongate parallel to the lineation or flattened parallel to the foliation and are fractured in a more or less regular pattern. Oriented rows of fine bubble inclusions run continuously through several large quartz grains even though crystallographic orientations may vary from grain to grain (plate II, figure 3). There is not the least break or deflection in the rows in passing from one grain to another, suggesting Tuttle's (1949) explanation that they develop in quartz that has failed by shear or tensional rupture. Muscovite is abundant, generally equal in development to biotite. Quartz shows irregular, carbonaceous and other inclusions, similar to the quartz in the felsic Bolton phases; ribboned quartz is also common. Microcline is the most abundant mineral after quartz, with many pleochroic inclusions of high relief. Plagioclase is present everywhere; as with all other facies, it is in the oligoclase range. Small euhedra of apatite, accompanied by magnetite, and sulfides are also common, as in the western border facies.

An interesting feature to note here is that the pleochroism of biotite is closer to that of the Bolton biotite than to that of the other Glastonbury facies. Thus:

Rock	X Pleochroism	YZ Pleochroism
Schistose facies Contact phase	pale olive-dark greenish yellow (10Y6/4)	moderate olive brown gray (5Y4/2)
Interior phase	greenish yellow (10Y8/4)	olive gray (5Y3/2)
Porphyroblastic-augen facies	greenish or grayish yellow (10Y8/4, 5Y8/4)	olive gray (5Y4/2)
Eastern border facies	pale greenish yellow (10Y8/4)	moderate yellow brown (10YR5/4)
Bolton schist east band	pale greenish yellow (10Y8/2)	moderate brown (5YR4/4)

Thus YZ is more analogous to the Bolton moderate brown than the Glastonbury olive gray.

Mafic schlieren. Irregular areas of mafic schlieren commonly occur, especially in the porphyroblastic facies and, to a lesser degree, in the flaser (plate I, figure 3). They are finer grained than the enclosing rock, generally with a discordant contact but with harmonious foliation, and are thus an early-formed phenomenon. In thin-section, two directions of foliation are shown by the micas (plate II, figure 2). One direction includes all the large flakes and is parallel to the macroscopic gneiss foliation. This direction is also shown in large elongated porphyroblasts of sutured smaller grains of quartz in the schliere. The other direction is seen in small flakes of mica only and is at a high angle to the first. Most probably this latter direction represents an original one; it is sensibly parallel to the contact, and may represent a pre-metamorphic S-plane, as a bedding or flow banding.

Grain-size is under ½ mm. The minerals present are identical to those of the gneiss itself; percentage of each is the only difference. Biotite and epidote are very abundant. Muscovite, microcline, quartz and calcic oligoclase round out the assemblage.

These schlieren may represent isolated remnants of former continuous marly pelitic beds to which potash-rich granitic fluids had been added. Certainly, there are mafic layers among the gneiss bands that approach these schlieren in composition, with grain-size the chief difference. The suggestion is again that of an origin in migmatization.

Aplites. Aplite dikes are very common throughout the Glastonbury gneiss, especially about the porphyroblastic and western border facies and, to a lesser degree, in the flaser. Generally pegmatites accompany the aplites and, though one is not seen stemming from the other, any area that abounds in one abounds in the other.

Contacts between the dikes and the gneiss are generally sharp, but the foliation of the Glastonbury runs through the aplite. Aplitic veins are also found in a lit-par-lit relationship; these latter veins are nowhere over a few inches thick. The intrusion of aplite appears to be early syn-tectonic, explaining the presence of both the discordant contacts and the concordant foliation and concordant veins. Under the microscope, the concordancy is well shown by the interruption of the gneissic biotite layers at the vein contact, but a weak continuation of this layering in the aplite is carried along by fine-grained felsic minerals. Occasionally, a larger flake of biotite identical to the biotite of the gneiss is seen in the aplite, still parallel to its original gneissic direction. Small euhedra of epidote are also seen in stringers parallel to this direction.

Texturally, the aplites are fine grained, xenomorphic-granular. In some of the elongated grains that show foliation, dimensions reach 0.4 x 0.2 mm.; however, the grains are generally smaller, equidimensional, about 0.2 mm. The aplite minerals are the same as the felsic minerals of the gneiss, except that oligoclase is more sodic here. Microcline with inclusions is very common, reminiscent of the porphyroblasts with inclusions; quartz has numerous bubble inclusions, but they do not seem to be oriented. Epidote and biotite, generally inherited from the intruded gneiss, round out the assemblage.

Pegmatites.† Pegmatites in the Glastonbury are common in the aplite areas. Their greatest concentration, however, is in the southwest, intruding the Bolton schist, Middletown gneiss, and Glastonbury gneiss. It is in that area that the chief commercial pegmatites occur.

Pegmatites represent at least two different ages. Many of the narrower ones, under a few feet in diameter, show the same harmonious structure that the aplites do. Samples from Town Woods Hill and the New London Turnpike area, and from the Buckingham quarry (plate I, figure 4) show this very well. A foliation is preserved in the pegmatite by elongated quartz stringers that never get over 3 mm. in diameter, but reach 10 mm. and more in length. These seem to cut through the coarse potash feldspar crystals that make up the bulk of the pegmatite. Other definite evidence relating the pegmatites to the gneiss can be seen in the common joint patterns that run through both rocks. This is especially well shown at the Buckingham quarry, where, again, the foliation of the gneiss is preserved in the harmonious quartz stringers. The foliation of the gneiss here is N25°E, 10°NW, with a lineation due to mineral orientation of S40°W. plunging 2°. It is cut by a cross joint N75°W, 87°SE, and a longitudinal joint N35°E, 75°SE. Both these joints are early, and also cut through the pegmatite whose contact with the gneiss is clearly discordant.

The larger, commercial pegmatites do not show this harmonious relationship. They seem to lie in the joints of the gneiss rather than being cut by them. Occasionally, a crude fracture cleavage is developed in them, but this is not parallel to the foliation of the gneiss and may indicate an early post-tectonic age. This pegmatite type has yielded samarskite and

† The pegmatites of the area were studied by Dr. Frederick Stugard, Jr. (1953 and report in preparation), of the U. S. Geological Survey, and are covered in detail in his report.

uraninite whose age has been determined. Samarskite from the Spinelli quarry of East Glastonbury was analyzed by Nier, Thompson, and Murphey (1941, p. 113), using the more precise mass spectrographic methods rather than the formerly popular simple chemical analysis. Their results for the three radioactive series, in millions of years, are as follows: RaG—253, ThD—266, AcD—280, all $\pm$ 60. The close agreement in the three determinations indicates that there was no serious alteration and that equilibrium was achieved. This age suggests Mississippian. Since these pegmatites are probably post-tectonic, deformation and migmatization in the Glastonbury area may have been Acadian rather than Appalachian.

Monson Gneiss

The Monson gneiss crops out as a persistent band to the southeast of the eastern Bolton band. It can be traced northwards through the state, and to its type locality in Massachusetts where it has been called the Monson granodiorite by Emerson (1917, p. 241). In the Glastonbury quadrangle, it occurs only in the southeast corner. It bears a superficial resemblance to the Glastonbury gneiss, which led Foye (1950, p. 51) to consider the Glastonbury as equivalent to the Monson. However, the coarse flaser and porphyroblasts of the Glastonbury are not seen in the Monson, potash feldspar and perthite are practically non-existent, and plagioclase is better developed and more abundant; besides it is a sodic andesine, Ab_{63-67}, rather than oligoclase. Lastly, hornblende is more abundant than biotite, though Foye states that biotite is better developed away from the Bolton contacts (thus off this sheet).

The rock is a fine- to medium-grained, well-foliated felsic gneiss. Plagioclase makes up over half of it, quartz about 40 percent and hornblende and biotite the rest. Apatite and magnetite are abundant in the sections studied. Elsewhere (Westgate, manuscript) orthoclase and garnet are seen. Amphibolites are very common, largely as concordant bands in the gneiss. They have also been reported as discordant and massive; Westgate's conclusion that they were therefore eruptive could not be tested here because of the lack of outcrops. Well-developed hornblende crystals comprise about half the rock, and andesine plagioclase, Ab_{63}, the rest. Apatite and magnetite are important accessories. Texturally, the amphibolites are fine- to medium-grained, xenomorphic-granular, with a directed texture due to aligned hornblende prisms.

STRUCTURE

Structural relationships in the Glastonbury quadrangle will be considered under three general headings: structure of the Triassic Lowland, form of the Triassic border fault, and structure of the crystalline upland.

Triassic lowland. There are decidedly few outcrops of Triassic formations in the Glastonbury quandrangle, and so few structural data are available. Practically the entire area underlain by Triassic is now covered by river alluvium, aqueoglacial deposits, and ground moraine.

Structural readings, in the northern part of the sheet, about Addison and Salmon Brook, reveal a northwest strike and a dip northeast of 15° to 18°. To the south, in the bed of Roaring Brook, a northeast strike and a dip of 28° southeast were obtained. Between these two outcrops, 0.3 mile northwest of Williams School, in Glastonbury, Connecticut Highway Department road core 112 passed through Triassic siltstone having a very low angle of dip. These limited data suggest an anticlinal structure plunging east or east south-east, and offset about 3 miles northward of the Rocky Hill anticline just across the Connecticut River.

No observations regarding possible Triassic Valley faulting, such as the Lamentation fault of Davis (1898), were made in these few outcrops, which showed no sign of such deformation.

Triassic border fault. The fault cannot be directly observed anywhere in the quadrangle but abundant evidence for its presence can be seen. Those phases of the crystallines that border it are invariably mylonitized, or are fine-grained aggregates of former coarser rocks. Lineations caused by mineral alignment or slickensides are abundant in all formations near the fault and point down dip towards it. Away from the fault, these lineations die out, and different ones pointing in different directions appear. These observations, however, merely prove the existence of the border fault and yield no information on its general form.

From the limited well data available, the fault appears to enter the quadrangle, in the southwest, some 500 feet west of route 17 headed north. About South Glastonbury, it arches gently northeast, then appears to arch back to the north about the Manchester town line. Davis (1898) attributed these directional changes to an offset of the border fault by the Triassic Valley Lamentation fault. Wheeler (1939), after making aeroplane observations, thought them due to a warping of the fault plane itself. He believed that the Rocky Hill anticline indicated a "lag point," the result of friction on the Triassic beds when they were downfaulted along this warp.

The evidence for and against these two hypotheses in the Glastonbury sheet is decidedly inconclusive. If the Rocky Hill and Glastonbury Triassic anticlines are equivalent, then the part of the border fault that enters the quadrangle from the south is continuous to at least north of Glastonbury. In that case, Davis, Lamentation Fault, whose direction is northeast, becomes the border fault about South Glastonbury. However, no "trap conglomerate" was found in South Glastonbury, alleged by Davis to prove the continuation of the Lamentation fault. Further, the foliation in the crystalline rocks generally follows the direction of the border fault with little suggestion of discordance. The crystalline rocks themselves all show lineations that are partially displayed by early formed tectonic minerals and point towards the border fault. This last evidence suggests that the direction of the Triassic border fault had already been determined in pre-Triassic times, and further, that it is a single warped plane.

In the structural cross-section, the border fault is shown dipping to the west at an angle of 60°. This figure is derived from Longwell (1922), who concluded that the dip is 67° west, and Digman (1950) who made a direct measurement of 55° west.

Crystalline upland. The Middletown and Bolton appear conformable to each other where they are in contact, to the west of the Glastonbury gneiss. In general, both formations strike north-south, parallel to their contact, and to the Triassic border fault, and dip westward at moderate to steep angles into the fault. Their structure may be much more complicated than may first appear from the map, for lacking key beds to prove or disprove the hypothesis, there is a very good possibility that either the Middletown or the Bolton, or both may be isoclinally folded. At many outcrops, small-scale isoclinal folds and intense crenulation can be observed in both formations, suggesting strongly that these same structures are repeated at a larger scale (plate I, figure 1, and plate II, figure 1).

Further evidence for isoclinal folding in the west band of the Bolton is that its dips are steeper on the west side than on the east. Thus dips in the Middletown, along the Bolton west contact, average about 75° west; in the Glastonbury, along the east contact, the dips average only about 30° west. The Bolton must then disappear rapidly in depth if these dips persist in depth. This disappearance is easily explained if the present Bolton outcrop area merely represents the trough of a nearly isoclinally folded syncline.

The eastern Bolton schist band also dips to the west at moderate to steep angles. If the western Bolton band is isoclinally folded, and the eastern Bolton band is also overturned, then the two bands form the limbs of an anticline strongly overturned to the east. The Glastonbury gneiss takes the stratigraphic place of the Middletown gneiss which was partly granitized and partly stoped out. The presence of this anticlinal structure can be demonstrated within the Glastonbury gneiss itself. Keppel (1941) made this observation on the Glastonbury gneiss: "The structure of the gneiss seems to be a dome with the axis overturned to the east in the southern portion." To the north, where the Glastonbury thins out in outcrop area, Keppel noted that "both walls of the intrusion dip at angles of 30-40° to the west, and the whole structure seems to be a monocline dipping to the west."

Mapping in the Glastonbury quadrangle confirms the existence of this dome. In the area about Buckingham, the strikes can be seen wrapping around, from northeast in the west to east-west to southeast in the east, everywhere with a northerly dip. In the central and southern parts of the quadrangle, the dome pattern is complicated by a thrust fault, which probably dips steeply to the west with about the same dip as the axial plane of the elongated dome. The dome structure can still be generally made out, with steeper dips along its east margin than on the west, indicating an overturning to the east in the eastern border facies of the Glastonbury gneiss, as well as in the Bolton schist.

The Glastonbury gneiss appears conformable to the Bolton schist contact, in the west, striking parallel to the contact and dipping west under it. The contact in the east is generally conformable; in those places where a structural discordance appears, it is probably due to the presence of the thrust fault. Near the western contact, the Glastonbury is represented by the schistose facies, but it rapidly passes into the porphyroblastic facies. As it does, the trend parallel to the Bolton is lost, and the dips become much gentler, rarely over 20°.

The foliation planes are then gently undulating both in the porphyroblastic and in the flaser facies which appears next to the east. A strong lineation, largely of felsic minerals and streaked and elongated biotite knots, plunging N35°E, is seen in this central body. This direction is also parallel to the Triassic border fault and emphasizes the early nature of the Triassic direction.

The central area must represent an axis of migmatization. Mafic schlieren are very common in these coarser-grained facies, and abundant concordant and discordant aplites point to a source for the large-scale potash metasomatism that effected the change. The transition into a schistose facies to the west, which in turn is in contact with the Bolton schist, adds further credence to this argument.

The eastern border facies of the Glastonbury appears against the eastern Bolton contact. This is concordant in most places, as stated above. Both formations strike about N20°E and dip west steeply; the chief exception to this is the non-foliated phase of the Glastonbury eastern border facies. These rocks have a better than average lineation which may indicate that rotation about this lineation destroyed the existing foliation (Cloos, 1946, p. 17). The rotation could best be attributed to cataclastic deformation in the area as indicated by the thrust fault contact between the Glastonbury and the Bolton. Going south, this fault appears to head into the Glastonbury.

Southwards, this fault may be indicated by a discordance between the border facies and the flaser facies. The border facies shows high dips and a structural trend parallel to the Bolton contact. The flaser facies shows no such thing, and there is no structural transition. Thus, the fault may be traced roughly along the Bolton-Glastonbury contact north of the New London turnpike, and trending into the Glastonbury south of the turnpike. It strikes about N25°E and dips steeply to the west.

Evidence for this fault may also be found on other quadrangles. In the Middle Haddam sheet, a thick band of Bolton quartzite suddenly disappears below Great Hill Pond. The fault trends directly towards the pond and would cut off the quartzite. Northwards, on the Rockville sheet, the quartzite also disappears. Aitken (personal communication), mapping in the Rockville quadrangle, has found a marked structural discordance along the fault trend line. Keppel (field notes) found a continuation of this well-lineated facies in the Rockville sheet, also in contact with the Bolton. His thin-sections show a tendency for two mica orientations; one pronounced and including all the large mica flakes, and the other, weaker, transverse to the first, and consisting only of small flakes. The weaker one shows the old foliation; the newer, stronger direction is an outgrowth of the developing fault.

It seems plausible that this felsic gneiss represents a transition into the Bolton. The Bolton here is sericite-rich, quartzose, and coarse grained. Thus, an analog can be made to the western contact where a transition may also exist.

The Bolton and the Monson, in the southeast corner, appear conformable, striking parallel to their contact and dipping moderately to the west.

SUMMARY AND CONCLUSIONS

The Glastonbury quadrangle is divided geographically into a northwestern low flat area and a southeastern rolling upland. The northwest is underlain by easily eroded Triassic arkosic sandstones, a fluvial deposit called the Portland formation, and is bounded to the southeast by the border fault. The highlands are underlain by a series of schists and gneisses, probably of early to middle Paleozoic age: the Middletown gneiss, the Bolton schist, the Glastonbury gneiss, and the Monson gneiss, with included pegmatites and aplites. The Middletown, Bolton, and Glastonbury all appear to be concordant in the west, and in part overturned towards the east. The east and west Bolton bands may be the limbs of an overturned anticline, and the Glastonbury occurs dome-like along the axis of this anticline. The western border phase of the Glastonbury is a schistose facies that may represent a transition from the Bolton, with increasing felsic mineral concentration and potash metasomatism. The source for large-scale potash metasomatism appears to be in the coarse porphyroblastic facies next east, which includes much aplitic and pegmatitic material. This grades east into the flaser facies which represents a phase closer to the original rock. Flaser are largely of quartz and might be quartz pebble relicts; the large quartz bulk in the rock further indicates a sedimentary origin. To the east, an eastern border facies appears with a high felsic content. This too seems to represent a transition into the Bolton, for the first Bolton facies in the east band is a sericitic quartzite. A non-foliated phase of this facies shows a very strong lineation. It seems probable that this rock has undergone cataclastic deformation as a result of thrust faulting between it and the Bolton. A fault in this place would also explain the disappearance of the Bolton quartzite south of Great Hill Pond on the Rockville sheet. The quartzite itself shows a good lineation, by slickensiding, towards the fault. This fault may be Paleozoic because it lacks some of the phenomena associated with the Triassic faults. There are no mylonites here, but rather coarse-grained rocks. Further, these rocks have not undergone marked retrogressive metamorphism to the chlorite facies, as crystallines associated with Triassic faulting show. The fault must have developed after the doming of the area for it obliterates the foliation that is associated with the doming. A late-tectonic date for faulting would explain the recrystallization of any mylonites. A structural discordance exists in places between the eastern border facies and the flaser gneiss facies, indicating that the fault either does not follow the schist contact in all places or maybe more than one fault, en echelon. The Monson gneiss, southeast of the Bolton is concordant. Pegmatites in the area are either narrow, with a harmonious foliation indicated by elongate quartz blebs, or wider, the commercial varieties, some of which posses a fracture cleavage harmonious with the gneissic foliation. The former are earlier than the latter.

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PLATE I

Figure 1.

Figure 2.

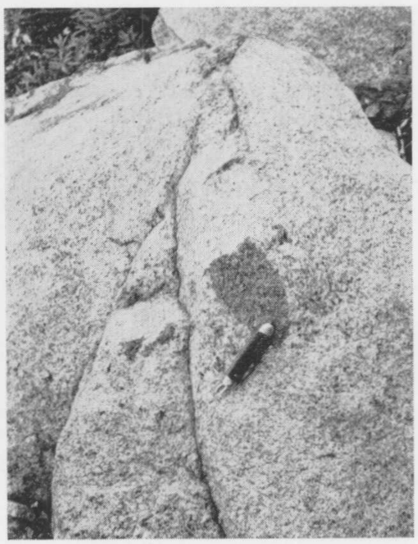

Figure 3.

Figure 4.

Figure 1. Epidote-rich facies of Bolton schist, western band. Picture taken in area of isoclinal folding, Nob Hill road, 1½ miles northeast of South Glastonbury.

Figure 2. Discordant contact between augen gneiss facies (left) and interior schistose facies of Glastonbury gneiss. Shows harmonious foliation passing from one into the other. Sunset Drive, near Hopewell.

Figure 3. Mafic schlieren in coarse pink augen facies of Glastonbury. Foliation nearly vertical. Chestnut Hill road, about 1½ miles northeast of Hopewell.

Figure 4. Syntectonic pegmatite intruding interior schistose facies of Glastonbury gneiss. Shows a discordant contact, harmonious foliation, and a mutual joint pattern between the two rocks. Buckingham quarry.

PLATE II

Figure 1.

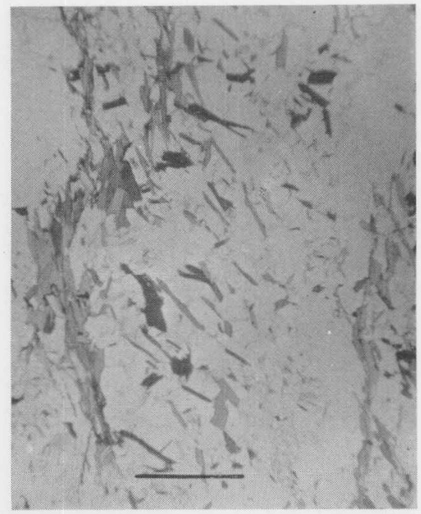

Figure 2.

Figure 3.

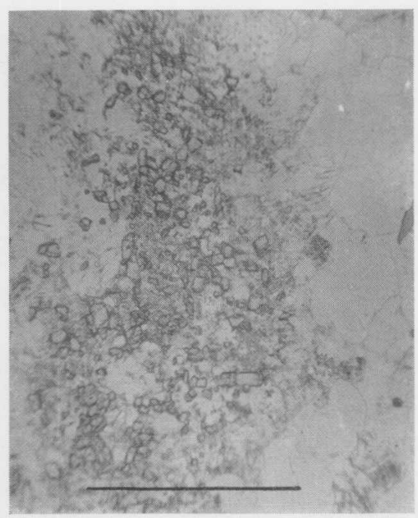

Figure 4.

Figure 1. Isoclinal folding in Bolton schist shown in mica-epidote bands. Crossed nicols.

Figure 2. Two directions shown by biotite in Glastonbury gneiss. Vertical direction visible in hand specimen as the foliation plane; direction inclined upper left—lower right may represent the S-1 plane (bedding, flow, etc.). Plane light.

Figure 3. Mafic banding alternating with felsic in eastern border facies of Glastonbury gneiss. Mafic bands biotite-epidote rich; felsic, feldspar-quartz rich. Oriented bubble inclusions in quartz (near center of field) run through several grains. Plane light.

Figure 4. Epidote grains concentrated in a large potash feldspar porphyroblast. Surrounding grains largely quartz. Plane light.