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# REPORT

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## COMMITTEE ON THESIS

THE undersigned, acting as a committee of the Graduate School, have read the accompanying thesis submitted by Alfred E. Mallon for the degree of Master of Science. They approve it as a thesis meeting the requirements of the Graduate School of the University of Minnesota, and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science.

W. H. Emmons,
**Chairman**

Frank F. Grout

C. F. Sidener

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Chairman

191

# THE HOLYOKE RANGE.

A Thesis Submitted to the Faculty of the
Graduate School of the University of Minnesota

by

Alfred E. Mallon

In partial fulfillment of the requirements
for the degree of Master of Arts.

1915

## THE HOLYOKE RANGE.

### Location.

The Holyoke Range is situated in the central part of Hampshire county, Massachusetts. It extends west from the Belchertown Ponds to the Connecticut River, which it crosses, and turning at a right angle follows the river south into Hampden county.

That part of the range which is treated in this paper extends from Mt.Norwottock, three and one half miles west of the Belchertown Ponds, to the Connecticut River. This district lies fifteen miles north of Springfield and five miles south of Amherst. It is 42°16' north latitude, and between 72° 30' and 72° 38' west longitude.

### Previous Work.

The first geological work done in this region was by Edward Hitchcock in 1815. His most detailed work, however, was done from 1845 to 1855, when he came to the conclusion that the Holyoke Range was formed by the upturned edges of two successive lava flows.

W. M. Davis is of the opinion that the two trap sheets are partly intrusive and partly extrusive.

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Descriptions of sections measured across sandstone and trap of Connecticut.
Proc.Am.Assoc.Adv.Sci. Vol.IX p.225.

Structure of the Triassic formation of the Connecticut Valley.
Jour.Sci. 3rd series, Vol.XXXII p.342

Dana in his Manual of Geology (page 807) considers both trap sheets as intrusive.

B. K. Emerson, who has worked with greater detail in this region than any of his predecessors, believes the main Holyoke sheet to be extrusive, and the smaller one to be a series of dikes intruded into the sandstone.

U.S. Monograph XXIX.
U.S. G.S. Folio 50.

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Structure of the Triassic formation of the Connecticut valley. - Am.Jour.Sci.3rd series, Vol.XXXII, p.342. (1886)

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Whittle, C.L.
Intrusive and extrusive Triassic trap sheets of the Connecticut valley. - Bull.Mus.Comp.Zool. Harvard College, Vol.XVI, p.99. (1889)
Triassic of the Connecticut.- 18th Ann.Rep.U.S.G.S. Vol.II, p.1.

## Topography.

A bird's eye view of the district would show two ridges, the northern one high and the southern one low. The north side of each ridge is precipitously steep, while the south side is a gentle slope. A level plain surrounds the two ridges.

The lowest point is in the western part of the district, at the river's edge, with a height of 85' above sea level. The Holyoke Range rises rapidly for a mile from the eastern side of the river to Mt.Holyoke,954', but reaches its highest point four miles farther east,where Mt.Norwottock rises to 1115'. Many drumlins flank the steep northern side of the main ridge.

It is a long ridge, with numerous breaks. The first low place is where the Connecticut River cuts its way through the rocky mass. The second is just to the east of Mt.Holyoke, where the altitude of the range drops from 954' to 645'. The third is a lesser depression, with an elevation of 690'. The fourth is the well known Notch, where the altitude of the ridge decreases to 525'. This is the only place along the ridge, except at the river, that is suitable for a road crossing. The fifth is east of Rattlesnake Mt., where the ridge falls to 610'; and the last is east of Mt.Norwottock.

## Mapping.

The mapping of this region was done during the spring months of 1913 and 1914, under the direction of Prof.B.K.Emerson of Amherst College; part of it was done in the advanced courses of field geology, for the primary purpose of correcting certain inaccuracies in the geologic map of Folio 50, and much of it was done independently of the college course in field work.

The Holyoke Range is heavily covered with timber and dense underbrush. As but one road crosses the range, the geologist must depend for location on a few indistinct wood roads, pacing, and compass.

## Acknowledgments.

The writer wishes to express his thanks to Prof.Emerson, whose instruction and advice were of great assistance; to Messrs. R. W. Whipple and A. L. Kimball, who assisted in mapping; and to Dr. W. H. Emmons of the University of Minnesota for aid in preparation of this report.

## Descriptive Geology.

There are two sandstone formations in this district, one being a coarse variety known as Sugar Loaf Arkose, the other, very fine-grained, known as Longmeadow Sandstone. The latter extends in a narrow strip up the Connecticut Valley, with arkose bordering on both the eastern and western boundaries. Its most northern extremity is just south of the high Holyoke ridge, with the arkose bordering also on the north. The contact between these two sandstones is not sharp, but is a gradation from fine to coarse. They are both of the same period of deposition, the arkose being the shore deposit, and the Longmeadow the quiet water deposit.

Only the southwestern part of this district contains Longmeadow sandstone, all the eastern, northern and central being arkose.

For the sake of description, the sandstones in this district are divided, regardless of formation, into the lower, middle, and upper. The lower sandstone lies north of the high ridge; the middle sandstone lies between the high and the low ridges; and the upper lies south of the low ridge. The traps are divided into lower and upper, according to their relation with the sandstones. Actual contacts show the stratigraphical succession to be upper sandstone resting on tuff, tuff on upper trap, upper trap on middle sandstone, middle sandstone on lower trap, lower trap on lower sandstone.

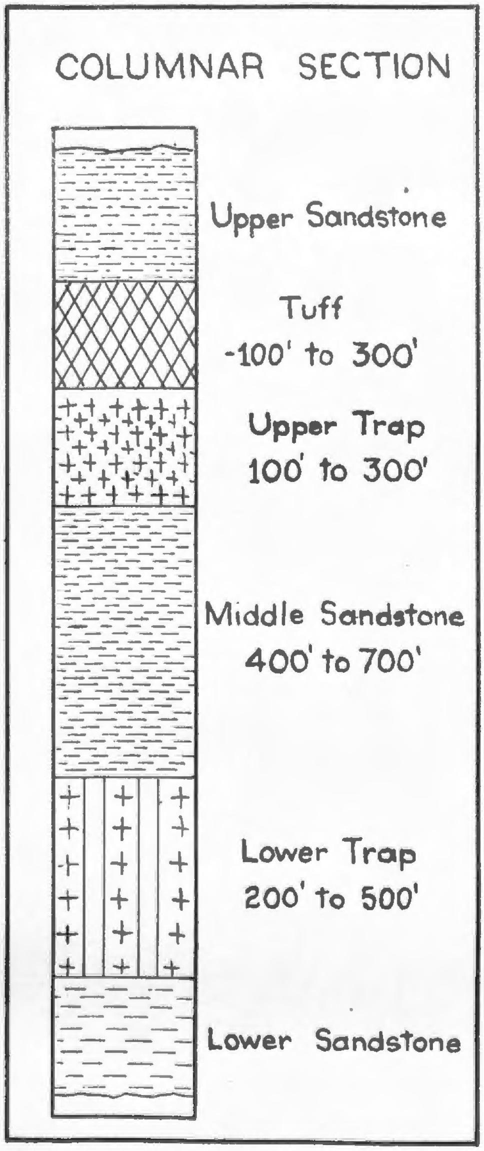
COLUMNAR SECTION
Upper Sandstone
Tuff
100' to 300'
Upper Trap
100' to 300'
Middle Sandstone
400' to 700'
Lower Trap
200' to 500'
Lower Sandstone

Fig. 1

## Lower Sandstone.

Lower sandstone immediately underlies the trap of the main ridge, and outcrops on the steep northern and northwestern side of the range for six miles from the Connecticut River to Mt.Norwottock. Its depth is unknown. The artesian wells of the Parson Paper Co. in Holyoke (510' and 685'), and that of the Belding Silk Mill in Northampton (3,700'), have not reached the bottom.

The dip and strike of the lower sandstone is somewhat variable. On Mt.Norwottock (E 50) it strikes N. 86° W. and dips 16° S. North of Rattlesnake it strikes N. 75° W. and dips 30° S. On Bear Mt. the strike is the same but the dip is 20°. The same dip and strike continue to the west, until at Titan's Piazza (P 2) the strike changes to N. 65° E. and dip to 22° S.E.

The lower sandstone consists entirely of Sugar Loaf Arkose - water-rounded pebbles of granite, gneiss, and quartz, and micaceous and argillaceous slates varying from sand to boulders two feet in diameter. Hematite is the cementing material. Its heterogeneous appearance and red color continue throughout its whole extent. Cross-bedding is absent, and generally stratification is visible only where frost action has split the rock along bedding planes.

The contact between the sandstone and the overlying trap is an even, straight line.. The sandstone appears to have been baked from two to twenty inches, as the pore space is greatly decreased, the rock is harder and more crystalline, and is changed from red to a dark brown. The contacts on Mt.Norwottock (E 50) show the sandstone baked over six inches, on Rattlesnake (F 43) for four inches, on Bear Mt. (G & H 40) the sandstone is baked a dark brown for over a foot and a half from the contact; on Mt.Holyoke (H 10) the sandstone is slightly baked; at Titan's Piazza the sandstone has been changed to a quartzite for ten inches below the contact; while at Titan's Pier (S 1) the sandstone has been baked but a few inches. The depth and intensity of baking varies, but at every contact the sandstone is more or less changed.

## Lower Trap.

The lower trap is widely distributed. It forms the summit of the whole range, with no covering of earth mantle, and the whole southern slope, gradually becoming more and more deeply covered with earth until only a few scattered outcrops show its presence. It also extends continuously from the Connecticut River to Mt.Norwottock. Its thickness varies from nearly 500' in the west down to 200' east of Rattlesnake, and 350' in Mt.Norwottock.

The trap contains a vast number of joints, the planes of which run in a direction generally perpendicular and parallel to the cooling surface; and along these planes the rock splits up into approximately rectangular blocks, from an inch to many feet in length. It is these joints that form the nearly vertical north side of the range, and by means of which erosion in the vicinity of a fault produces overhanging cliffs. Well defined columnar structure is developed at Titan's Piazza and at the Notch.

The trap is uniformly fine-grained throughout, but is very scoriaceous at the top from one end of the district to the other. The best exposure is at G 44, where a large hole has been blasted, exposing the trap for ten feet below the middle sandstone. Amygdaloidal trap filled with calcite and zeolites is found only in the first four feet below the contact, and the amygdaloids increase in size and number toward the surface.

Furthermore, amygdaloidal trap is found at the base of the trap sheet at Titan's Piazza and Titan's Pier. The trap is honeycombed with steamholes, some six inches in length, as far as ten feet above the bottom contact of the trap. Another peculiarity at Titan's Pier is the occurrence near the base of numerous spheres and fragments of fine-grained, dove-colored, clayey, calcareous nodules, and micaceous sandstones included in the trap. The inclusions in some cases are coarse crystalline limestone containing tremolite. These foreign materials are not segregated, but give the appearance of having been stirred in with the trap. West of the Connecticut such inclusions are fairly common, but this is the only example in the district being discussed.

## Plate A.

Photomicrograph of lower trap from Titan's Piazza.

Under the microscope it has a diabasic, porphyritic texture. This section is less altered than is usually the case in the lower trap. The lath-like plagioclases (a) are distinct and well formed in the shapeless ground mass of augite. Magnetite is not abundant, but uniformly distributed.

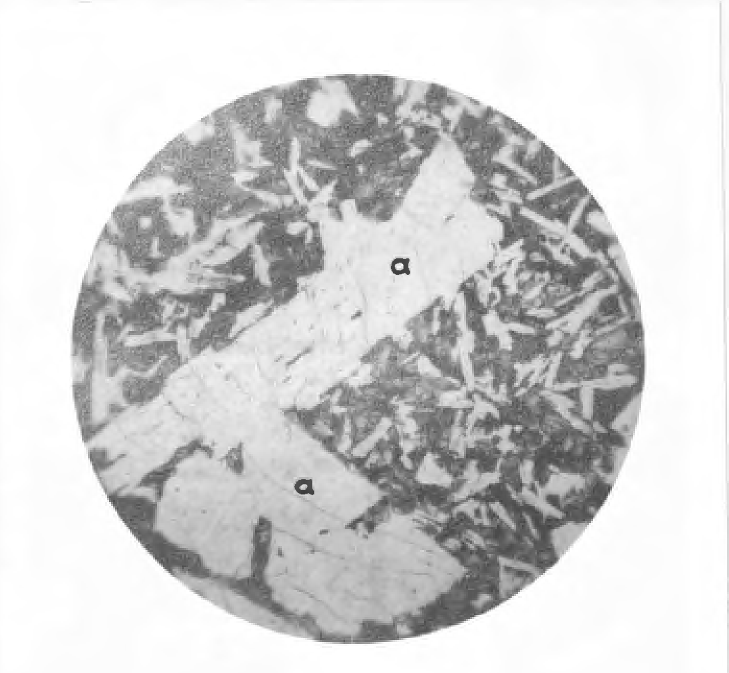

Plate A.

## Plate B.

**Photomicrograph of lower trap at Mt.Holyoke (H-10).**

Under the microscope, the rock has the common diabasic structure, but is considerably altered - a characteristic of the lower trap. Although decomposition is common to all constituents, the feldspars (a) are in the more advanced state. Plagioclase predominates. There is considerable augite and a little magnetite (b). Apatite is sometimes found. In this section there are a few small crystals of orthoclase (c).

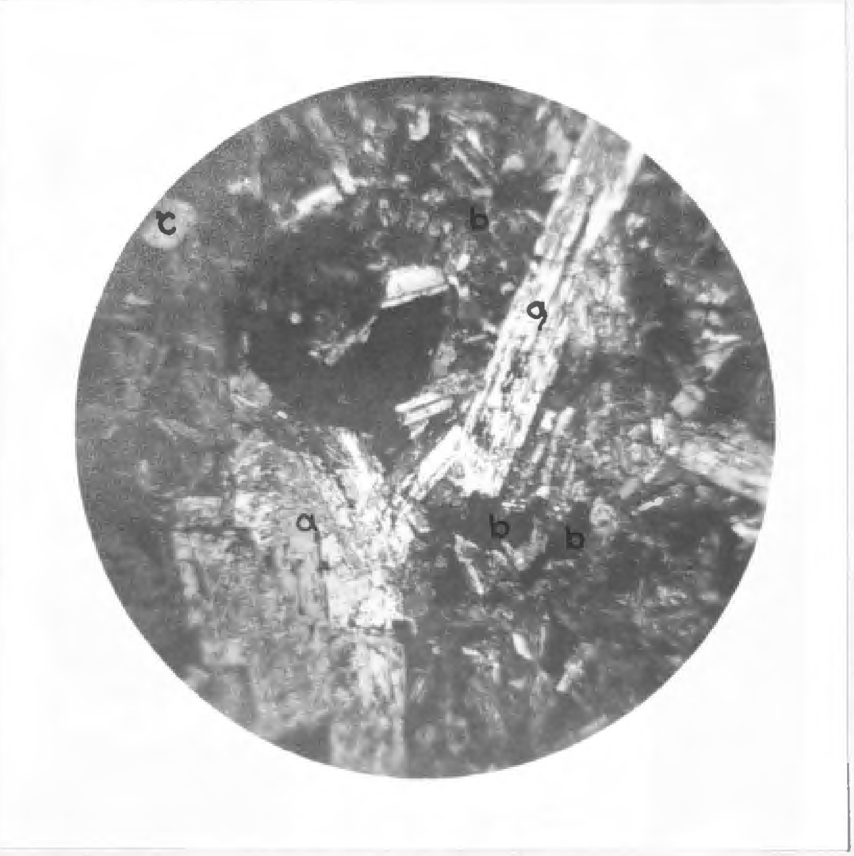

Plate B.

# Plate C.

## Photomicrograph of zeolite from lower trap on Power Line (H-44).

Is magnified eleven times. It represents a vesicle filled with zeolites and calcite. The dark mass is the trap. Around the border of the vesicle is a thin film of glass. The interior is filled with numerous, but small calcite (a) crystals, and large, feathery zeolites (b). The picture was taken with nicols crossed.

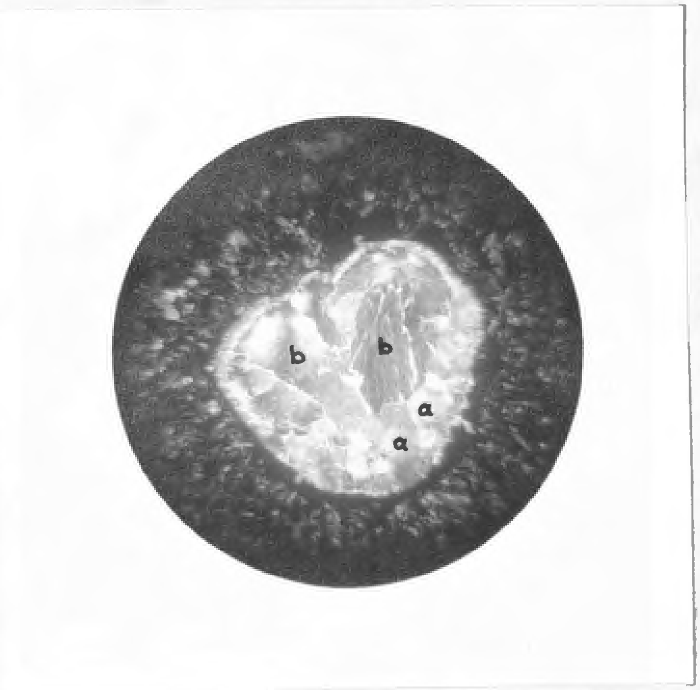

Plate C.

## Plate D.

**Photomicrograph of preceding thin section.**

Under 100 diameters with the nicols crossed. The feathery structure of the natrolite (b) crystals can be distinctly seen. The other crystals are calcite (a).

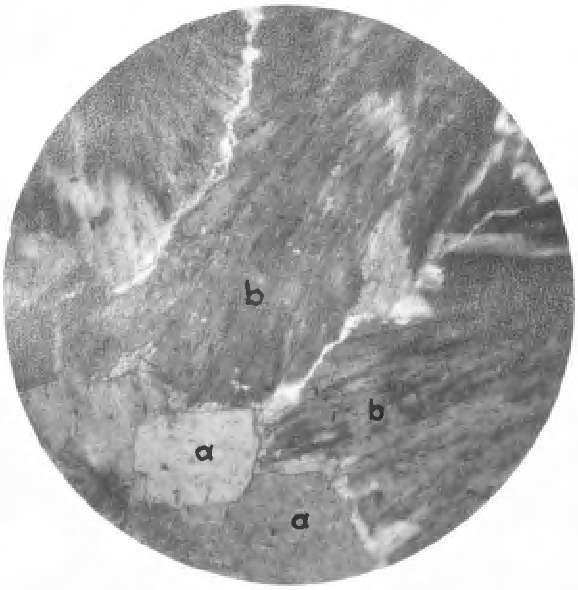

Plate D.

## Analysis of the Holyoke Trap.

by G. W. Hawes.

| | | | Mean. |
|---|---|---|---|
| $SiO_2$ | 52.70 | 52.65 | 52.68 |
| $Al_2O_3$ | 14.11 | 14.17 | 14.14 |
| FeO | 9.78 | 9.80 | 9.79 |
| MnO | .45 | .44 | .45 |
| CaO | 9.36 | 9.39 | 9.38 |
| MgO | 6.42 | 6.35 | 6.38 |
| $Na_2O$ | 2.54 | 2.57 | 2.56 |
| $K_2O$ | .89 | .87 | .88 |
| $H_2O$ | | | |
| S & loss | | | |
| Ig. | 1.61 | 1.58 | 1.60 |
| $Fe_2O_3$ | 1.87 | 2.03 | 1.95 |
| | 99.73 | 99.85 | 99.80 |

In no place does the trap bake the overlying sandstone. In fact, in many places along the almost continuous line of contact south of Mt.Norwottock, each little cavity in the scoriaceous surface of the trap was observed to be filled with sand grains, with no indication whatever of metamorphism. The trap baked the sandstone below, but did not affect the sandstone above.

From the Notch road (I 39) west to the Connecticut River the contact between the trap and overlying sandstone is concealed.

The lower trap is a black, aphanitic basalt, and is the same throughout its whole extent. Under the microscope it is a porphyritic diabase, with phenocrysts of plagioclase in a groundmass of augite, and a few scattered grains of magnetite. Small crystals of orthoclase and apatite are sometimes present.

The trap is an extrusive flow; as evidence of this, the underlying sandstone is baked but the overlying sandstone is unchanged. The trap is scoriaceous along the top, and contains steamholes and inclusions at the bottom, besides other evidences of flow and underrolling along the bottom of the mass.

## Middle Sandstone.

From the eastern end of the district to Trap Hill, middle sandstone lies in a wide belt between the high and low trap ridges. The hard edges of the sandstone outcrop everywhere through the till, in parallel ridges of miniature hogbacks. It also extends in a narrow strip west of Trap Hill and along Dry Brook. Its thickness is problematical, as its width of outcrop is so diverse, but probably varies from 400' to 700'.

There are great variations in the strike and dip. South of Mt.Norwottock the sandstone strikes N. 85° W. and dips 20° S. To the east of the supposed power line fault (H 44) it dips 21° S., and on the western side 28° S. Westward to Tuff Hill the strikes average N.85° W. and dip is 22° S. West of Trap Hill the strike suddenly changes to almost north and south, with a dip of 20° to the east. Just south of Mt.Holyoke (L 12), a small outcrop of

Longmeadow Sandstone entirely surrounded by trap strikes N. 75° E. and dips 40° E. Farther south (P 7) where the same sandstone again appears, it strikes N.70° E. and dips 28°E.

The middle sandstone consists of Sugar Loaf Arkose already described, and Longmeadow Sandstone. The latter is a thin-bedded, fine-grained, micaceous, shaley sandstone, deep red in color. It contains ripple marks, mud cracks, rain drops, and - on the western side of the Connecticut - hundreds of tracks of Triassic animals.

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Emerson,B.K.-Geology of Hampshire Co.,Mass.
U.S.G.S. Monograph XXIX, p.379.

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It is finely laminated and in places cross-bedded.

The middle sandstone along Dry Brook consists entirely of the Longmeadow type. Its gread width at the river road (U 4) pinches out toward the north until no middle sandstone separates the two trap sheets. A small outcrop appears again on Dry Brook, directly south of Mt. Holyoke (L 11).

West of trap hill (O 15), the arkose variety appears in the middle sandstone. But the Longmeadow does not suddenly disappear. Beds from two to six inches thick can be found grading into or interbedded with the arkose. East of Trap Hill this interbedding of the Longmeadow and the arkose still continues, but with a gradual disappearance of the former, until, east of Elmer Brook (N 32), the Longmeadow sandstone can no longer be found.

The contact between the sandstone and the lower trap is exposed continuously south of Mt.Norwottock. West of the Notch the contact is usually concealed, but can be mapped with fair accuracy by drawing the boundary between the nearest outcrops of the two formations.

The upper trap overlies the middle sandstone on a plane surface, as can be seen in many places:
(1) west of Trap Hill; (2) east of Lithia Brook where the Lithia road cuts through the upper trap; (3) from the power line (N 43) east. The arkose portion does not seem to have been baked by the trap, but the Longmeadow sandstone at the

Lithia road has been baked for half a foot. At S 6, where it is all of the Longmeadow variety, the sandstone has been baked over two feet deep. This baking makes the Longmeadow sandstone more brittle, develops good cleavage, and changes the color to a deep brown. The mineral composition remains the same. Quartz grains have increased in size, and mica is more evident.

## Upper Trap.

The upper trap is in wider blocks in the west than in the east. East of Dry Brook it forms the great ridge which extends northeast, forming the base and part of the top of Tuff Hill. It extends from the river road (V 8) eastward to Lithia Brook, and thence northward for half a mile, forming the whole of Trap Hill. From Lithia Brook to the Notch road, it appears irregularly along the ridge. It is continuous from a point 40 rods E. of the Notch road to the eastern end of the district. Its thickness varies from 300' in the west to 100' in the east.

Megascopically the upper trap is the same as the lower trap. It is an aphanitic black basalt, divided by joints in identically the same way as the lower trap, but does not develop columnar structure. The only certain means of distinction is by microscopic examination. The upper trap has the same texture and mineral composition as the lower, but with the addition of olivene crystals.

The trap is uniform from the top to the bottom of the bed. It rests on and bakes the middle sandstone in the places already mentioned. It is overlaid by tuff. It contains no inclusions, but its upper surface is very scoriaceous. Scoriaceous trap appears from:
(1) U 7 to R 11; (2) S 12 to R 18 on Lithia Brook; (3) R 16 to R 18; (4) M 17 to R 18; (5) in patches along the southern border of the trap blocks to the eastern end of the area mapped.

In some places no distinction can be made between the upper surface of the trap and the overlying tuff. There seems to be a neutral zone from one to six feet think, in which both tuff and trap are mingled. Distinct blocks of trap can be seen cemented together by more trap. It

## Plate E.

## Photomicrograph of upper trap at the Lithia Road (P 22)

It is a dark gray, compact, fresh-looking rock. Under the microscope it has a diabasic structure with an abundance of the plagioclases, anorthite and labradorite in a well formed, but somewhat altered augite. The plagioclases (a) stand out prominently in the photograph, while the augite and sparsely scattered octahedrons of magnetite (b) are less distinct. One crystal of olivene (c) can be seen near the center. Olivene is present in the upper trap in small amounts, and is the only means of distinguishing the upper trap from the lower. There are also a number of calcite crystals. This photomicrograph is magnified 100 times.

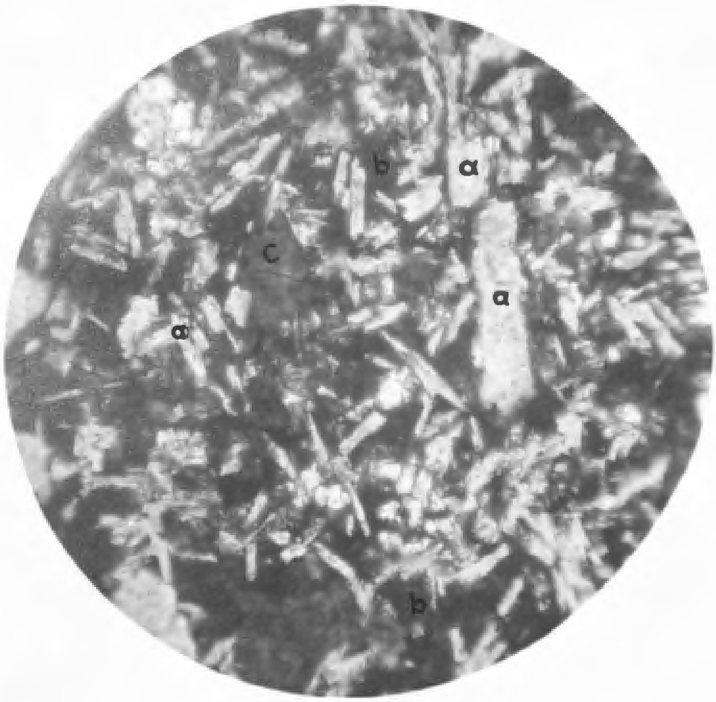

Plate E.

gives the appearance of solidified blocks of trap and tuff dropped into the semi-liquid surface of a trap flow. This can be seen on the north slope of Trap Hill, and where the Lithia road crosses the upper trap.

The zone of fragmental trap and tuff in the top of the trap sheet, and the scoriaceous top surface, wherever the latter is exposed, indicate that the trap is extrusive.

### Tuff.

Tuff is more widely distributed in the western than in the eastern portion of the area mapped. It forms the top of Tuff Hill and extends southward in a block almost a mile long by a quarter of a mile wide. A narrow band of tuff borders the eastern side of Trap Hill. Farther south of these two occurrences, it extends continuously from the river road to the eastern end of the district, varying from a few rods to a quarter of a mile in width.

The tuff has its greatest thickness on Tuff Hill, where it reaches 300'. This is exceptional, as it is usually a little less than 100' thick, and in places much less.

On Tuff and Trap Hills, the tuff strikes north and south and dips east at a low angle. Throughout the remainder of its extent, however, it strikes generally east and west, and dips south. At Lithia Brook it strikes N. 75° E., and dips 18° S. At the Notch road, it strikes east and west, and dips 16° S. From the Notch road to the eastern end of the district, the tuff dips between 21° and 25° S.

The tuff is not perfectly uniform. Most of it is reddish in color and consists of volcanic ash, bombs, and pieces of trap, gradually changing into an ash bed. In other places it is a fine-grained black rock much similar to trap, but intermingled with grains of sand and small pebbles, and it has an easy cleavage along the bedding plane. This variety overlies the former and is transitional between it and the upper sandstone. It is called tuffaceous sandstone. It seems to consist of fine trap dust which took longer to settle, gradually becoming intermingled with muds and sands washed in from the surrounding hills. It grades into the upper sandstone. It is found in two places: south of the Notch road and west of Lithia Brook.

The tuff grades from coarse to fine, from bottom to top, and from west to east. The best example is found at Tuff Hill. The lower part of the tuff consists of great blocks of trap, some three and four feet in length, in a mass of volcanic ash, bombs, etc. Toward the top, the tuff presents a less heterogeneous appearance. The blocks of trap gradually become smaller in size and fewer in number, until they disappear entirely. It then consists of trap dust and ash. This gradation can also be traced in the tuff from west to east. It becomes finer and finer, until at a point east of the Notch road it consists only of volcanic ash.

In some places the tuff is so hard and black that it has the appearance of trap, but the invariable presence of mica gives the clew to its identity. Under the microscope its heterogeneous character is apparent. It is composed of fragments of glass, steam-hole trap, trap with inclusions of plagioclase, biotite crystals, quartz, calcite and magnetite.

The tuff is probably the result of a volcanic explosion somewhere west of the Connecticut, which hurled blocks of trap, bombs, dust and ash into the air. The heavier blocks sank in the surface of the upper trap, while the rest dropped on the surface. Part of the tuff was evidently water sorted, and grades into upper sandstone.

### Upper Sandstone.

The upper sandstone is concealed by glacial lake sands from the river to the Notch road, but outcrops farther south show it to consist of Longmeadow sandstone. From the Notch road east, the upper sandstone is entirely arkose, and rests conformably on red tuff with the same strike and dip. West of the Notch road, tuffaceous sandstone is a gradational zone between red tuff and upper sandstone; but east of the Notch road the gradational zone is wanting. Even where the gradational zone is absent, as on

# Plate F.

## Photomicrograph of tuff at Lithia Brook (S 19).

This section of tuff has all the appearances of trap. Under the microscope small pieces of trap (a) can be seen, with inclusions of plagioclase. Quartz with wavy extinction, calcite and magnetite are scattered through the groundmass of fine-grained trap. The presence of biotite in the section distinguishes the tuff from the trap.

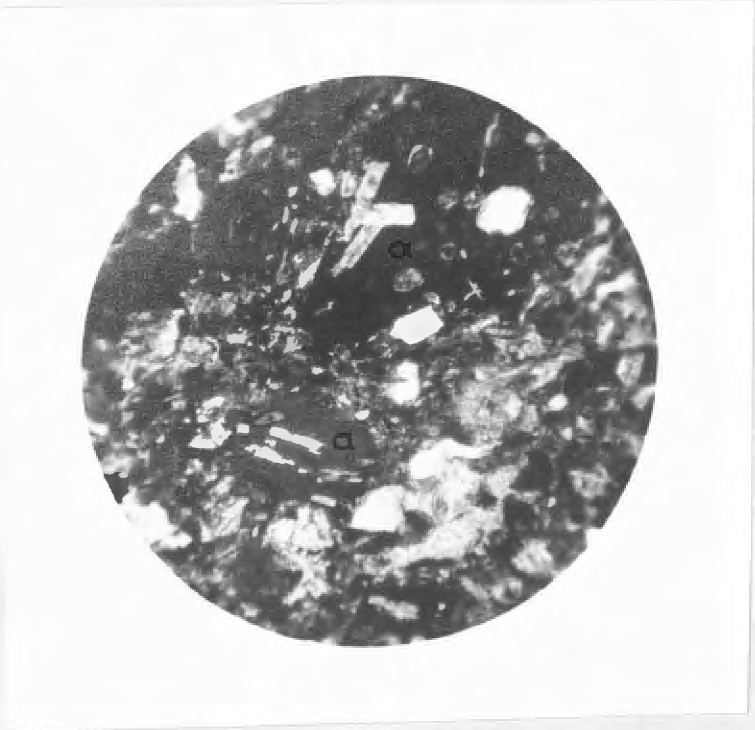

Plate F.

the power line, on close inspection, fine grains of trap can be found in the upper sandstone.

## Structure.

All the formations outcrop with escarpment to the north and gentle slopes to the south, with a general east and west strike, except in the western part of the district. In general, the strikes and dips of both the high and low ridges are the same, east and west strike with a southern dip of 22°, excepting the western part. The outcrops, some very large, others very small, suggest hogbacks stretching in parallel lines east and west.

## Monoclinal tilting of the ridge.

The dip of the sandstone is the same as the dip of the trap-sandstone contact. This is true throughout the district. The sandstone which immediately overlies the trap contains footprints of land animals. These footprints could only have been made by animals walking on a horizontal surface. There is no indication of slipping in the direction of dip, or ridge of mud on the lower side of the track. So it is impossible to conceive of the tracks having been made when the formation stood at its present angle. Because the trap flows have moderately uniform thickness over considerable areas, it is improbable that they flowed over such steep slopes as they now occupy.

If the two trap ridges at one time were part of the same sheet, and were brought to their present position by anticlinal folding, scoria would be found on the north side of the north ridge and the south side of the south ridge, and baked sandstone on the south side of the north ridge and on the north side of the south ridge. With the exception of Titan's Pier, scoria is found only on the southern side of each ridge; baked sandstone is found only on the northern side of each ridge. This would tend to disprove its formation by anticlinal folding. The idea of synclinal folding involves similar difficulties. Still further evidence against anticlinal or synclinal folding is: (1) the high trap ridge has three times the thickness of the low trap ridge; (2) the northern trap contains no olivene, while the southern does; (3) the uniform southern dip of the surrounding sandstone would not indicate close folding. (4) the general angle of dip between the trap-sandstone contact is the same in both ridges; such uniform dips of the beds are more common in those deformed by tilting than by anticlinal or synclinal folding.

The only method of deformation that remains to be considered is monoclinal tilting, for in the greater part of the district the beds have the same general strike and dip.

### Tilting within Ridge.

From one end of the district to the other, the trap blocks have been more or less tilted. This is ascertained by a comparison of the levels of the trap-sandstone contact at each end of a trap block rather than by change of dip, which is often of considerable variation in the same block.

The trap-sandstone contact along the northern side of the eastern block of Mt.Norwottock is practically horizontal. But in the western block of the same mountain the contact slowly descends from the 800' contour line to the 600' level. This shows that the block has been either tilted up in the eastern end, or down in the western, or both.

The contact on the eastern side of Rattlesnake Mt. is on the 620' contour, while on the western side it is far below the surface in the Notch, which is 525' above sea level. This indicates considerable downward tilting in the west.

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Emerson,B.K.- Geology of Hampshire Co.,Mass.
U.S.G.S. Monograph XXIX, p.499

On the western side of the Notch, the contact reappears at about 680' level. It continues westward with variations not to exceed 60', but no great change, until it reaches Mt.Holyoke, where, with a height of 700', it drops within a mile and a quarter to 85' above sea level, at the edge of the Connecticut River.

In the second ridge, the tilting - though not on so great a scale, is more pronounced. In the trap block which forms the base of Tuff Hill, the approximate trap-sandstone contact of 400' above sea level in the north drops to the 240' contour at the river road.

In Trap Hill the contact drops from the 640' level in the north, to about the 240' level in the south.

The block east of Lithia Brook has already been described. The contact rises from the brook on the western end to within ten feet of the top of the fifty foot ridge at the eastern end.

From Lithia Brook to the power line, the trap-sandstone contact is in many places far below surface.

From the power line to the trout brook at R 45, the trap-sandstone contact - though horizontal - is dropped continuously until it disappears beneath the surface at the brook. Then it rises sucessively until it regains the same height in the eastern end as on the power line.

In the high [illegible] ridge, the elevation of the trap determined by its contact with the sandstone varies from 85' to 1000' above sea level. In the low ridge, the elevation of the trap varies 200' to 600', while in many places it is so low that it has not yet been exposed by erosion. All of this indicates unequal tilting and differential settling of the blocks.

It is a general rule that where the dip is steepest, the outcrop, unless cut off by faulting, is narrowest, and outcrops are broadest where dips are lowest. The best examples of this are to be found in the wide tuff outcrops, and in the width of the lower trap on Rattlesnake Mt. and Titan's Piazza.

In the unequal settling, the upper trap at the western end of the district was brought in direct contact with the lower trap, while in the eastern end, half a mile of sandstone separates the two traps. Just north of the central part of the high ridge, or upper ridge, a huge block has been dropped far below its former position. A small block of trap on the power line was apparently faulted far out of its former position.

There can be little doubt that during the tilting the blocks in this region settled differentially. In some places the trap may have remained in place, while in others it may have been dropped below the present sea level. In the erosion which followed, the higher hard parts were removed and so left the sandstone beneath exposed to rapid erosion. Where the trap was dropped farther it was not exposed until recent geological times, and where it was dropped the deepest, it has not yet been exposed. The present structure, therefore, is due to the unequal settling of the fault blocks and to the processes of erosion.

### Faulting.

But the trap ridges are often interrupted and apparently displaced. Also, there are abrupt changes of dip in a short distance. Such indications suggest faulting. Slickensides, the most important evidence of faulting, was found in only one place - on Lithia Brook (A 19). Abrupt changes in level of the plane contact between trap and sandstone are also significant.

On Mt.Norwottock (E 49) the visible contact of trap and sandstone running east and west on the 1000' contour, is interrupted, and begins again with the same east and west direction on about the 800' contour. At J 49 on the south side of the mountain, the east-west trap-middlesandstone contact is broken and begins again ten rods farther north. A deep ravine crosses the mountain between both points, and is the source of springs on both sides of the mountain. The strike and dip of the sandstone are uniform on both sides of the ravine.

At G 44, one of the low places in the range, the trap rises steeply on both sides of the power line. On the eastern side of the ravine, the lower sandstone strikes N.76° E. and dips 20° S., while on the western side it strikes 80° W. and dips 30° S. In the middle sandstone the dip is 21° S. and 28° S. respectively. The trap lower sandstone contact is 20 feet higher on the western side of the ravine. The outcrops of the trap and sandstones as shown in Fig. 2 also suggest displacement by faulting.

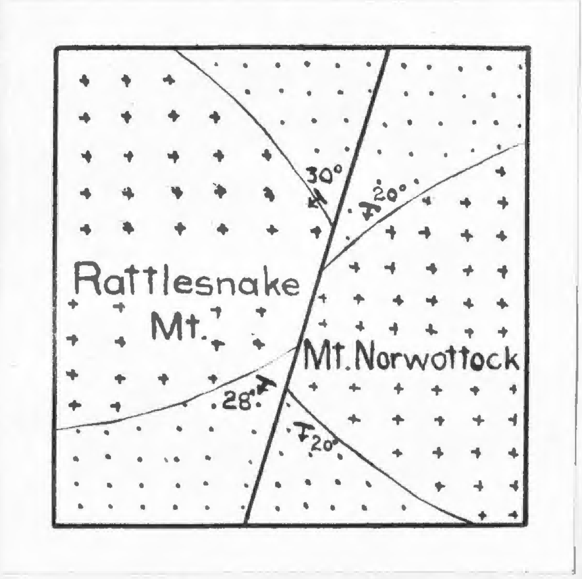


FIG. 2.

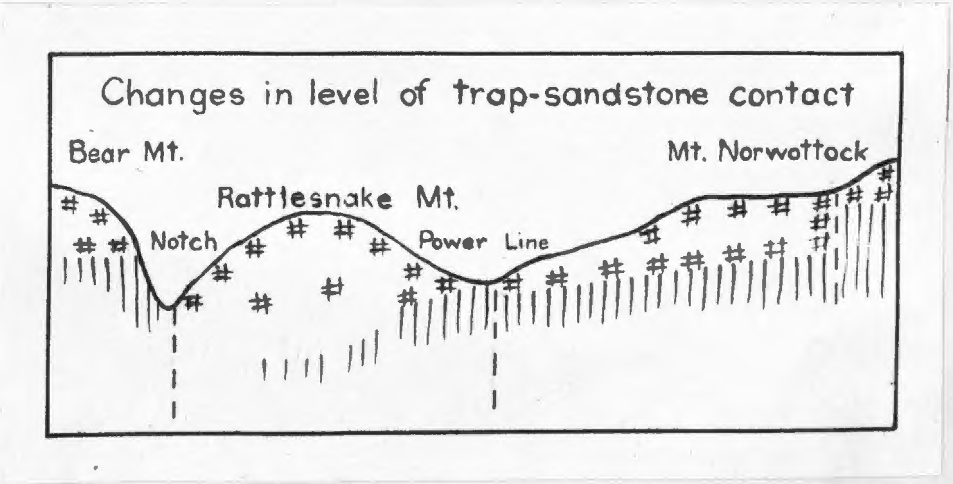
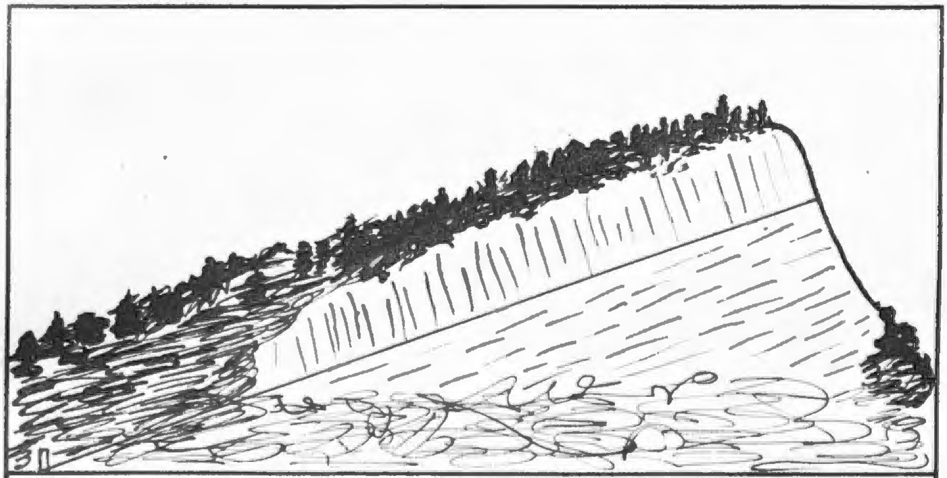


FIGURE 3.



THE NOTCH
From Rattlesnake Mt.
Columnar Trap on Sandstone

FIGURE 4.

In the low place known as the Notch, a perfect cross-section of the high trap ridge is exposed at right angles to the strike, as shown in Figure 4. The ridge towers precipitously 400' to 500' on each side of the road which here crosses the range. On the western side of the Notch and northern side of the ridge, sandstone rises 150' above the road, but dips south to the road level at the Amherst-Granby township stone. If there were no fault or fold, the projection of the trap-sandstone contact along the strike should reappear on Rattlesnake Mt. 150' above the road. But such is not the case. The western side of Rattlesnake Mt. is entirely of trap, and no sandstone is exposed, not even where a quarry has been cut into the trap below the level of the road.

In the center of the range, F 27, the indications also suggest faulting. A few outcrops of trap

(A 29, D 28, E 27, D 26, and B 25) show the occurrence of a block of trap farther north than is found in any other place in the district, and the highest point of which is over 50' below the bottom of the trap in the main range (E 29 and E 25). This block extends for a quarter of a mile north of the range, and is almost entirely covered by two drumlins. A ravine extends from F 27 southeast across the range, as if following a continuation of this probable fault. The outcrops show a displacement to the south of the trap middle sandstone boundary on the eastern side of the ravine(I 30).

An abrupt change of strike within a few rods from east-west to north-south, as on the eastern side of Trap Hill, is further indication of faulting. The middle sandstone dips 20° south, while a few rods to the west, tuff dips 25° E. Also, the tuff appears to dip under the middle sandstone, the line of contact being concealed by till. But a score of contacts have shown only lower trap and lower sandstone dipping under middle sandstone, and tuff dipping only under upper sandstone. These relations indicate a fault extending from the northeastern side of Trap Hill to Lithia Brook.

On the eastern side of Tuff Hill, both tuff and middle sandstone strike north-south and dip 23° E., with the tuff appearing to dip under middle sandstone, with concealed contact. But at M 15, upper trap visibly overlies middle sandstone, while at J 15 the upper trap is overlaid by tuff. Consequently, this is another case of a break in the stratigraphical succession. The only plausible explanation is faulting from Tuff Hill to R 15. This fault would also explain the small hill of upper trap at Q 14. This trap is surrounded by tuff and sandstone, with no evidence of baking in the latter, as would be the case if the trap were intrusive.

At a point southwest of Mt.Holyoke (J 13) and another one half mile directly south (N 9), upper trap is on the eastern side of Dry Brook and lower trap on the western side. No middle sandstone separates the two. But at L 11, a narrow strip of middle sandstone lies between the two traps and again appears at P 7, gradually increasing in width to the river road, T 3. The supposed fault line along which this displacement took place is marked by a deep ravine

STEREOGRAM ILLUSTRATING NATURE OF FAULTING ALONG POWER LINE

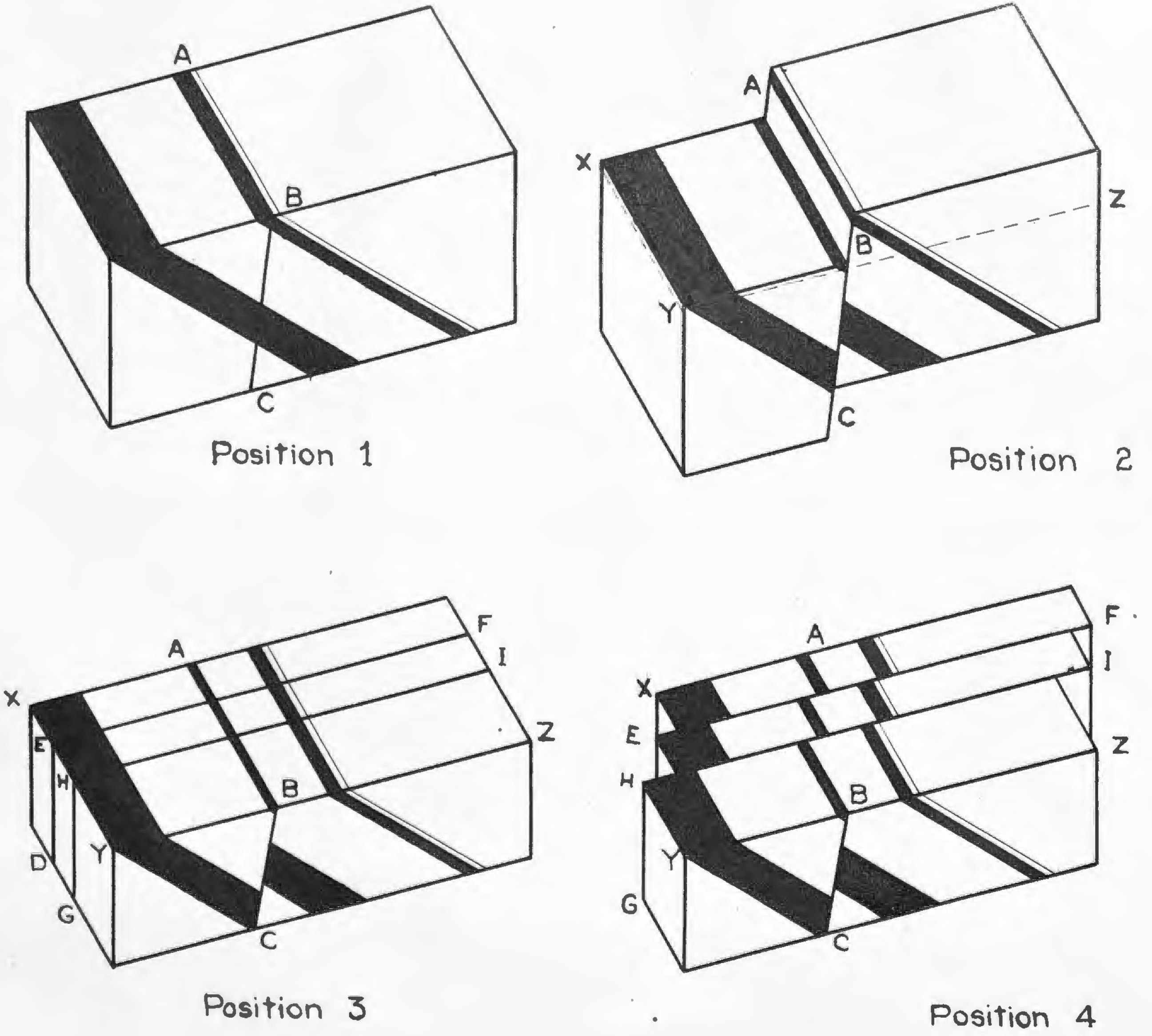
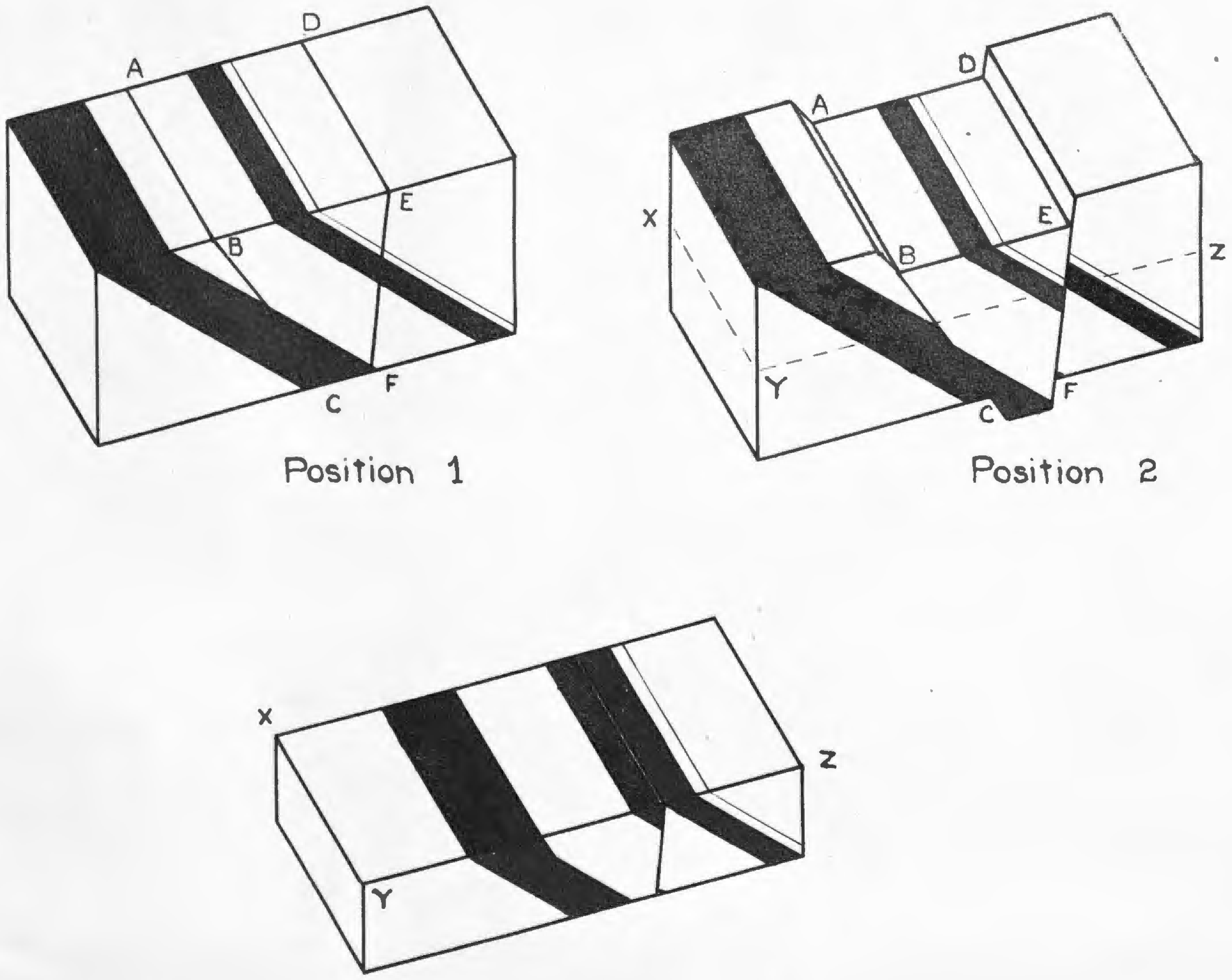


Fig. 7

STEREOGRAM ILLUSTRATING NATURE OF FAULTING ON RIVER ROAD



Position 1

Position 2

Position 3

Fig. 5.

between Tuff Hill and Mt.Holyoke, and extends along the bed of Dry Brook to the river.

From the river road (V 7) to R 11, a strip of scoriaceous trap is bordered on both sides by black trap. As scoria indicate the top of the trap flow, it is probable that the scoriaceous trap marks a fault line. A possible explanation is shown by the block drawings of Figure 5.

From R 11 to Lithia Brook, a great trap escarpment rises fifty feet above the tuff valley to the north. The trap and overlying tuff strike N. 75° E. and dip 18° S., while the tuff north of the trap strikes north-south and dips 23° E. This also indicates faulting.

On the eastern side of Lithia Brook (Q 19) trap extends from the brook to the top of the fifty foot ridge. At the eastern end of the same trap block, where the ridge exhibits the same cross-section as at the Notch, the trap sheet is only ten feet thick at the top of the hill, being underlaid by sandstone. This indicates a tipping of the block. Just to the north of the trap is a block of red tuff apparently dipping under the trap, but with the contact concealed. As in every other exposure, tuff lies on trap, this unusual occurrence north of the trap can be explained by faulting. The only example of slickensides in district was found on Lithia Brook.

On the power line (M 43) there is a small outcrop of upper trap surrounded by outcrops of middle sandstone. The trap does not seem to have baked the sandstone as it would if it were a plug. The same dip, 24° S., being found in the sandstone surrounding the outcrop, and southward to the low trap ridge, would tend to throw out the possibility of folding. A possible explanation by faulting is shown in Figure 7.

The trap ridge east of the power line is continually broken by jogs which can be traced in the tuff upper sandstone boundary farther south. Each jog changes the level between the contact of the trap and middle sandstone. In each block this contact can be seen as a horizontal straight line. In each block the sandstone strikes N.80° W. and dips 24° S. But in each block this contact is lowered from six to twelve feet, until it disappears at Q 46, near a little trout brook.

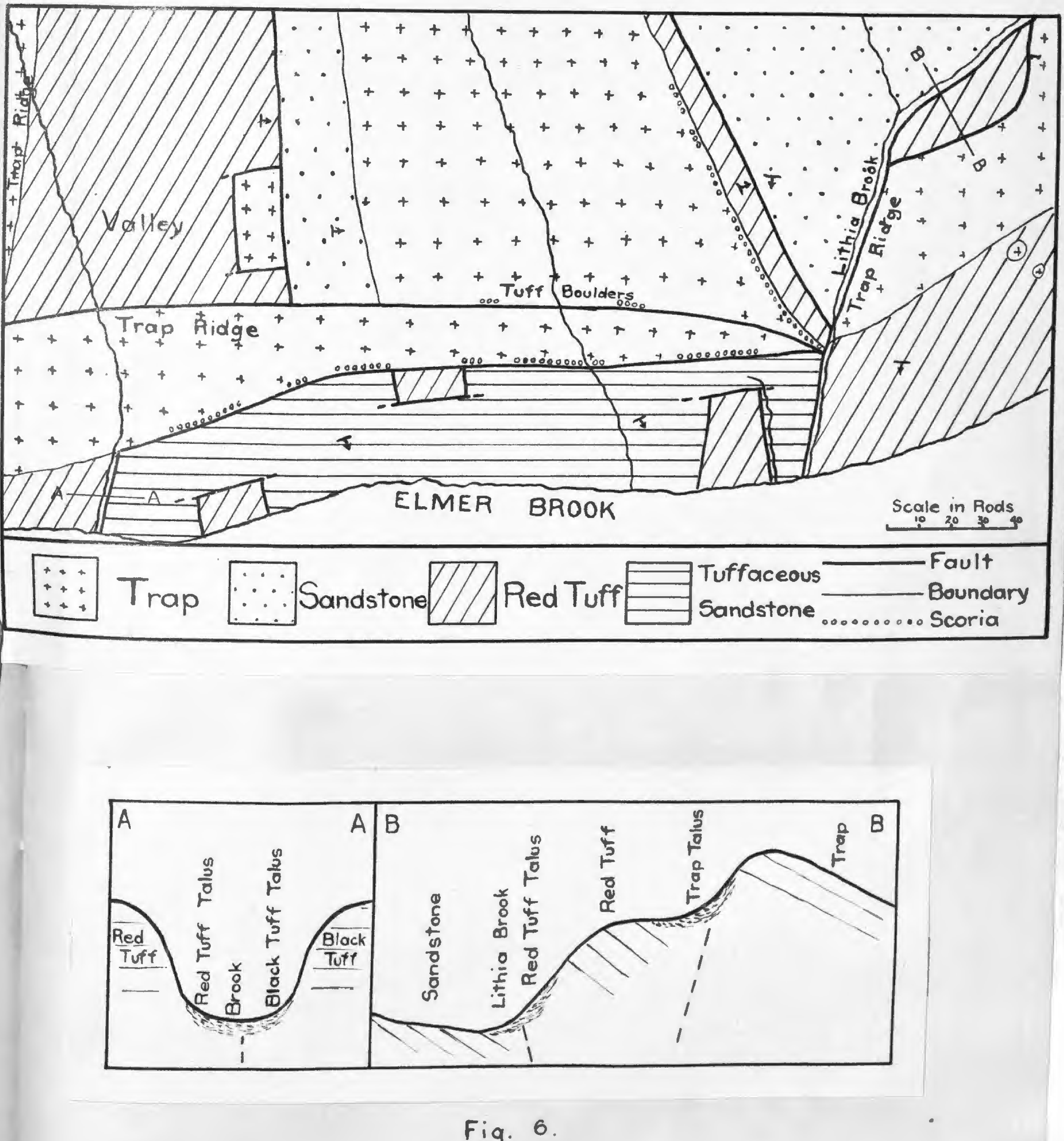

Trap Ridge
Valley
Tuff Boulders
Trap Ridge
Lithia Brook
Trap Ridge
ELMER BROOK
A
A
B
B
Scale in Rods
10
20
30
40
Trap
Sandstone
Red Tuff
Tuffaceous Sandstone
Fault
Boundary
Scoria
A
A
Red Tuff
Red Tuff Talus
Brook
Black Tuff Talus
Black Tuff
B
B
Sandstone
Lithia Brook
Red Tuff Talus
Red Tuff
Trap Talus
Trap

Fig. 6.

It is near this same brook that the best example of trap supposedly faulted below the surface is found. The outcrops of trap are shown by crosses, and the dips of the tuff and sandstone are shown. The regularity of the trap ridge is broken. Tuff and sandstone are not separated by trap. The contact is concealed. To the east appears the first small outcrop of trap. Farther east, the outcrops are several rods in width, until at the trout brook the whole width is exposed. At the eastern end, along the strike of the middle trap block, there is tuff across the brook. The northwestern corner of the eastern trap block is bordered by sandstone across the brook. Such irregularities along the strike of a formation, and the gradual appearance of trap between sandstone and tuff, indicate faulting and tilting.

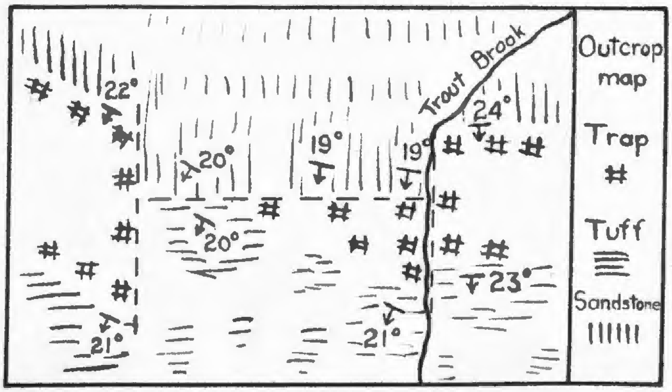


FIGURE 8.

The stratigraphic succession in the low ridge has been established as:

3. Tuff
2. Trap
1. Sandstone.

Whenever trap is found to be missing between tuff and sandstone, it is considered as due to faulting. Such relations are common between the power line and Lithia Brook.

This district seems to consist of a great number of fault blocks. The evidence in favor of faulting (already discussed) has been so clear that it has warranted the drawing of fault lines in places of similar characteristics and where faulting was not so certain, but was indicated by such field relations as the occurrence of outcrops out of their normal position, escarpments, ravines, and streams. The dotted lines on the map represent supposed faults, the existence of which is uncertain.

## Historical Geology.

The history of this region is admirably stated by B. K. Emerson in Monograph XXIX. It is briefly given here, with modifications made necessary by further information.

Triassic rocks extend northward from Long Island Sound along the Connecticut River valley, with a width of about twenty miles, through the state of Connecticut, and narrowing in Massachusetts until they finally end at Northfield, Mass. The eastern and western boundaries of the sandstone are everywhere coincident with the older ridges which rise on both sides of the river valley. Through the middle of the sandstones extend the trap ridges from West Rock, New Haven, northward, forming the Holyoke Range.

Since the youngest of the crystalline rocks that border the valley are carboniferous intrusions, it was sometime after the Carboniferous that the folding took place which formed the broad syncline of the Connecticut valley. Contemporaneous with the folding, a sinking took place, which admitted the waters of the sea. A long, narrow valley was the result, extending from the ocean to nearly the Vermont border.

This peculiarly shaped bay had peculiar currents. It had tides of a height and force unknown today, for they carried boulders from six inches to a foot in diameter, miles from the shore. Another peculiarity of the currents - judging from the materials in the sandstone - was that they seemed to rush up the western side of the bay and down the eastern side, leaving a large area along the middle, of comparatively shallow mud-flats. These mud-flats extended to the present site of the Holyoke Range. North of the range, the valley narrowed to such an extent that even the central portion was disturbed by the rapid tidal currents.

After the bay had filled at the expense of the surrounding hills, unequal stresses were produced. The adjustment which followed was either due to these unequal stresses, or was a part of some larger movement. The bottom of the basin sank, the sandstone faulting against the older metamorphic shore formations.

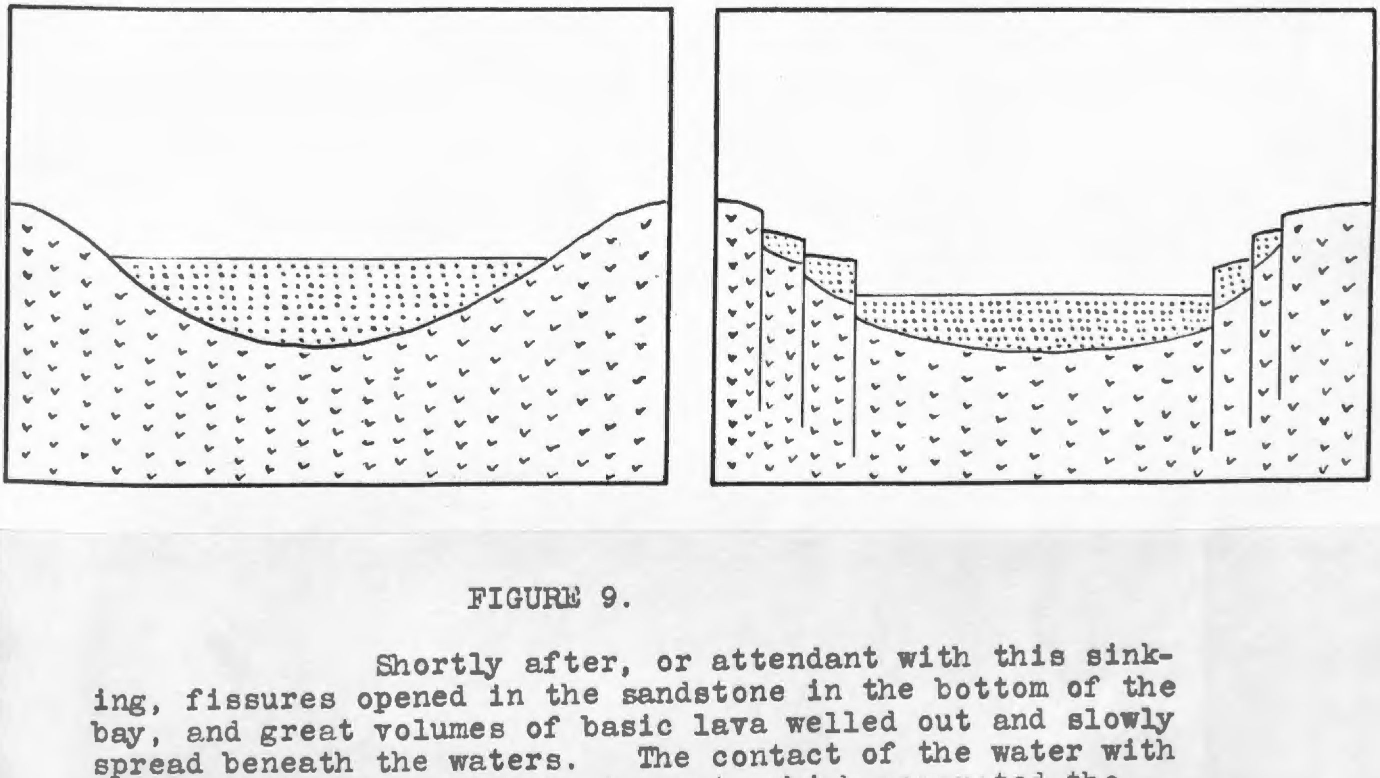


FIGURE 9.

Shortly after, or attendant with this sinking, fissures opened in the sandstone in the bottom of the bay, and great volumes of basic lava welled out and slowly spread beneath the waters. The contact of the water with the trap formed a thin, hard crust, which separated the water from the molten interior. As the trap moved, cracks formed in the solidified surface in which calcareous muds settled and were caught. The under-rolling caused by the movement of the lava, carried the enclosed mud and a portion of the gas-filled top to the bottom, as at Titan's Pier.

The process of sedimentation continued. Sandstone formed around and over the hardened lava sheet, which had so shallowed the basin that Longmeadow Sandstone, characteristic of the shallow middle, was deposited on the trap along the central portion of the bay. The same coarse arkose was deposited along the shore where tidal currents kept an open channel. The shallow central portion was laid bare at low tide, and there can now be found perfectly preserved mud-cracks, rain-drops, ripple marks, and the so-called "bird-tracks" made by reptiles and great land animals that walked on these soft, mud-flats.

Sedimentation was interrupted by more adjustment. The bottom of the basin once more sank, and faulted along the contact with the crystalline rocks. Fissures opened, and once more lava poured out on the bottom of the bay. Almost immediately following the lava flow came a volcanic explosion, which scattered huge masses of trap, cinders, ash, bombs, and dust over a wide area. This material fell into the waters of the bay and settled on the surface of the still fresh lava sheet forming the tuff bed.

Sometime after sedimentation had covered the tuff with a thick bed of sandstone, great diastrophic movements took place. It was probably the lateral pressure produced in the Triassic deformation of the Appalachians that tilted the sandstone and trap into the present Holyoke Range. The tilting also raised the valley above sea level as sedimentation ceased.

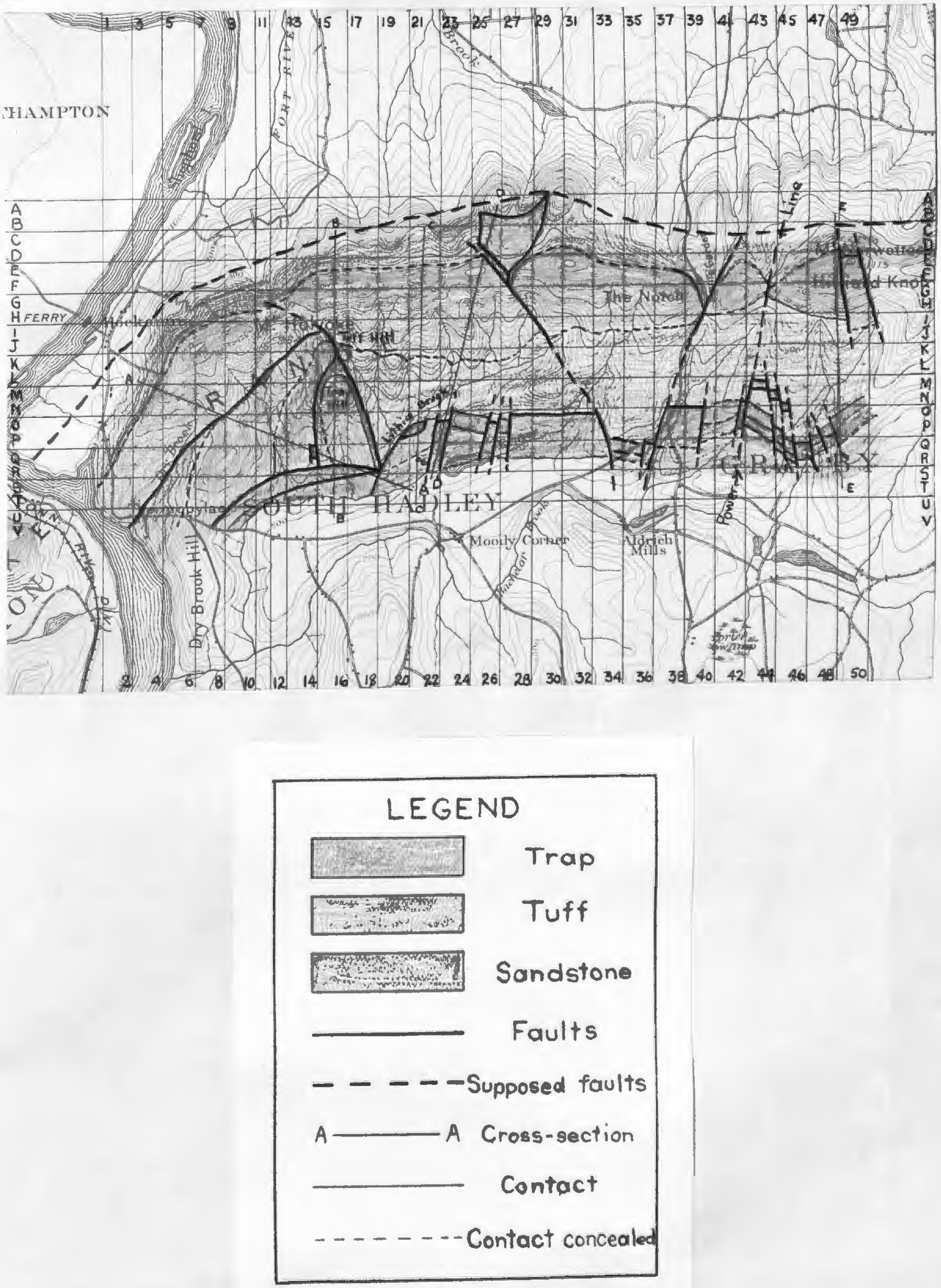
The tilting was follows by a long period of erosion. Then came the glacial period. It is chiefly due to the action of the ice that this region owes its present shape. The hard trap ridges withstood the grinding of the ice from the north, while the softer sandstones were easily eroded.

During the retreat of the ice and for a long period after its disappearance, a large glacial lake occupied the northern end of the Connecticut Valley. Shore line deposits were formed along the sides, while great clay deposits accumulated in the middle. The Holyoke Range was an island during this period. Lake sands were deposited along the southern slopes, but in especially great thickness south of the low ridge.

As the outlet of this lake was lowered, the lake itself gradually decreased until it ultimately disappeared. The Connecticut River now ran along the lake bottom. Since glacial times, the region has been little changed.

## Conclusion.

It has been shown herein: (1) that the trap ridges forming the northern end of the Holyoke Range are extrusive flows, not intrusions; (2) that the irregularities in the trap ridges were caused by faulting, and not by erosion along joint plains; (3) that the structure is due to monoclinal tilting, not to folding; (4) that the unequal surface exposures of the different formations are due to the differential settling of the fault blocks after tilting, and to subsequent erosion.



HAMPTON
FERRY
FORT RIVER
Brook
The Notch
Holyoke
Mt Hill
Lithia Springs
Dry Brook Hill
SOUTH HADLEY
Moody Corner
Aldrich Mills
GRANBY
Hilliard Knob
Line
LEGEND
Trap
Tuff
Sandstone
Faults
Supposed faults
A —— A Cross-section
Contact
Contact concealed

Fig. 10.

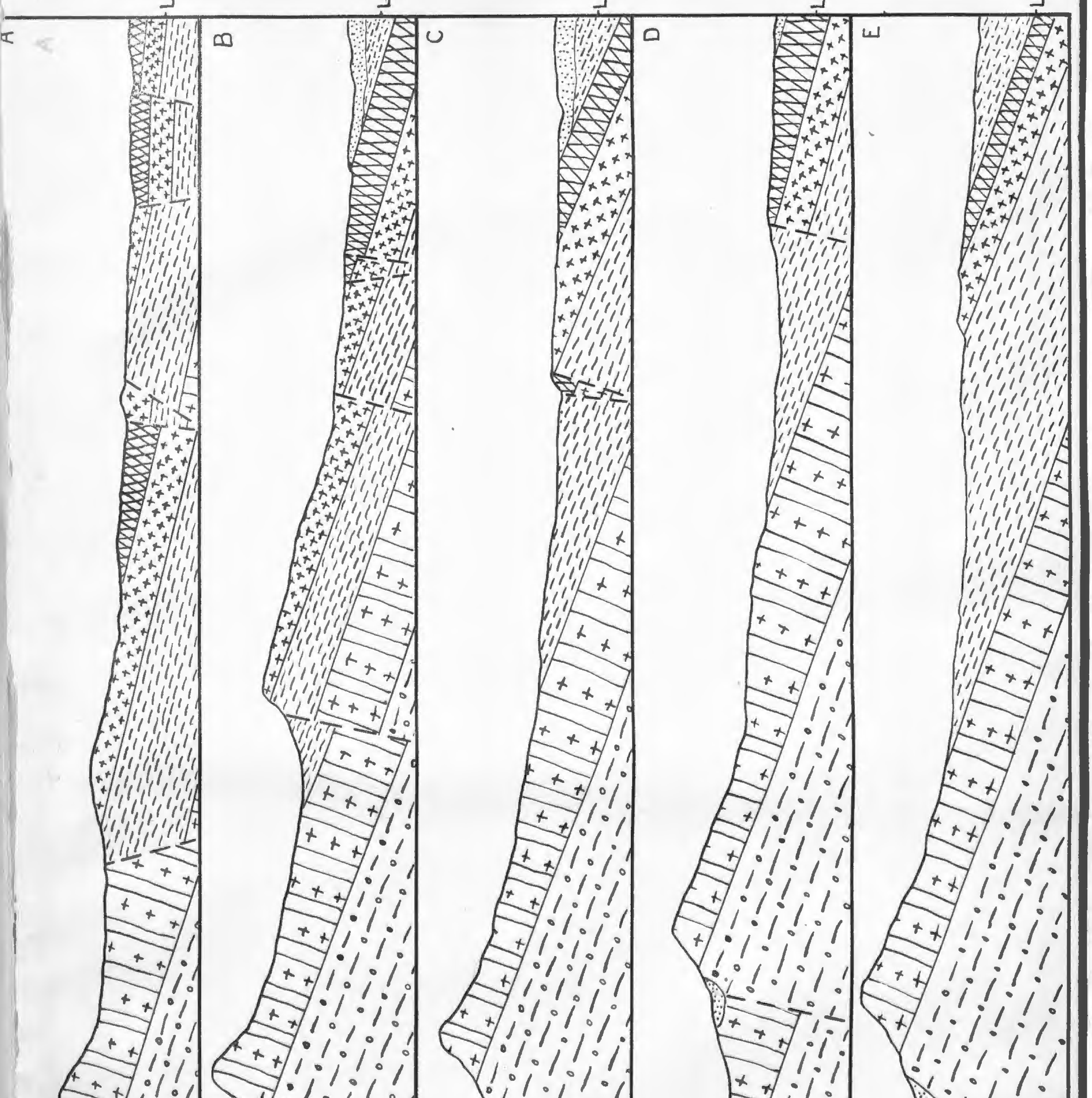


Fig. 11.