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were, however, sold at these figures. There are very large quantities of ore in sight in these mines, as even a brief inspection clearly shows, and they are capable of yielding thousands of tons for some years to come.

The output of the mines for the past year can be given only approximately. They have produced about 750,000 pounds of lead and from 3,000 to 3,500 tons of zinc. But it must be remembered that, as already stated, most of the zinc mines were closed during the past season. They are easily capable of yielding from 8,000 to 10,000 tons of ore annually.

THE AREA OF SLATE NEAR NASHUA, N. H.

BY J. L. TILTON.

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Maps of Crosby and Hitchcock.—Crosby's map of eastern Massachusetts represents an area of slate, or argillite, as it is termed, running from Worcester through Lancaster and Pepperell to the New Hampshire state line. The eastern part of this argillite, two and one-fourth miles wide on the map, but four miles wide according to the text,* continues north into New Hampshire just west of the Nashua river. On the east of the argillite lies mica schist in an area very narrow (three-fourths of a mile) near the state line, but much wider toward the southern part of the township of Dunstable. On the west

*Crosby's "Geology of Eastern Massachusetts," p. 137.

of the argillite lies gneiss close to the state line, but mica schist a little farther southwest (in Townsend).

Hitchcock's geological map of New Hampshire (Rockingham Sheet) represents an island of gneiss extending from Mine Falls to a mile south of the Massachusetts line near Hollis Station (occupying a part of the area where Crosby locates argillite). This island lies in "Rockingham Mica Schist," extending along the northwest side as an area three and three-fourths miles wide, on the average, and along the southeast side as an area two and a half miles wide. Both these areas of mica schist are represented as continued toward the northeast across the Merrimac river and southwest into Massachusetts.

It is the object of this paper to mark out and describe the slate rock in the vicinity of Nashua (Crosby's argillite, or the northern of the two areas marked by Hitchcock as mica schist).

The Area Briefly Defined.—The slate rock is found to lie in an area six miles wide extending northeast-southwest, just northwest of the Nashua river.

Along the southeast of this area the contact between the slate and the adjacent schist and gneiss extends from Runnells' bridge in a northeasterly direction parallel with the general course of the Nashua river as far as Nashua, where the river leaves the vicinity of the contact. In the city of Nashua the contact extends northwestward in a line between Shattuck's ledge and the reservoir.

Along the northwest of this slate area the boundary-line extends from where Gulf brook crosses the slate line, northeastward through the valley just east of Proctor Hill, near Long pond, Pennichuck pond and Spaulding's pond (or Reed's pond, as it is called locally) and crosses the Merrimac river a mile below Thornton's ferry. This line is not perfectly straight but curved slightly with the convex side to the northwest. Just north of Gulf brook the line curves somewhat suddenly toward the southwest, passing between the two exposures half a mile northeast of the mouth of Gulf brook.

Southeast of Nashua no slate was found in the area represented on Hitchcock's map as a branch of this slate there marked "Rockingham Mica Schist."

General Description of the Slate Area.—The area of slate is marked by an extent of lowland occupied partly by swamps

and ponds.* It contains the Nissitisset river, Flint pond, Long pond, Parker's pond, Pennichuck pond, Round pond and Spaulding's pond, besides a large area of swamp. The southeastern part of the slate area is largely occupied by the present valley of the Nashua.

Within this area the hills of slate rise in ridges to a height of one hundred feet above the adjacent lowland. They do not form continuous ridges, nor does their general direction conform to the direction of strike. This general direction is N. 70° E., while the strike is on the average N. 57° E., though the strike varies a few degrees even in strata but a few feet apart, as the rock is much contorted. These hills are low in contrast with the hills in the gneiss and schist area adjoining. From the top of Long Hill, a hill of the Monadnock type just south of Nashua, these slate hills appear below the Cretaceous peneplain.

The valleys between these hills, even the hills themselves, are mantled with drift, and the river valleys deeply covered with washed drift; but further reference to this important feature is here omitted as not a part of the problem under consideration.

Description of the Rocks.—The character of the rocks and the relation of them one to another is perhaps best seen along a line from Shattuck's ledge, Nashua, northwestward. At Shattuck's ledge, the rock is gneiss in part heavy, in part quite schistose.

At the reservoir, three quarters of a mile west, occurs slate with bands of graphite. Northwest for three miles the rock is a slate very much crushed and crumpled, and in the northern part of this area, a shaly slate interbedded with gneiss. The dividing lines, then between the slate and the schist, and between the schist and the gneiss, are not definitely marked lines, but are intermediate places in a series of gradations.

Similar gradations from slate through schist to gneiss are to be found in the southwestern part of the area near the confluence of Gulf brook and Nissitisset river. Here, south of the Massachusetts line, the slate is both shaly and quartzose. Just north of the Massachusetts line quartz veins are very marked in a dark schistose rock. This same structure is found in a railroad cutting near by, revealing in an excellent manner

*The contour lines of the accompanying map are as given on the New Hampshire state geological atlas.

the schistose structure with quartz veins. A little farther northwest gneiss appears instead of schist. Here, then, there is a passage from slate through schist to gneiss.

Just west of Hollis Center is still another opportunity to observe an approach to the dividing line between the slate and the schist, though not so good as either of the two already described. Just west of Hollis Center there is slate. This grades through schist to the gneiss quarried at Proctor Hill.

Southeast of the slate area are several outcrops of gneiss: one at Shattuck's ledge in the northeastern part of the city of Nashua, another in the western part of the city, where it is quarried in one place, a third on the Nashua river, five miles above Nashua, a fourth at Flat Rock quarry, and again at Long Hill, south of the city.

The sudden transition from slate to gneiss close to the Nashua river will be referred to under the heading "Faults."

Eastward from Runnells' bridge, near Hollis, there is a gradation from the slate through schist to the gneiss at Flat Rock quarry, and a similar gradation from schist to gneiss between Nashua and Long Hill.

Thus southeast there is a gradation from slate through schist, schist with quartz seams to gneiss, similar to that from the slate area northwest.

Attempts to Harmonize Descriptions of Crosby and Hitchcock.— The above description of gradations in the character of the slate, schist and gneiss, suggests an explanation of an apparent lack of harmony between Crosby and Hitchcock. Crosby distinctly records gradation between the three rocks, and because of this gradation seems to call both the slate and the schist argillite, even though the argillite southeast of Nashua is exceedingly clear mica schist. Judging by the map, Hitchcock apparently recognizes the same gradation between the rocks, though I find no description in the text to confirm this inference, and calls both schist. I fear, however, that because of the schistose character of many of the slate outcrops, the area of slate has been entirely neglected.

Concerning Hitchcock's location of the gneiss area along the Nashua river, between Mine Falls and just south of the state line, there is a single area of probable gneiss on the river about four miles west of Nashua. This area is cut off on the southwest by slate just south of Runnells' bridge, and on the northeast by mica schist at Mine Falls. Hitchcock has overlooked

the gneiss east of Mine Falls, where two areas exist: one a mile west of Nashua (Main street) and south of the canal, where outcrops occur at a large quarry, and in the hill just west of the cemetery. The other area omitted is in the northeastern part of the city itself, at Shattuck's ledge, near the Merrimac river, a mile and a half from the outcrops just west of the city.

It is possible that these two areas should be classed as one, since no outcrops exist between the two areas to tell what the rock between them may be.

The line bounding Hitchcock's "Rockingham Mica Schist" seems to indicate the line between schist and gneiss, as if he did not recognize the slate as a separate rock from the schist. My northwestern line bounding the slate lies about parallel to his line bounding the Rockingham Mica Schist and a mile to the southeast of it.

Strike.—On the map accompanying this paper numerous dips and strikes may be found recorded. It now becomes necessary to observe their relation to determine what folds may exist in the area, for there are no strata within the slate area itself whose repetition can indicate the structure.

Within the slate area and in the gneiss along the northwestern boundary the strikes measured are much the same. North of Nashua there is slight evidence that the anticline there tends to form a nose; but all other variations from N. 33° E. are such

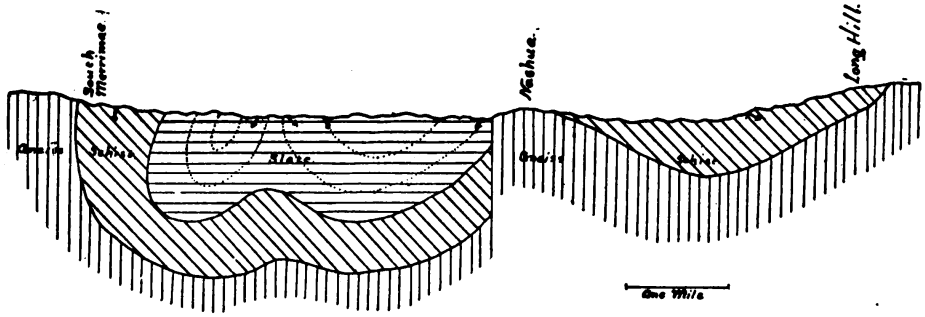
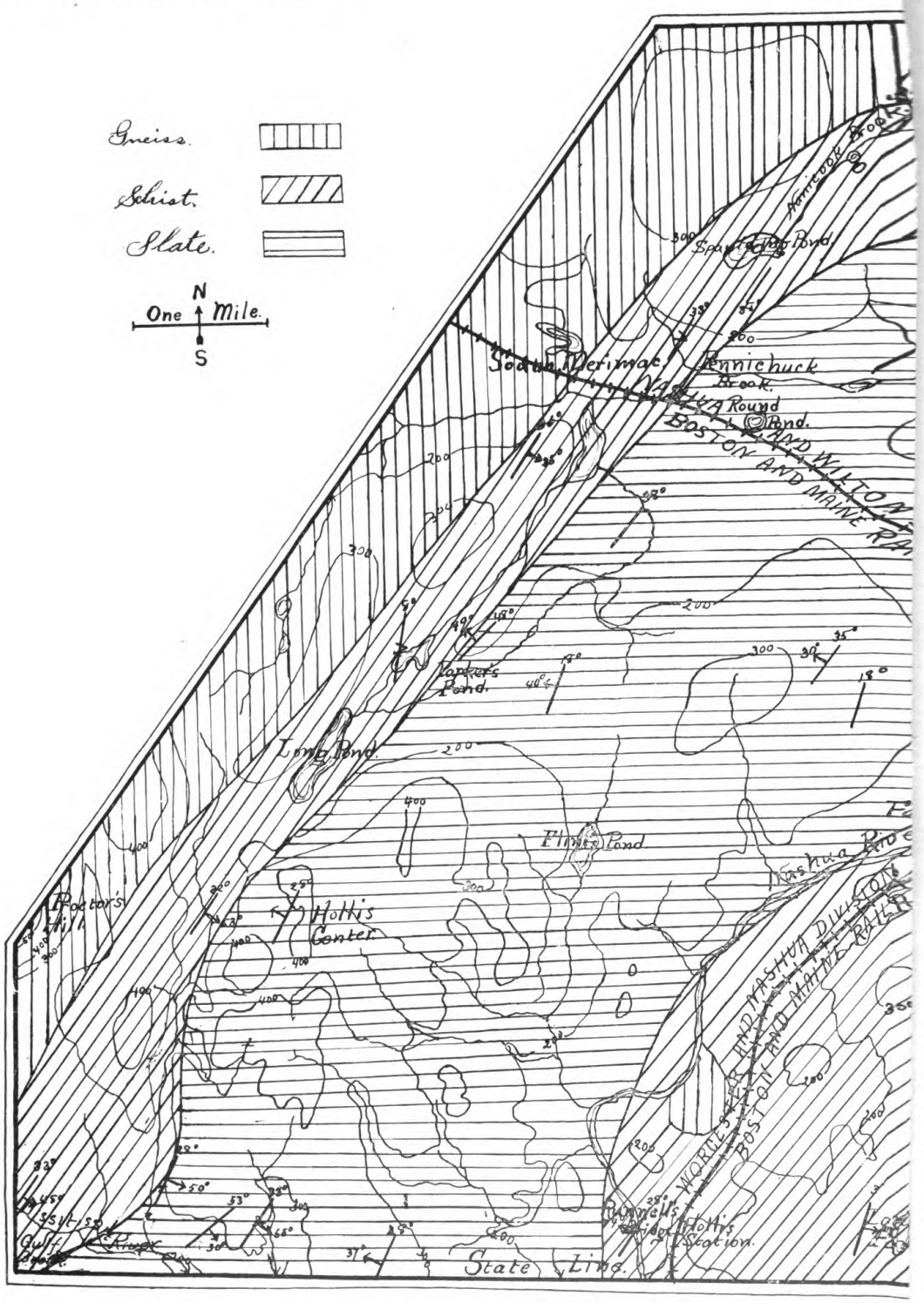


FIGURE 3. Section northwest-southeast across the area.

as a badly crushed area might represent; variations too small to be systematized even by minute observations at all points. This general similarity of strike indicates horizontal folds extending in the direction of the strike.

A study of the dip along lines at right angles to the strike reveals the anticline of a fold running in the direction of the strike along the western half of the slate, while a syncline runs along the eastern half. These are here represented in a diagram. (Fig. 3.)


Gneiss.
Schist.
Slate.
N
One Mile.
S
Penniehuck Brook.
Round Pond.
Parker's Pond.
Long Pond.
Holli's Center
State Line.

Faults.—At the reservoir in Nashua are evidences of a fault; there is in the slate a seam of graphitic slate with veins of quartz near by. In this graphitic slate much crushing and slipping has occurred. The strata are on edge with strike N. 73° E.

The argument for a fault in this locality is sustained, in fact made necessary, by the structure of the region. The general succession of strata from southeast to northwest, is gneiss, schist, slate, schist, gneiss, with no evidence of unconformity; but at Shattuck's ledge the gneiss appears in close proximity to the slate, with little chance for schist between. The dip at Shattuck's ledge compared with the dip observed in the schist to the south indicates that the gneiss exposed at Nashua is in an anticline.

North of the gneiss at the quarry just west of Nashua a fault is possible, but not necessary to explain the structure, if schist not exposed underlies the river valley. While schist occurs at Mine Falls, schistose gneiss occurs two miles farther west with no schist that is exposed to the north, and beyond Runnells' bridge the eastern boundary of the slate area bends southeastward across the line of strike. Thus while the evidence of faulting is very marked near Nashua it becomes less marked southwestward.

Other evidences of faulting exist near the mouth of Gulf brook, and just west of Hollis Center. Along this line the presence of slickensides in graphitic slate, with quartz seams near by, indicate that a line connecting these two points is a line of faulting.

Cause of Metamorphism.—Finally, it remains to ascertain the cause of the metamorphism. This involves a petrographical problem, especially on the gneiss. There is no igneous rock to be found in the area, unless the gneiss itself be of igneous origin.

If the gneiss itself is not of igneous origin there may be igneous rock not far below, or not far beyond the margins of the area, though no locality of such minerals as are common where igneous material comes in contact with sedimentary material is here to be found, nor is there any evidence of intense heat.

Regional metamorphism affords a satisfactory explanation. The intense crumpling of the strata, the steep dip, the bands of quartz alternating with the slate along the margins of the gneiss, with lack of evidence of intense heat in the immediate vicinity, all indicate that the metamorphism is regional.