

Thesis.

The Geology of the Newbury Mining District

by

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Course III Option 3.

M.I.T.

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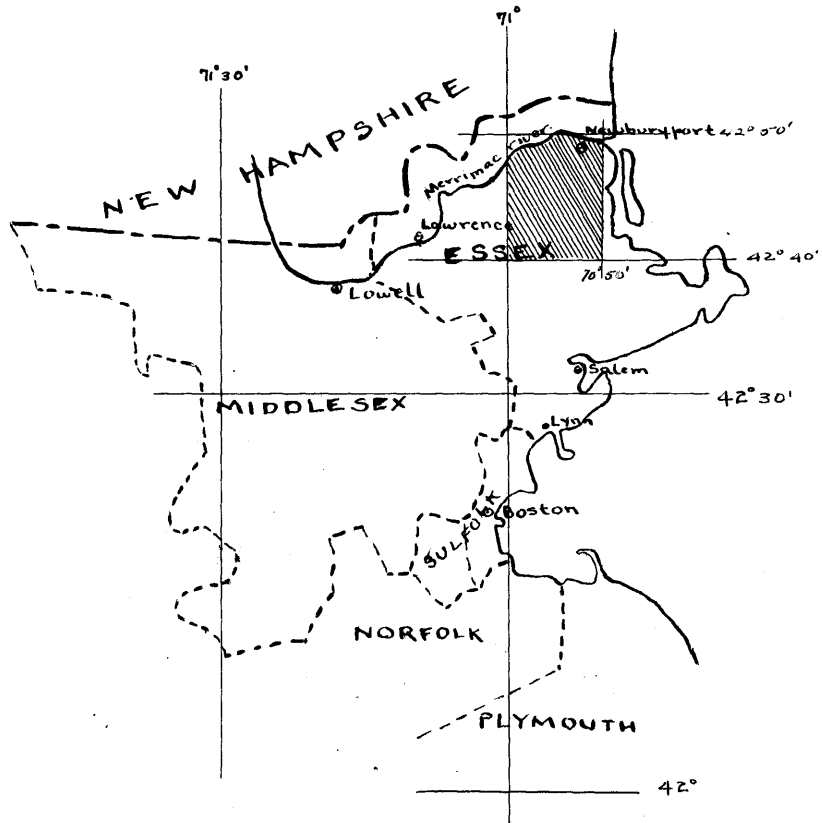
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A. General Introduction and Synopsis.



Scale 1 inch = about 16 miles

Note: Shaded area represents the area covered by this thesis.

A-I. Location.

The area covered by this thesis lies in the extreme northeastern corner of Massachusetts. It comprises a part of the area represented by the United States Geological Survey topographical sheets of Newburyport and Salem. These sheets are each divided for convenience into nine five minute rectangles, and these rectangles have been numbered as follows:-

| | | |
|-----|----|------|
| I | IV | VII |
| II | V | VIII |
| III | VI | IX |

Thus for example, the lowerleft hand rectangle is called Newburyport III. The rectangles embraced by our work are Newburyport III and VI, and Salem I and IV. These rectangles lie between latitude $42^{\circ} 40'$ on the south and $42^{\circ} 50'$ on the north, and between longitude $70^{\circ} 50'$ on the east and 71° on the west; and cover about 90 square miles. This area includes parts of the towns of Newburyport, Newbury, West Newbury, Groveland, Georgetown, Boxford, Rowley and Ipswich.

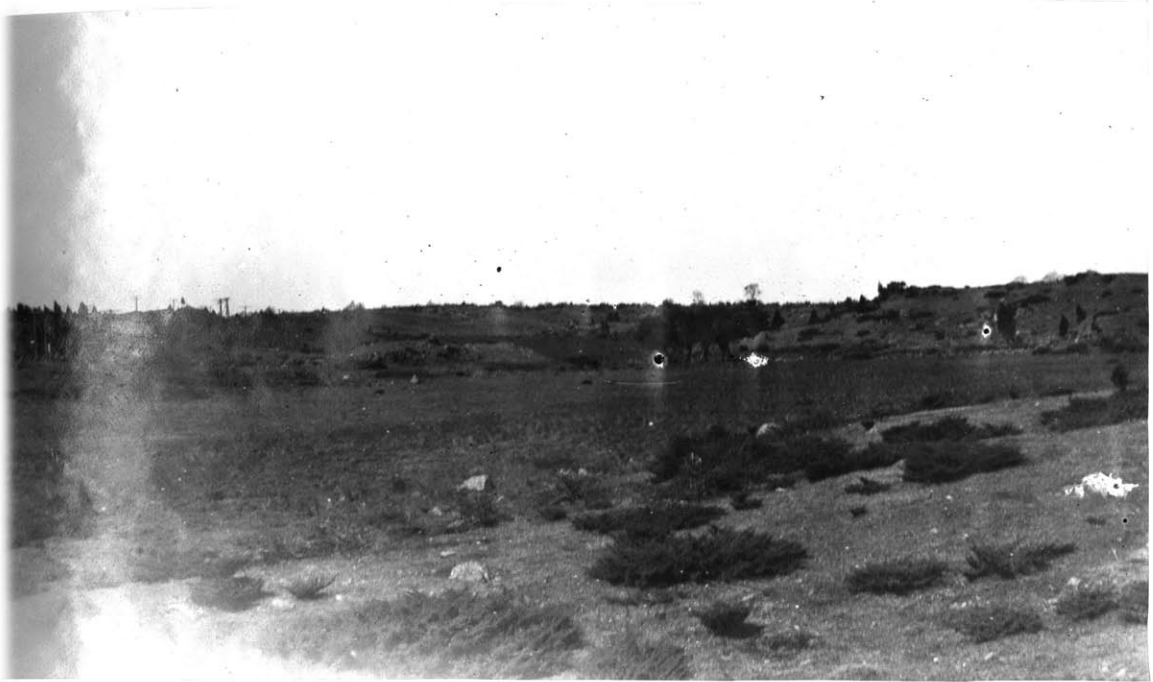
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A-2. Field Work.

The geological fieldwork, upon which this thesis is based, was done during the months of April and May of the year 1905. Many intersecting traverses were made over the rectangles III and VI and the work in these two rectangles has been more or less detailed. Three or four long traverses were made across the rectangles Salem I and IV on a bicycle, the work being principally confined to general rock relations bearing on the problems of the northern rectangles.

A-3. Drainage.

The area forms a part of the drainage system of the Merrimac, Parker, Rowley and Ipswich Rivers. The Merrimac is by far the largest and forms the northern boundary. The Parker, Rowley and Ipswich Rivers, are much smaller and extend only a few miles back from the coast. Tributary to the Merrimac, we have the Artichoke and Indian Rivers, which drain West Newbury. The Parker River with its tributaries, the principal ones being Little River, Beaver Brook, Mill and Mud Creeks, drain the greater part of the rectangles. The Rowley River drains a small part of Rowley and Ipswich. The Ipswich River is next in size to the Merrimac, but merely runs across the southeast corner of Salem IV.

Plate I.



ROCKY TOPOGRAPHY.

Highfield hills, looking to the west.

The topography of these rectangles is of three types:- rocky, drift-covered and marshy. The so-called rocky topography is determined by outcrops and ledges of rock. This type is not confined to the town of Newbury, but extends into Groveland, Georgetown and south to Boxford. It forms low rugged hills covered by a dense growth of shruberry and scrub cedars, and is impossible farming land. One belt in particular extending along the Newburyport branch of the Western Division of the Boston and Maine railroad from Georgetown to Newburyport, is extremely wild, rough and uninhabitable and contains most of the mining lands.

The drift-covered topography is the most prominent and beautiful. There are numerous, high, smooth, broad-topped drumlins whose axes are mainly northwest-southeast. The most prominent of these are: Archelaus Hill, Crane Neck Hill, Old Town Hill, Ox Pasture Hill and many high hills of Rowley and Ipswich. The majority of these hills reach an elevation of a little over 200 feet. There are many sand plains which are very fertile. This topography covers almost the whole of the towns of Newburyport, West Newbury, Rowley and Ipswich.

Along the coast and extending back along the rivers, principally along the Parker River, and between the rocky ridges of Newbury, are fresh and salt water swamps, some of them being of great extent. The Parker River flows through this swampy country which extends inland to Byfield where there are several small falls or rapids. The Rowley River flows through a similar salt marsh. In the glacial valleys of Ipswich and Georgetown, there are several broad fresh water marshes and ponds. Whereas these

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small rivers flow through comparatively wide valleys, the course of the Merrimac is very narrow and rocky.

There are two types of rocks represented, metamorphic and igneous. The metamorphic rocks are undoubtedly both of sedimentary and igneous origin. The oldest sedimentaries are bands of serpentine marble and interstratified quartz-hornblende schists. In West Newbury, there is a much less metamorphosed sedimentary formation which is intermediate between a phyllite schists and a shale. In Rowley, in a belt of schists similar to the schists of Newbury, fossils of Cambrian Age have been found by John H. Sears and identified by C. W. Walcott. This fixes the age of these belts as Cambrian. The West Newbury formation on the other hand, is entirely different, and its age is doubtful.

Some of the hornblende schists are feldspathic and grade into diorites. This seems to indicate that at least some of the schists are of igneous origin.

Cutting the schists, we have diorites and granites. The diorite, a quartz-hornblende diorite, is older than the granite as shown by intrusions of the granite in the former rock. A phase of this rock outcropping in Newburyport contains hornblende and basic feldspar, but is very silicious and is called a grano-diorite. On the periphery of the diorite and cutting it so as to form a breccia on a very large scale, are two types of granites. To the north, of the diorite belt we have a coarse porphyritic granite and to the south a finer hornblende-mica granite.

Along the valley of the Parker River there outcrops a series of volcanic rocks, which are probably effusive. These include felsites, agglomerates, andesites and possibly basalts. Besides these effusive volcanic types, numerous trap dikes probably

cut all other formations.

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A-6. Structure.

The Cambrian rocks occur in the form of lenticular blocks having the long dimension east-west. These blocks occur in the diorite, granite and felsites, and are distinctly cut by the diorites and granite. Their relation to the volcanic series is not clear. Large fragments of the schists are included in the diorite and granite.

Similarly, the diorite is cut by the granite forming at times a complete breccia. Where the diorite is in excess of the granite, the granite is in the form of dikes and veinlets minutely splitting up the diorite. Where the granite is in excess, the diorite is in the form of large and small inclusions. These inclusions do not occur, however in the grano-diorite or the porphyritic granite, but this granite-diorite complex covers almost the entire rectangles Salem I and IV. Where the erosion has been excessive, as along the mining district, the granite-diorite complex is also exposed.

The relations of the igneous intrusions to the volcanic series is not well exposed, but a rock resembling the andesite or basalt has been found included in the granite. Also the occurrence of the granite between felsite and the diorite would seem to indicate that the Plutonics are younger than the volcanic series.

So far as known the West Newbury formation is not cut by any plutonic or intrusive rocks. The superficial deposits consist of recent alluvium and glacial drift.

A-7. Economic geology.

a. Lead-silver:- This district has been in the past the site of a silver-lead mining excitement. In 1874, numerous prospects and a few shafts were sunk. The prospecting was mainly carried on in the belt of rocky hills extending from Byfield to Newburyport. At present there is no mining.

b. Limestone:- About two miles south of Newburyport, there are two quarries of serpentine limestone that were worked for lime in colonial times.

c. Building stones:- The grano-diorite and porphyritic granite have been extensively quarried for ballast, road metal and rough construction work.

d. Clays:- The glacial clays have been intermittently worked for pottery and for brick. The principal industry being situated at a point about a mile south of the city of Newburyport.

A-8. Problems.

There are eight general problems to be considered in the geology of this area.

- a. The structural relations of the Cambrian limestones and schists, and the West Newbury formation.
- b. The structural relations of the sedimentary rocks to the volcanic series.
- c. The structural relations of the sedimentary rocks and the plutonic rocks.
- d. The structural relations of the volcanic rocks and the plutonic rocks.
- e. The relations of granites and diorites.
- f. Deformation of the rocks.
- g. The structural relations of intrusive rocks to all others.
- h. The source and mode of deposition of ores.

A-9. Conclusions.

In Cambrian times sediments were deposited over the whole area, and sedimentation may have continued longer, but all evidences have since been removed. The age of the volcanic rocks, which appear to be interstratified with a bed of phyllite, is very uncertain, and may or may not be younger than the intrusion of a granite batholite. This intrusion probably took place in late Devonian times. This batholite swelled up into the sediments stopping off large and small blocks which sank into the magma. The peripheral layer was more basic than the interior. This basic crust had solidified or partly solidified when the granite below was injected into it.

Concomitant with the Appalachian revolution the region was strongly folded, changing the sediments into schists and the plutonics into gneisses. Subsequent to this folding, the region was fissured and faulted. In these fissures, where they cut the sedimentary formations, the lead-silver ores were developed. Also along these fissures the trap dikes were injected.

Since these dikes were injected, the district has suffered long continued erosion, forming two successive peneplains, the Cretaceous and Tertiary. In glacial times, immense deposits of drift were spread over the area.

B. GEOLOGY.

The general features regarding the drainage and topography have been covered in the introduction. It was also mentioned that while the smaller rivers, such as the Parker and Rowley, flow through wide valleys, the Merrimac flows through a comparatively narrow valley. The Merrimac River has a steep grade and falls over rocky ledges at Lowell, the total fall at this point being about 40 feet. From Lowell to the ocean, it flows through a narrow, crooked valley, between and over rock ledges. Also at Lowell, or more specifically at North Chelmsford, it makes an almost complete bend, and instead of flowing south, it flows to the northeast. This is explained by Prof. Crosby in his paper on, The Geological History of the Nashua Valley. He believes that the Merrimac held a former course which has been traced by borings and lack of outcrops across Chelmsford, Woburn to the Charles River and into Boston Harbor, through South Bay, which is south of South Boston. The diverting of the Merrimac may have been caused during Tertiary time by the backward cutting on a band of relatively weak rock, (the Merrimac slates), of a small stream following the present course of the Merrimac below Lowell. This diversion may also be explained by the deposition of glacial drift in the course of the stream, which turned the river over a low divide at Lowell into the valley of the northeastward flowing stream.

The rocky hills forming the western part of the town of Newbury and through which the upper part of the Parker River flows, reach a maximum elevation of about 100 feet. The tops of these hills forms a fairly even skyline, and Prof. Crosby considers this skyline as representing the Tertiary peneplain. But rising above

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this plain as already stated, are the prominent hills of glacial drift.

The deposition of this drift over the area has given rise to many interesting forms of topography. Numerous marshes and ponds were formed, which are of minor importance in the present study. One interesting feature might be mentioned, and that is the utilization of one of these ponds, which lies in a kettle-hole, as a reserve reservoir for the city of Newburyport.

B-2. Descriptive geology.

a. Sedimentary formations:- The oldest rocks in the area are of sedimentary origin, some of them being of Cambrian age. These are cut by the igneous complex, therefore these rocks are properly described first.

(I) Cambrian schists and limestones:- Under this title are described the large masses of schists and limestones which occur surrounded by granite and diorite in the towns of Newbury and Rowley. These masses form large lenticular blocks up to two and a half miles long by a quarter of a mile wide. The line of hills, which extend from Georgetown to Newburyport along the Newburyport branch of the Western Division of the Boston and Maine railroad, have been mentioned under topography. That portion of these hills, which lies between Newburyport and Byfield, is known locally as Highfield. Here is found the largest belt of schists and limestones. As we go south from Newburyport along the old turnpike, five successive belts of schists are met with. These belts, with the exception of the one just mentioned, are only 25 to 300 feet wide and a half a mile to a mile in length. Other outcrops of sedimentaries are found in Rowley. Many other smaller patches of sedimentary rocks, which are too small to map, are scattered over the town of Newbury.

The age of these sediments is placed as Lower Cambrian. The basis of this statement is the following from John H. Sears in his paper on the stratified rocks of Essex county.

"In the month of July, 1890, I discovered an outcrop of this Olenellus limestone, (referring to the Lower Cambrian fossiliferous limestone of Nahant), in a valley between Prospect Hill and Hunslow's

Hill in Rowley. It has nearly all become altered to chert and epidote, but the fragments of the Hyolithes fossils are still to be found in it. We could not find the outcrop referred to, but there is a general resemblance between the schists and limestones just described, and the known Lower Cambrian sediments of Nahant. For these two reasons these schists and limestones are assumed to be Lower Cambrian.

The Lower Cambrian sedimentary series are composed of quartz-hornblende schists and metamorphic limestones. The schists and limestones occur interbedded with one another. This is a dark grayish green heavy rock, and in places developing a poor cleavage; and again it is very massive, but all of the specimens show a banded structure. They are completely but finely crystallized. The banding is produced by an alternation of light and dark constituents, and frequently represents the bedding. The rock is very lustrous, due to long, fine, parallelly-arranged, shiny hornblende crystals.

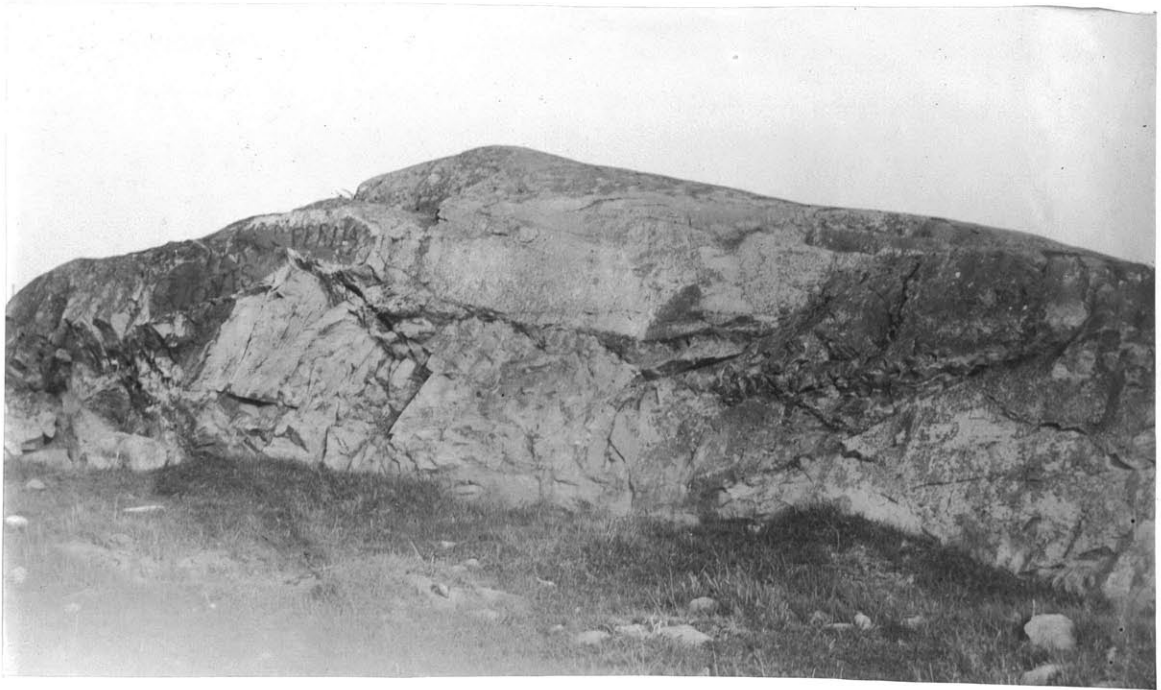
In the thin sections, the elongation of the constituents is in one direction in some of the slides but in others it is not so well marked. The principal constituent is quartz. Hornblende and chlorite is also abundant in the rock. Other important constituents are calcite, pyrite and magnetite. Small quantities of feldspar, epidote, actinolite, zoisite and biotite. The quartz is in the form of large and small grains scattered irregularly through some specimens and in others it occurs in bands. These grains have been shattered and give a cloudy extinction. Hornblende is very abundant and occurs as light green flakes showing medium absorption. Much of the hornblende is altered to chlorite. Calcite occurs in veins and clouded masses, and is present in large

enough amounts to show effervescence with acids. Magnetite and pyrite are scattered through the rock quite abundantly in cloudy masses. Ferruginous dust also clouds the section. A few feldspars are present and these are mostly striated. The extinction angles indicate labradorite; grains of epidote are scattered through the thin section. Needles of tremolite or actinolite are present, which are probably derived from feldspar. Biotite and zoisite occur very rarely, only one or two crystals being observed. As the principal constituents are quartz and hornblende, the best name for this rock seems to be a quartz-hornblende schist.

The associated limestone is highly metamorphosed. The pure varieties are white and light gray marbles being highly crystalline. The marbles are magnesian. In the Devils Den and Devils Basin, many metamorphic minerals are developed. The most prominent mineral is serpentine. This occurs throughout the limestone in large irregular masses and veins, most of the serpentine is of a yellowish green color and of all grades of purity. Some of the veins are of the dark green translucent variety and is known as noble or precious serpentine. Fibrous serpentine is also found and is locally called "rag-rock." Wollastonite is also very common and resembles tremolite in occurrence, Dr. Wadsworth being the first man to distinguish between these minerals at this locality. It occurs as large, tabular, brittle masses and is of exceptional purity. Massive brown garnet occurs disseminated through the wollastonite.

These limestones are sometimes silicious and cherty, and grade into calcareous hornblende schists. The relation of the schists and limestones is thus made evident. Like the schists the limestones are mineralized being impregnated with pyrite and galena.

Plate II.



INCLUSION OF SCHIST.

Schist inclusion in grano-diorite on Parker street. The schist forms the dark, dike-like mass running across the face of the ledge.

The blocks of sedimentary rocks are cut by granite and diorite. Fragments of the schists up to many feet in diameter are sometimes completely enclosed by the igneous rocks. One of the largest of these occurs in the grano-diorite quarry opposite Carr's Island. This is in the form of a large sheet. It is about 40 feet long and 8 feet thick. Plate II shows another inclusion in the grano-diorite on Parker Street. In the neighborhood of Turkey Hill many large inclusions are found in both diorite and granite. Besides these, numerous other inclusions of all sizes have been observed in the plutonic rocks.

(2) West Newbury formation:- In West Newbury there is a large area of sedimentary rocks which outcrops on the sides and around the base of the drumlins, and also along the valley of the Merrimac.

These rocks possess very good cleavage and are usually good true phyllites; but in places they are so little metamorphosed as to be almost a shale. They are however, near the contact with the diorite, harder, tougher and more massive, and more nearly resemble the quartz-hornblende schist. In the valley of the Parker River, on Kent's Island, a phyllite schist or slate outcrops, which bears a close resemblance to the West Newbury formation.

The structural relations of this formation is not well exposed. Along the contact with the porphyritic granite, which runs nearly parallel to the Artichoke River, the porphyritic granite grows fine grained. The granite along this contact is also very much sheared, so that the actual contact between the phyllites and the granites is obscured. Near the contact with the diorite, to the south of Archelaus Hill, the slate is metamorphosed in a similar manner to that already mentioned. The Parker River slates are

seemingly interbedded with basalt.

Both the known Cambrian schists and limestones and the West Newbury formation are highly folded. Their main strike is northeast-southwest and the dips are highly inclined to the northwest. The strike of the Cambrian schists and limestones varies from $N 10^{\circ} W$ to E. W., but the principal strikes lie between $N 30^{\circ} E$ and $N 60^{\circ} E$. With the exception of one dip to the N.E., all the strata dip to the N. W., the most common dip being about 60° . The strikes of the West Newbury formation are more uniform, the common strike being $N 70^{\circ} E$. The limits of the strike are, however, $N 25^{\circ} E$ and $N 85^{\circ} E$. The dips of this formation are also to the N. W., varying from 40 to vertical, but 50° is by far the most common. The various strikes and dips are shown on the geological map.

b. Igneous formations:- The igneous formations cover the greater part of the area. They are of two types: plutonic and volcanic. As the plutonic rocks are most important, they are described first.

(I) Plutonics:- The plutonic rocks vary in composition from a diorite to a binary granite. Although a complete series of rocks of varying acidity are found they are grouped for convenience into three classes: diorites, grano-diorites and granites. In the rectangles Salem I and IV, the granite and diorite sometimes occur so intimately associated that it is impossible to distinguish the two in mapping. This has been called the granite-diorite complex. Under this head also will be discussed the facts regarding the relation of the different kinds of plutonic rocks.

(a) Diorites:- The typical diorite covers quite a large area. It extends from the rocky hills, known as Highfield, to West Newbury, and covers the southern part of West Newbury, Groveland,

Byfield and the northern part of Georgetown. To the east of the Eastern Division of the Boston and Maine railroad, there are also several ledges of diorite. The diorite also occurs in close relation to the granites in the two lower rectangles.

The normal diorite is rather a fine grained dark green rock. When the feldspars are more abundant, it has a lighter color. Occasionally it is also coarser grained. The green color is due to the large amount of hornblende. The hornblende is usually more or less foliated and arranged in parallel sheets and gives the rock a more or less gneissic structure. This structure shows various degrees of development; thus near the contact with sedimentary schists, it becomes an amphibole gneiss which grades almost imperceptibly into schists of sedimentary origin. In other places, however, no gneissic structure is distinguished.

In the thin section, the rock is seen to be composed of plagioclase feldspar, green hornblende, a little quartz, chlorite and accessory minerals such as magnetite and titanite. The feldspar is all striated and is probably labradorite. The hornblende is of the green variety and resembles the uralite of the Maryland and Minnesota gabbro-diorites described in the Educational series of rock specimens, the U. S. G. S. Bulletin 150. The resemblance of the hornblende is very striking and most of the hornblende of the diorite is uralite, and may have been derived from pyroxene. In one of the thin sections, a crystal resembling diallage was found, and it may be possible that the uralite has been formed from pyroxene. The hornblende in some specimens is quite fresh but in others it shows considerable alteration to chlorite. The quartz, which is quite common, though not abundant, is in the form of small grains occurring in the interspaces between the other constituents. Titanite

and magnetite are quite common.

(b). Grano-diorite:- The principal development of the grano-diorite is in the town of Newburyport. Here it is of large extent and uniform in character. It also occurs south of the rocky hills, separating the diorite and the granite proper. It likewise forms one of the constituent rocks of the granite-diorite complex.

The typical rock is medium grained^h holocrystalline and ^{hyp}idiomorphic. In the hand specimen quartz, feldspar, hornblende and titanite are noticeable. The feldspar is stained green and the hornblende is chloritic. In the thin section the quartz is very abundant and was evidently the last mineral to crystallize. The feldspar is about as abundant as the quartz and is all striated and give extinction angles around 18° . This is therefore, probably, labradorite. They are highly altered mainly to calcite and epidote. These alterations cloud the feldspar, which exhibit all the characteristics of decomposed plagioclases. Hornblende is quite common and is of the green variety, this been altered to chlorite and a little serpentine. Magnetite occurs along the cleavage planes of the hornblende and in separate grains. Pyrite is also present in small grains. Titanite is quite an important accessory mineral. To a slight extent apatite is present. This rock is either properly called a quartz-diorite or a grano-diorite; but as this rock distinctly cuts and contains inclusions of the normal diorite which also contains quartz, it has been thought best to call the rock just described a grano-diorite.

(c). Granites:- The granites are of several types, but all seem to be more or less related. In West Newbury, there is a large area of porphyritic granite. Along the mining belt and cutting the schist and diorite, there is a red granite. This gran-

ite outcrops north of Devils Den and although not always stained with iron, outcrops between the volcanic series of the Parker River valley and the diorite. In Rowley and Georgetown, there are many outcrops of a fine grained granite and granite gneiss.

The granite of West Newbury is a coarse granite sometimes containing porphyritic feldspars from 1 to 2 inches long. It is a very silicious rock and is practically a binary granite. Under the microscope much quartz is seen, which shows a cloudy, undulatory extinction, that is evidence of the crushing and shearing which the rock has been subjected to. The feldspars are abundant sometimes porphyritic, usually highly altered, cloudy in the complete crystal, to calcite and muscovitic material. Some of the feldspars are striated and show extinction angles of 10 to 12 degrees. Considering the large amount of quartz present and the lack of ferromagnesian minerals, the feldspars are albite oligoclase.

The red or brown granite is practically a binary granite stained with iron. The rock has a general gneissic character due to streaks of dark minerals probably wholly limonite. The slide shows an abundance of quartz and a good development of feldspars. These feldspars are orthoclase and microcline with some plagioclase. The rock also contains calcite, epidote and kaolin as alteration products. Grains and clouds of limonite occur throughout the section, and are often arranged in streaks surrounding the other minerals.

The binary granite outcrops along the Parker River between the volcanics and the plutonics. In Rowley, there are also outcrops of binary granite. This granite resembles the granite described in the preceding paragraph except that it is not stained with iron oxide. It is a fine grained light rock with a pinkish tone

Plate III.



INCLUSIONS OF DIORITE IN GRANITE.

A typical development of the normal diorite inclusions
in the granite.

and is usually much sheared. In Rowley near the contact with the volcanics, this rock has a tendency to develop quartz porphyritically. These quartzes are of a peculiar blue color and resemble chalcedony.

In the greater part of Georgetown and Boxford, the country rock is granite gneiss. This is clearly related to the fine grained binary granite and grades into it. The gneiss is a light colored rock, the gneissic structure being made evident by the streaks of chlorite. Under the microscope the quartz is seen to be very abundant, but of course shows a wavy extinction. The feldspars are highly altered to calcite and epidote. The fresh feldspar is striated and has extinction angles varying from 10° to 12° . From the general resemblance of the constituents of this rock to the grano-diorite, it is believed that these feldspars are plagioclase. Chlorite and some hornblende are grouped in streaks across the slide.

(d). Granite-diorite complex:- In many places, the diorites, grano-diorites and granites occur in close association. Even where the diorites reach their best development, around Byfield, they are intersected by granite dikelets. In the neighborhood of Highfield, the diorite is intersected by a regular network of granite dikes and dikelets of all sizes, so as to form a breccia on a large scale. Along the Parker River, although the granite and grano-diorite is in excess, inclusions of the normal diorite are scattered all through the outcrops. These inclusions are very large, sometimes composing most of the ledge. This granite-diorite complex is especially well developed over large areas in Rowley and Boxford. Throughout these plutonic rocks, the acid rocks cut the more basic. There are no exceptions to this statement, but the contact with the granite porphyry is different from the other

contacts. This contact seems to be a fairly definite line and beyond the contact zone, both the diorite and granite porphyry are normally developed, neither containing inclusions of the other. In this contact zone, which varies from 300 to 150 feet in width, the porphyritic granite grows fine grained. The majority of the rock of this contact zone is highly sheared and undeterminable. The contact zone of this granite extends around its whole periphery, even where the contact is with the sedimentary formation. Near the contact with the diorite, however, the fine grained granite and even fairly coarse granite in the form of dikes, cuts the diorites. The plutonic rocks invariably cut the Cambrian schists and limestones and the contact phenomena have already been described.

The relation of the plutonic and volcanics is obscured by swamps and rivers. A striking feature of this phenomena is, however, that the granite is always nearest to the volcanics, and becomes binary and fine grained. The relation of these two formations is further described on page 35.

(2) Volcanics:- The volcanic rocks are of two types: extrusive and intrusive.

(a) Effusive:- The extrusive rocks are the more important. They lie along the valleys of the Parker River and Mill Creek, and extend south into Rowley. They consist of a series of volcanic rocks of varying acidity, from rhyolites to basalts. The rocks are altered and metamorphosed, the acid rocks to felsite and quartz porphyry and the andesites and basalts to greenstones and melaphyrs.

Felsites:- The felsites are usually red, banded, hard and massive. There are however important exceptions. The principal areas of red normal felsites are Newbury Old Town, Kent's

Island, the immediate neighborhood of Dummer Academy, and in the vicinity of Doles Corner, Rowley. This felsite is a hard, compact rock resembling jasper. The lamination of dark and light colored portions makes evident the flow-structure of the original lava. The constituent minerals are not recognized in the hand specimen although in some places the rock shows porphyritic quartz and feldspar. A ledge of felsite outcropping about a mile north of Newbury Old Town along the state road leading to Newburyport, is a compact, greenish-white rock resembling a fine quartzite or a chert. It is a very hard, tough and fresh rock. The constituent minerals cannot be distinguished from one another in a fresh specimen, but it presents a uniform surface with a sub-vitreous lustre. The rock is also semi-translucent. The surface is slightly oxidized to a depth ranging from one eighth to one quarter of an inch. Here the rock is stained with iron, with little patches of brown material scattered through it, which are the result of the oxidation of tiny grains of pyrite. Some of these grains of pyrite can be distinguished on the fresh surface by the aid of a hand lens.

On the north side of Kent's Island a felsite occurs, which is spherulitic. The spherulites weather out in little knobs or marbles up to a half an inch or more in diameter, and stand out in strong relief. When broken open these spherulites show a concentric structure.

Some of the felsites are brecciated. Small angular fragments of felsite, which are arranged in parallel lines, are cemented together by lighter colored material. These fragments vary from microscopic in size to one eighth of an inch in diameter. These are seen, under the microscope, to be essentially the same composition as the cementing material, that is, an intimate mixture of extremely

fine granular quartz and feldspar. The rock is stained with red iron oxide, which occurs in clouds and minute grains throughout the slide. The rock is very silicious and numerous microscopic quartz veinlets traverse the rock in all directions, showing how great has been the fracturing. The fragments have no very sharp outline, but are distinguished by their difference of extinction, and also are more stained with iron oxide. They may only represent segregations of iron oxide but their angular and stratified character seem to indicate that these rocks represent a metamorphosed tuff. There are also other undoubted tuffs. These tuffs were formed during the eruption of the original rhyolite by the solidifying of a part of the flow and its subsequent brecciation by the still molten lava.

Agglomerates:- There is also at least one band of volcanic rock, which is a distinct volcanic conglomerate or agglomerate. An outcrop of this rock occurs on the turnpike to the east of Dummer Academy. The fragments range in size from minute grains up to pieces an inch in diameter. They are all volcanics, but vary in color green, red and purple felsites all being present. The cementing material is light in color. The rock has been greatly crushed obscuring to some extent its structure.

Andesites and basalts (greenstones and melaphyrs):- Seemingly interstratified with these felsites are andesites and basalts. The andesite is a dark green rock, but is more or less mottled and also contains porphyritic, striated feldspars. The ground mass is fine grained, prevailing green, but being stained with red iron oxide in places. It also contains magnetite and pyrite. In the thin section, lath-shaped feldspars are seen interbedded in a fine grained ground mass. The feldspars are striated and give

extinction angles between 10° and 18° , which with the entire absence of quartz, indicates that the feldspars are moderately basic plagioclase, possibly andesine. The feldspars are highly altered to calcite and epidote. Chlorite is very abundant and represents a decomposition product of hornblende or possibly augite. Some of the epidote may also be pseudomorph after hornblende. The ground-mass resembles that of an andesite very much, and for the above reasons the rock is called an andesite. This andesite outcrops along the southern bank of the Parker River, opposite Newbury Old Town, and in Rowley, near the contact of the volcanics with the granite.

Along the Parker River are many high, prominent ledges of a dark greenish and purplish rock. One of the striking features of this rock is the vesicular structure. These vesicles are arranged in parallel lines, and probably represent steam holes of an old lava flow. Scattered through the rock in irregular veins and patches and large stringers, are alterations to epidote. Black phenocrysts of altered material, pseudomorphs after augite, are common. The general appearance of this rock is strikingly similar to the Rock Island basalt in Quincy, about 10 miles south of Boston. These prominent ledges are therefore probably altered basalt or melaphyr, and represent surface flows. These volcanic rocks are all seemingly interbedded and no attempt has been made to differentiate them on the map. They are all very much altered, folded and fractured. This fracturing, especially on Kent's Island has been most extensive, minutely fissuring the felsite so that it is easily decomposed to kaolin, giving the deposit spoken of on page 49. The basalt is also very much sheared, and sometimes develops a slaty structure. On Kent's Island, and extending across the Eastern Division of the Boston and Maine railroad, there is a band of slate. This band of

sedimentary rock seems to be interbedded with the volcanics. Along the contact with the plutonic rocks are various inclusions in the granite. These inclusions are fine grained, dark green, epidotized and resemble the basalt very much. Similar inclusions are also in the felsite near its contact with the basalt.

(b) Intrusive (traps):- Cutting all other formations are numerous trap dikes. These are all basic and some of them are extremely so. They are black, usually fine grained rocks with a high specific gravity, and containing pyrite and magnetite. Some of them are normal diabases and show the typical diabase weathering of the lath-shaped feldspars. They weather brown and concentrically, and closely resemble the Triassic diabases of the Boston Basin. A table has been compiled giving the strikes and hade of all the dikes seen, but as the field work has been on a large scale, the table must necessarily be incomplete.

Trap dikes.

| | <u>Locality.</u> | <u>Width.</u> | <u>Strike.</u> | <u>Dip.</u> |
|-----|---|--|----------------|---------------|
| I. | Railroad crossing, High-field road | ----- | N 38° E | -----20° N.W. |
| 2. | Three quarters of a mile south of Chipman | --15 feet--- | N 30° W | -----25° S.W. |
| 3. | Mine | --15 feet--- | N 63° E | ----- Vert. |
| 4. | A mile and a half N.E. of Byfield | --25 feet--- | N 30° E | ----- Vert. |
| 5. | Grano-diorite quarry, | -- 2 feet--- | N 30° E | -----40° N.W. |
| 6. | mile west Newburyport | --18 feet--- | N 45° E | ----- Vert. |
| 7. | Half a mile N.W. of Turkey Hill, west bank of Artichoke River | complex of dikes. Total width 50-60 feet | N 20° E | -----10° N.W. |
| 8. | Quarry opposite Carr s Island | 15 feet--- | N. 50° E. | -----15° N.W. |
| 9. | One mile north of Dummer Academy. North of Parker River | 1 feet--- | N 40° W | ----- Vert |
| 10. | One mile south of Turkey Hill | 4 dikes, 4, 4, 3, 1 feet respectively | N 30° E | ----- Vert. |
| II. | 1000 feet S.E. of Chipman Mine | 6 inches--- | N 12° E | ----- Vert. |

C. ECONOMIC GEOLOGY.

The minerals composing the ore from the Chipman Lode are:galena,tetrahedrite,chalcopryrite,sphalerite,pyrite,and arsenopyrite. Galena is the most important mineral and is argentiferous. In the upper workings the galena composed the greater part of the vein;but in the lower workings it occurred as disseminated patches. It is,in the main,finely crystalline;but it also occurred as medium and coarse cubes. Mr. Shockley found these coarse cubes to assay higher in silver than the finely crystalline galena; but this fine ore contained more silver than the medium.

| | | |
|--------------------|-------|-------------------|
| Coarse galena----- | ----- | 102 oz.per ton. |
| Medium " | ----- | 29.16 oz.per ton. |
| Fine " | ----- | 65.9 " " " |

The float ore,and especially the ore near the surface, contained a great deal of tetrahedrite. Prof. Richards speaks of one specimen of float ore being covered on one side to a thickness of a half inch with tetrahedrite. The tetrahedrite is both argentiferous and auriferous,carrying from 400 to 3500 ounces of silver and from 1 to 7 ounces of gold. As the depth increased the quantity of this mineral fell off greatly. Sphalerite occurs sparingly throughout the vein. Pyrite,chalcopryrite and arsenopyrite were not abundant near the surface;but with increase of of depth,they became more important. It is probable that these minerals carry some of the gold values. They are never coarsely crystalline,but occur in fine grains. This ore has been spoken of by Prof.Richards as being similar to the Georgetown,Colorado, lead-silver ore.

The association of minerals is very uniform throughout the district. In no case do these minerals seem to be oxidized near the surface.

C-2. Gangue.

The gangue minerals are:-quartz,siderite,ankerite,limonite,calcite,serpentine,agalmatolite and kaolin. Quartz is by far the most abundant and is the principal vein mineral. It is usually crystalline and massive,but rarely shows crystalline form. Siderite is very abundant,especially in the lower workings. It is of the well crystallized spathic variety. There are different species the analysis of the white variety being given on page 55. The composition shows it to be essentially an ankerite. The siderite and ankerite occur in streaks parallel to the walls of the vein, giving the vein a banded structure. The oxidation of the pyrite and also the hydration of the siderite has produced limonite superficially. Calcite is a common gangue mineral though not important in the Chipman Lode. In a shaft situated about half way between Newburyport and Rowley just to the north of the locality known as Devils' Basin,a beautifully crystallized variety of calcite is found. Serpentine is common and represents an alteration product of the wall-rock. One of the pinite varieties,agalmatolite has been described and analysed by Mrs. Richards. It is a compact amorphous,pale yellowish green in color,with a lustre of serpentine;fusible only on thin edges and attacked slightly by acids; specific gravity 2.766 and hardness 2.5. The analysis of this mineral is given below.

| | |
|---|-------|
| Silica, SiO_2 ----- | 66.53 |
| Alumina, Al_2O_3 ----- | 25.09 |
| Ferric oxide, Fe_2O_3 ----- | Trace |
| Potash, K_2O ----- | 4.67 |
| Soda, Na_2O ----- | 0.39 |

Water, H₂O-----2.64

Magnesia and Lime, MgO, CaO-----Trace
99.32

The veins and country rock have been sheared and the alteration along the fissures, has resulted in kaolin. In connection with the ores, kaolin is not important.

C-3. Mode of occurrence.

a. Veins:- The ores of this district occur in veins formed in preexisting fissures. The fissures usually represent slight faulting. The preexistence of fissures is shown by the banded character of the veins. The wall-rock on each side shows slickensides. The general course of the fissures is northeast-southwest and northwest-southeast. The strike of the fissure containing the Chipman Lode is $N 80^{\circ} E$ and hases slightly to the south; thus the 220 foot level is pushed 20 feet to the south before the vein is reached, the shaft having been started on the vein. The most common northeast strike is about $N 30^{\circ} E$. Several of the trap dikes having this trend (see page 36) and some of the veins, a good example being one in West Newbury. The majority of these fissures have about 20° to the north. The other set of prominent fissures have strikes varying from $N 30^{\circ} W$ to $N 70^{\circ} W$. Besides these fissures the rocks have been very much broken and jointed along planes of varying strikes. Near the prominent fissures the rocks are usually very much sheared, the sheared zone being often 2 or 3 feet wide.

It is in these zones that veins occur, or are supposed to occur. These sheared zones are always stained with iron and the presence of this brown sheared material has been taken as a sure sign of a vein, unfortunately they were not always correct in their assumption. The actual quartz veins are usually small and cut all kinds of rocks, but only carry ore when they cut the sedimentary formations. The normal quartz vein is usually not more than 4 to 8 inches in width. An exception to this statement is a large quartz vein, about three quarters of a mile west of the top of Crane Neck Hill, which runs across the road between West Newbury

and Groveland. This vein, which is of exceptional purity, is about 10 feet wide. The veins in most cases, are composed of nothing but pure white quartz, but where they cut the red granites, they also contain siderite and pyrite. All of the shafts, which have produced any ore, are sunk on the veins where they cut sedimentary rocks. The sedimentary rocks are not always of great extent, some being hardly more than large inclusions. For example, the shafts south of Turkey Hill, show a little calcareous slate on the dumps, although the outcropping rock and most of the rock mined, is granite. These shafts did not produce much ore. A striking example of the limitation of the silver-lead minerals is in the Chipman Lode itself. The shaft was started in the normal quartz-hornblende schists. At a slight depth, probably, limestone was reached. A bed of limestone also outcrops to the south of the Newburyport branch of the Boston and Maine railroad, and it probably extends north under the rocky hills to the Chipman Lode. Kempton, who prospected with a diamond drill about a half mile east of the Chipman Mine, also reports limestone or dolomite. It is in these sedimentary rocks that the Chipman Lode was productive. From the large amount of granite on the dump, it is evident that the lower workings were driven in this rock. It is also very evident that the vein in these lower workings carried little but siderite. Throughout the district the restriction of the ore to the sedimentary formations is very striking.

b. Replacements:- In nearly all the limestone, disseminated through it in small patches and crystals, occur galena and pyrite. Thus the limestone around Devils Den and Devils Basin contains galena and pyrite. Also the schists are highly mineralized. This is seen especially well in the thin sections, although

it was impossible to distinguish the separate minerals. The patches of galena are too large to be original in their present form and represent replacements in the limestone.

For a discussion as to the source and mode of the deposition of the ore, see conclusions page 74.

Plate IV.



DEVILS DEN.

Colonial limestone quarry.

In colonial times, at the localities known as Devils Den and Devils Basin, magnesian limestone was quarried for lime. Judge Sewall records the discovery of these deposits by Ensign James Noyes in 1697. It is probably the first limestone discovered in Massachusetts, and was held to be so valuable that restrictive regulations were made for its use. From the size of the present excavations, the amount of limestone quarried could not have been large. The limestone has been metamorphosed and many metamorphic minerals have been developed. It has been a source for mineral collectors of the following varieties, which are abundant and of good quality:—massive and fibrous serpentine, wollastonite and garnet.

C-5. Building stones.

The grano-diorite and porphyritic granite have been quarried to some extent and also other rocks have been quarried for very local use as road metal. The principal quarry is situated on the Merrimac River opposite Carr's Island, and is in grano-diorite. It is about 600 feet long by 150 feet wide. Some good sized blocks were obtained. The rock has been used locally for bridge and building foundations. Shipping was very important at one time in Newburyport, and during this time this rock was used as ballast. Three other-smaller quarries are situated in an area of grano-diorite lying about a mile and a half southwest of the city of Newburyport. One of these quarries located on Anvil Rock Farm, furnished material for the railroad tunnel underneath the city. None of these quarries are being worked at present, except possibly when there is a local demand.

Plate V.

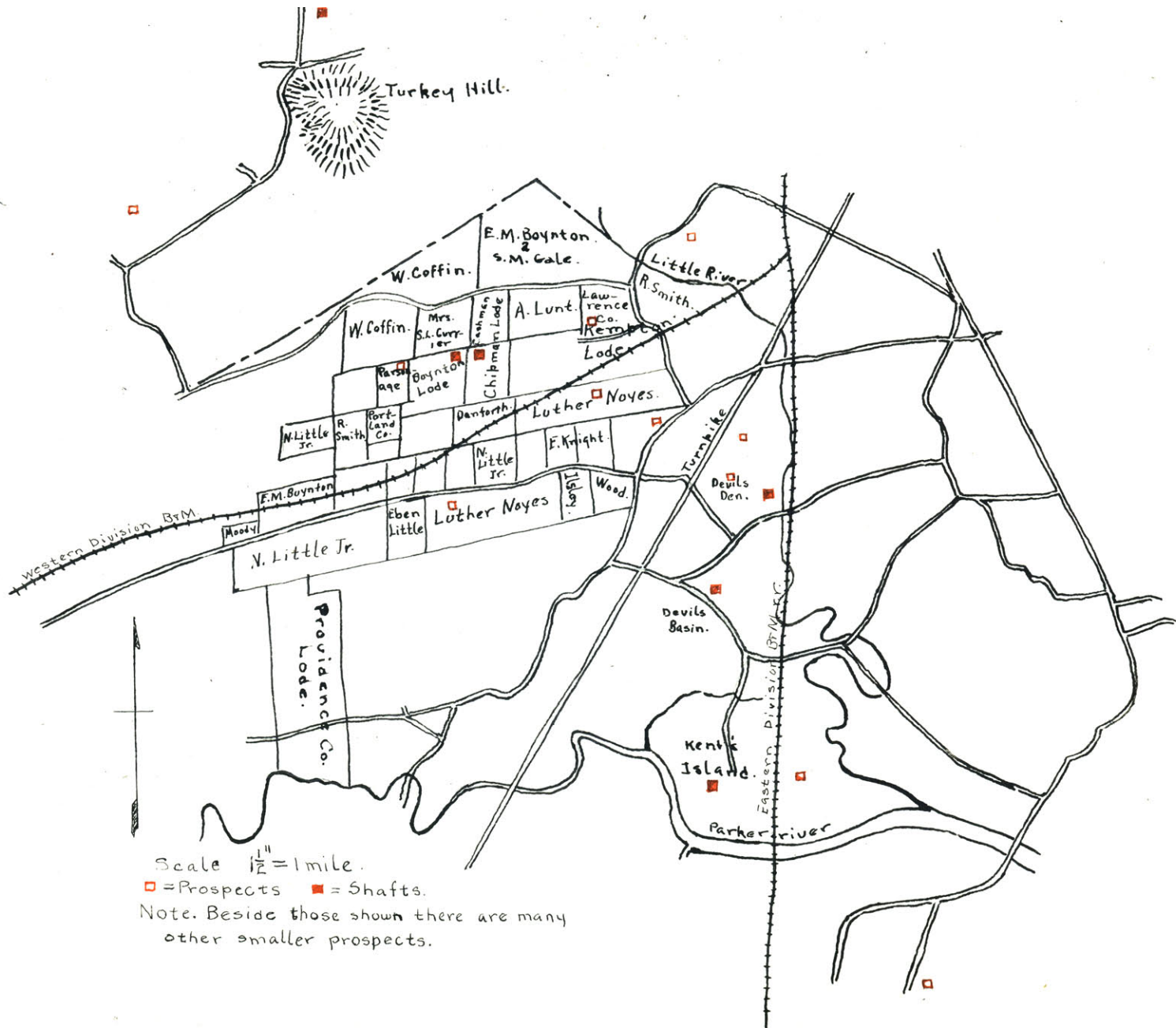


BRICK PLANT.

In the broad valley just to the south of Newburyport the glacial clays have been worked intermittantly. At first some pottery was manufactured. When that was given up, a plant for making brick and tile was built. This plant has a capacity of 40,000 bricks per day. The bricks, as they come from the brick-making machine, are first air dried in racks, and then when completely dried they receive their final baking. On account of an excess of sandy particles, the brick has a tendency to shale. This seems unfortunate as the deposit is very large and is conveniently situated near the railroad. The works were not in operation this spring, but the manager states he is going to begin work again in the immediate future.

On Kent's Island, in an old mining shaft, a seam of kaolin was found. This was probably derived from the decomposition of the felsite. Mr. John H. Sears has given the owners a promise of a future.

D. HISTORY OF LEAD-SILVER MINING AND TREATMENT OF ORE.



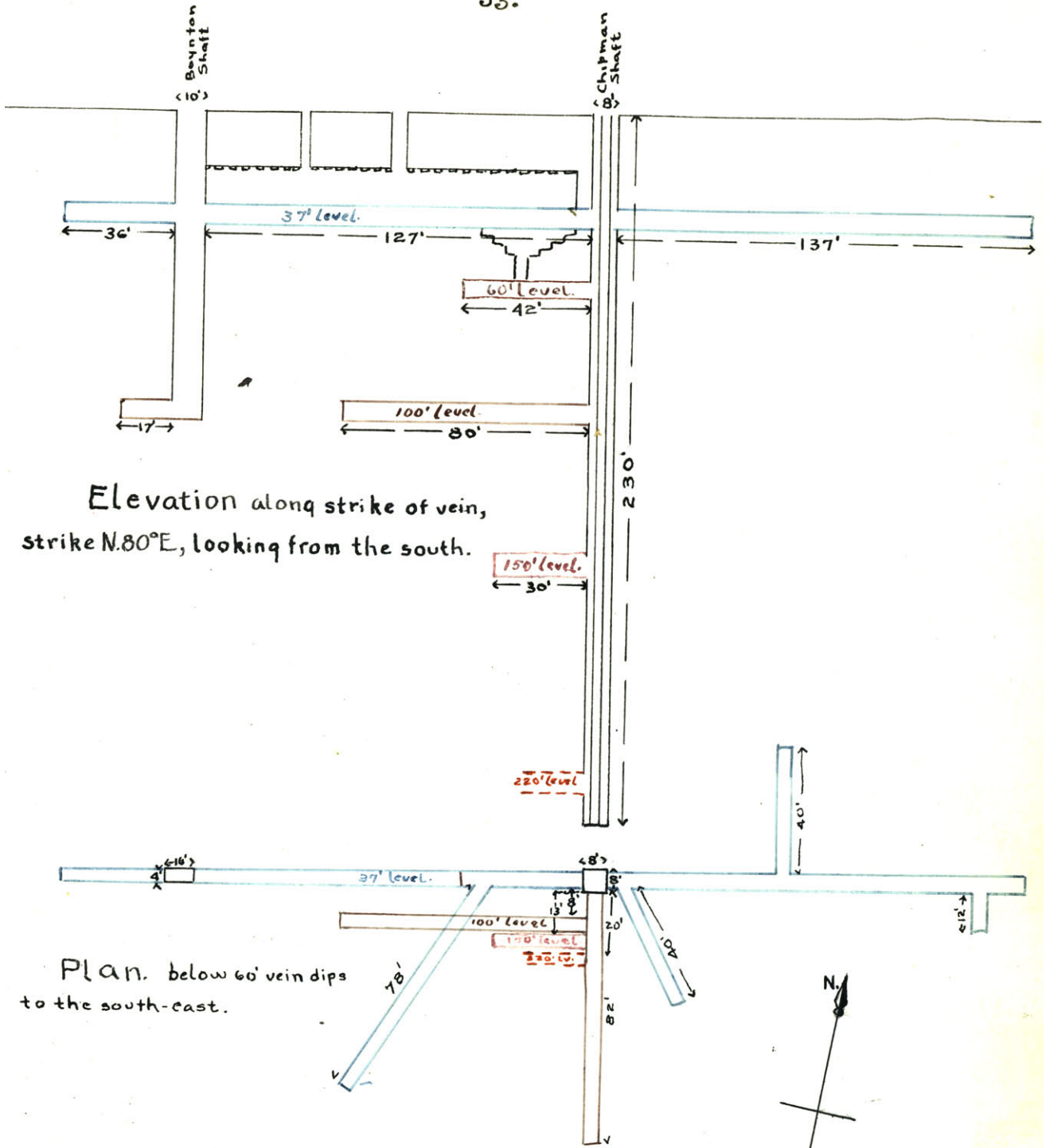
a. Discovery of Mining Lands:- A man named Rogers is purported to be the first discoverer of ore in Newbury. He showed a specimen to a Mr. Adams who upon recognizing the ore as being galena, bought the land upon which it was found, ostensibly to be used as a sheep pasture. The first pit was dug in May, 1874. Prof. Robert H. Richards of the Massachusetts Institute of Technology visited the property on August 8. The ore that he saw occurred as scattered specimens in the glacial drift and the streak of ore had a general trend of north 80° degrees east. He recognized in the ore galena, gray copper and pyrite, and after assaying the ore and finding it to run high in values, he advised systematic prospecting. Recognizing that the creep of the drift on the sloping hill must have carried the ore in a southeasterly direction and arguing from the strike of the streak of ore, that the vein had a northeasterly strike, he recommended that a trench should be dug in a northwesterly direction until the vein was struck. Instead of a trench successive pits were dug, and on October 10 the vein was found. This prospecting was done under the direction of a Mr. Chipman and the vein was called the Chipman Lode. A Mr. Boynton also sunk a shaft 150 feet west of the Chipman shaft and struck the same vein. Later these two men united and formed the Merrimac Mining Company.

The exposed vein consisted of a streak of lead ore 1 inch thick lying against the south wall. Elsewhere the vein was filled with gangue to a thickness of seven feet. After a few days a streak of lead ore 10 inches thick was found against the north wall. On November 1 another pit was sunk to the west of pit just mentioned and the galena was found to be 3.5 feet thick. The

sinking of the shaft soon opened the galena streak to a width of 6 feet.

b. Extent of Prospecting and Mining:- Upon the discovery of this lode a fever of prospecting spread over the whole of New England, but few were rewarded for their labor, and soon all search for precious metals ceased, except in the neighborhood of Newburyport. Here every prominent ledge that was stained with ironoxide was made the object of attack. If they found any galena they immediately started an 8 x 10 shaft and commenced to sink. The result being that many shafts from 40 to 50 feet deep are scattered over the town of Newbury. The only systematic prospecting besides that done at the Chipman Lode, was done by C. W. Kempton and J. H. Bartlett. These men employed a diamond drill but without finding any important ore deposits. On Kent's Island, a couple of shafts and a cut were made. Several other shafts are shown on the mining map; the most important of these are: the one to the north of Turkey Hill, another north of Crane Neck Hill and one just to the east of Devil's Den. Mr. Bartlett also found good ore, mostly gray copper, in the glacial drift at Byfield, but he failed to locate the vein. He also prospected a limestone bed in Rowley, but found little ore. Thus it is seen, that the only mining that could be called at all important was done on the Chipman Lode.

The Chipman shaft was sunk to a depth of 230 feet. Five levels and cross-cuttings were driven. These levels averaged 100 feet in length, that being about the size of the ore chimney. The map of the mine, which is appended, has been composed from a rough mine map made in 1876, and from other data. The vein which was 6 feet wide in the upper workings narrowed as the depth increased. At 75 feet, it was only 8 inches thick and the ore chimney about



Elevation along strike of vein,
strike N.80°E, looking from the south.

Plan. below 60' vein dips
to the south-east.

MINE MAP
of
MERRIMAC MINE



150 feet long. From 100 to 225 feet, the vein narrowed from 6 inches to 4 inches. With increase in depth, the values decreased, so that at 220 feet the vein, here 4 inches thick, consisted of quartz and siderite with specks of galena and gray copper. When this state of affairs was reached, in 1879, the mine was closed. The total production, which has been figured from the average production of the various years, was about 1500 tons of concentrates averaging \$100.00 per ton. The Merrimac Mine seems to have been the only mine to have any important production.

D-2. Assays and chemistry.

a. Ore:- A great many assays were made of the ore contained in the Chipman Lode, but a set of assays attached to a report by Prof. Vinton of Columbia on the Merrimac Mine is given here. These assays were made by Profs. Richards and Ordway. A picked sample of gray copper contained \$4584.00 to the ton in silver and \$26.69 in gold. The argentiferous galena concentrates yielded from 26 to 65% lead, and from 26 to 44 ounces of silver per ton, giving values ranging from \$76.00 to \$158.00 per ton. A good average value of the ore, considering the great number of assays we have examined, was about \$100.00 per ton. This takes account of the slight amount of gold in the ore. The price of silver having fallen from \$1.30 to \$.56 and the lead from 6 to 4 cents per lb., the ore would be worth at present just about one half as much as it was then. The concentrates formed about 10% of the ore mined.

Analyses of the ore have been made by Mrs. Ellen H. Richards of Technology and by students in classes of the years of '74, '75, '76. The following tables have been made from their work.

The following analyses are by Mrs. Richards.

| <u>Tetrahedrite.</u> | <u>Siderite (white variety)</u> |
|----------------------|---------------------------------|
| S-----27.60 | SiO ₂ -----0.72 |
| Sb-----25.87 | FeCO ₃ -----46.84 |
| As-----Traces | MnCO ₃ -----6.69 |
| Cu-----35.85 | MgCO ₃ -----8.83 |
| Fe-----2.66 | CaCO ₃ -----34.32 |
| Zn-----5.15 | H ₂ O-----undet. |
| Ag-----2.30 | <u>98.20</u> |
| <u>99.40</u> | |

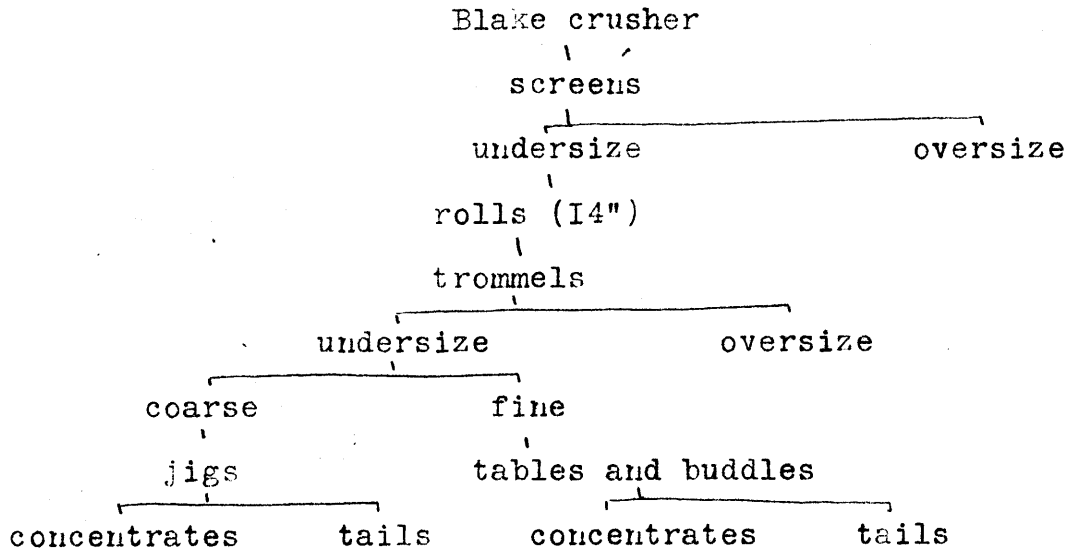
b. Wall-rock:- Mrs. Richards has also made analyses of the north and south wall-rocks.

| <u>South wall.</u> | <u>North wall.</u> | |
|---|---|---------------------|
| | Soluble part. | Insoluble part. |
| SiO ₂ -----66.53 | S-----0.25 | |
| AL ₂ O ₃ -----25.09 | CO ₂ -----5.60 | |
| K ₂ O-----4.67 | H ₂ O-----9.67 | |
| Na ₂ O-----0.39 | { Na ₂ O-----1.50-----0.80 | |
| H ₂ O-----2.64 | { K ₂ O | |
| ----- <u>99.32</u> | SiO ₂ -----26.25-----66.44 | |
| | FeO-----13.19 | |
| | AL ₂ O ₃ -----39.03-----26.73 | |
| | CaO-----4.51-----6.10 | |
| | ----- <u>99.90</u> | ----- <u>100.07</u> |

Mrs. Richards determines the north wall as being composed of quartz and agalmatolite. She does not give any minerals which compose the ^{south}~~north~~ wall.

D-3. Ore-dressing and metallurgy.

a. Treatment at the mine:- The following tree, has been made up from a statement as to the ore-dressing carried on at the mine by Mr. Susmann M. I. T. '76, and from Prof. Vinton's report:



A smelter was erected at the mine and many unsuccessful attempts were made with patent apparatus. As the ore contained copper, lead, silver and gold, a plan was devised to smelt this economically. A blast furnace was built with four tap holes one above the other. Out of the bottom tap hole they were to draw off the gold; after this they tapped from the one above, the silver; from the next, the lead; and from the top hole, the copper.

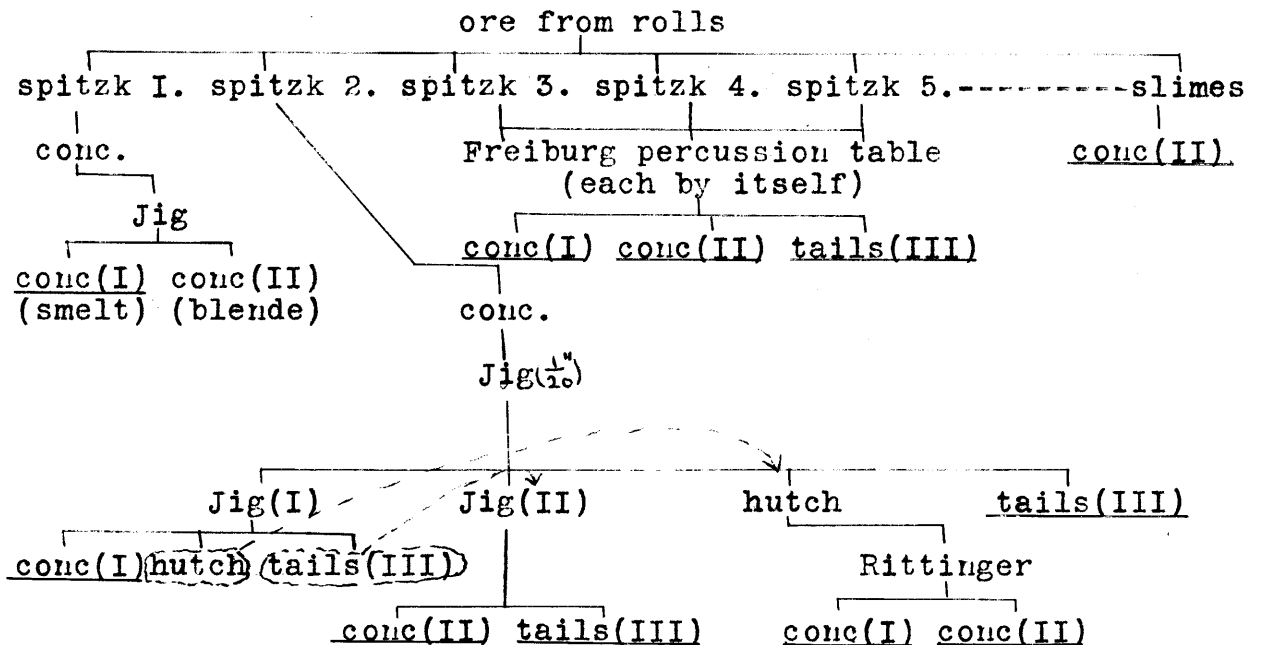
b. Review of M.I.T. thesis work on Merrimac ore:-

Several men of the classes '75 to '78, worked on the ore-dressing and metallurgy of the ore from the Merrimac Mine. Shockley '75 smelted a float ore from the Chipman Lode and got 46.56% extraction of lead silver and gold. Townsend and Susmann of the class of '76, concentrated a third class ore and smelted a float ore. In the concentration one quarter of the lead and over one third of the silver was lost. Their extraction was not high, owing to losses

in cupellation. In the class of '77, Flint and Stimpson concentrated a third class ore, and Baldwin and Hibbard smelted their concentrates. The extractions in lead, silver and gold ran 51.69%, 52.05%, 62.12% respectively. Some of the richer tailings were treated by Wood and Jenny. They tried chlorination and amalgamation without success.

Towne '78 was the last man to work on the Merrimac ore, and as he profited by the experience of his predecessors, his results are better. Also, as they are more up-to-date, we give them in preference to the others. The following trees are from his thesis.

Concentration of a third class ore.



Note:-

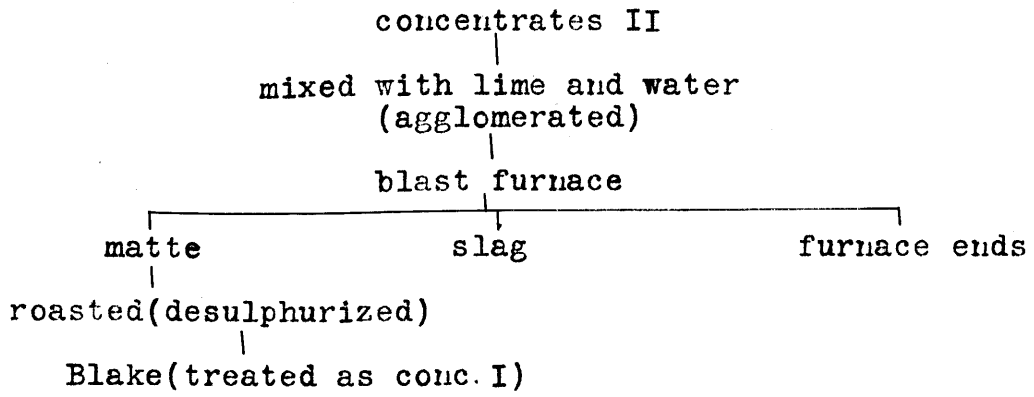
Underline denotes final products.

Concentrates I denotes rich smelting ore.

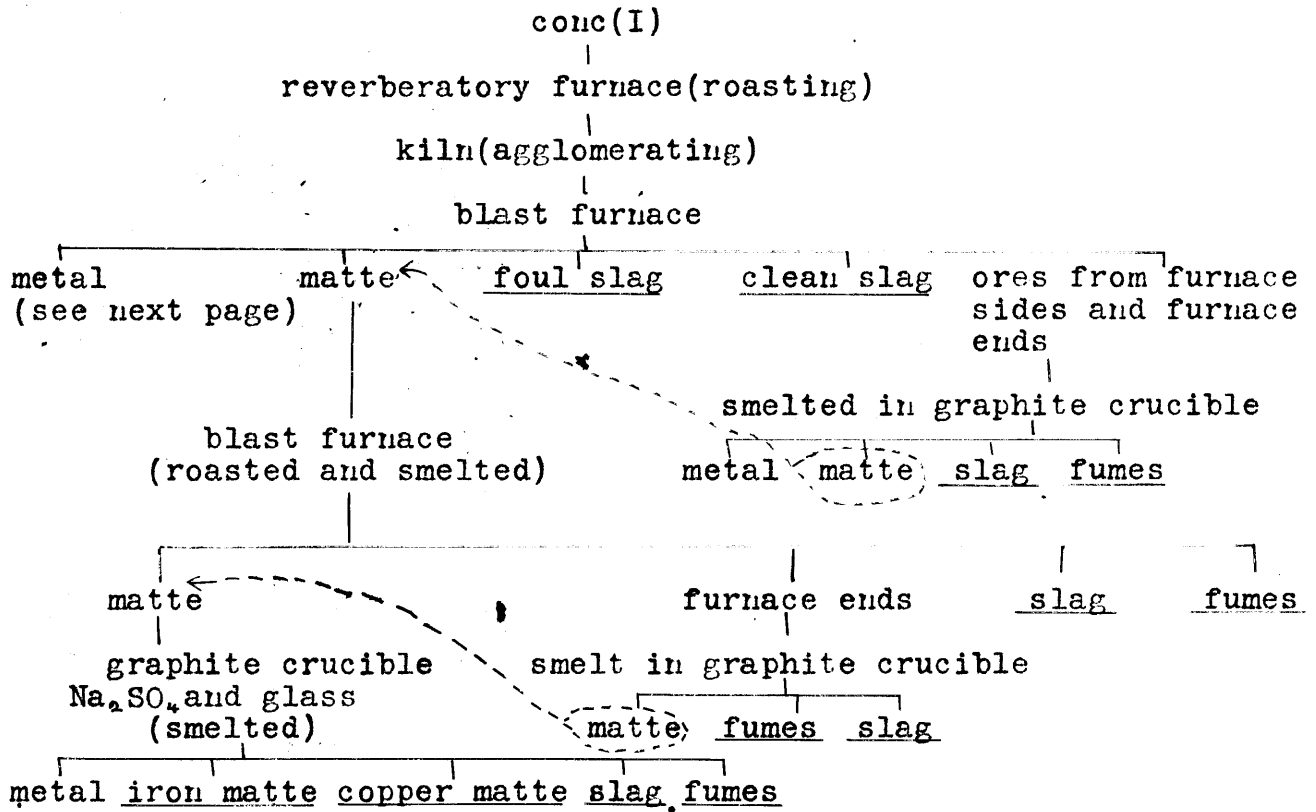
Concentrates II " medium argentiferous ore.

Tails III " refuse.

Agglomerating and smelting of medium argentiferous products.



Roasting and smelting of rich ore.



E. CONCLUSIONS.

E-I. Geological relations and history.

In the introduction eight general problems were given to be considered in the geology of this area. These problems will first be considered each by itself and then the problems will be treated as a whole. As a summary a probable geological history will be given.

a. The structural relations of the Cambrian schists and the West Newbury formation:- The lithology and the structure of these two formations are quite different and for this reason they are given separately. The Cambrian schists and limestones are highly metamorphosed and are everywhere cut by granite and diorite dikes and dikelets. No dikes have been seen cutting the West Newbury phyllite. The contact phenomena of this formation would seem to indicate, however, that this series is older than the granite and diorite. This West Newbury formation is mapped by Hitchcock in his geology of New Hampshire, as a part of the Merrimac schists. These schists are in some localities as at Lowell, cut by the granites. These same schists extend through the Nashua Valley. Here the phyllites are carbonaceous, and have been called by Prof. Emerson, Carboniferous. These schists are also cut by granite. It is therefore seen that the West Newbury formation is older than the granites. As Carboniferous or post-Carboniferous granites are still doubtful in Eastern Massachusetts, it is not likely that the West Newbury formation is Carboniferous, but is of earlier Paleozoic age. Whether or not this formation is of the same age as the known Cambrian schists is uncertain, but there seems to be evidence that these two formations are of the same age. Near the contact with the diorite the West Newbury phyllite becomes hard and massive,

resembling Cambrian slates. In this formation, at the northern base of Crane Neck Hill, and on Kent's Island, shafts were sunk which produced some galena. With these exceptions all the ore occurs in the Cambrian schists and limestones. It may be therefore that the West Newbury formation is of Cambrian age, but is merely much less metamorphosed than the quartz-hornblende schists and limestones. The carbonaceous character of the Merrimac schists would not be unique for a Cambrian sediment, as fossiliferous rocks of undoubted Cambrian age in Nova Scotia and New Brunswick are highly carbonaceous.

b. The structural relations of the sedimentary rocks to the volcanics:- The structural relations between the sedimentary rocks and the volcanics are very obscure. The only clue is the bed of slaty rock, closely resembling phyllite, which outcrops on Kent's Island. This rock is indistinguishable from the West Newbury phyllite. It appears to be interbedded with the felsites and basalts, although no actual contacts are seen. The felsites and basalts are true surface flows and cannot be considered as intrusive into Cambrian sediments. For this state of affairs, there are three possible explanations. The volcanic rocks may be Cambrian. All of the rocks on Kent's Island may be of later Paleozoic age. It is also possible, that the phyllite is not a true sedimentary rock but a greenstone in which a slaty structure has been developed. A chemical analysis would either prove or disprove the third assumption but this we have not had time to make. The other two explanations will be more fully discussed in the fourth paragraph.

c. The structural relations of the sedimentary rocks and the plutonic rocks:- Throughout the area the plutonic rocks cut the sedimentaries and are distinctly younger. The age of the plutonic

rocks is doubtful, but as they have been rendered gneissoid, probably by the Appalachian folding, and as pebbles of similar granite are found in Carboniferous conglomerate, they are undoubtedly pre-Carboniferous. On the coast of Maine, similar granitic bodies are found cutting Devonian strata. As plutonic intrusions probably take place on a grand scale, the granites of eastern New England are, to a certain extent, contemporaneous. Prof. Crosby believes this to be the case and places the age of the New England Coast granites as late Devonian. Considering the immense scale of more recent igneous activity, as in Post Laramie times in the Rocky Mountains, we also believe that the granites of eastern New England are, within long limits of time, contemporaneous. If this be so, their age lies between Middle Devonian and Carboniferous.

d. The structural relations of the volcanic rocks and the plutonic rocks:- The relations of the plutonics and volcanics are not well exposed, all contacts being concealed by marshes or drift, and these relations are therefore extremely uncertain. The inclusions resembling basalt in the granite, the increasing fineness of crystallization of the granite as the felsite is approached and the occurrence of the granite between the felsites and the diorites, constitute all the evidence. All of these facts indicate that the plutonic rocks are younger than the volcanic rocks and invade them. This conclusion is contrary to the one arrived at by Prof. Crosby in his studies of the Boston Basin. In the Stony Brook Reservation south of Boston, felsite and quartz-porphyr dikes cut the granite. In Middlesex Fells and Saugus north of Boston, Prof. Jaggar states that one type of granite is younger than the felsite. It is possible that the inclusions in the granite are not basalt but a fine grained diorite, but they resemble the basalts

so much in the hand specimen that they cannot be told apart. The fineness of the granite and its distribution around the felsite seems to point to the priority of the volcanics. Considering the evidence that the felsites are younger than the granites, and believing in correlation on a large scale, we can only say that the volcanic series appear to be the older. If this be true, the volcanics are of earlier Paleozoic age.

e. The relations of granites and diorites:- The granites and diorites of the district are clearly related to one another. Although many contacts between the igneous rocks are found, they grade into one another on a large scale. Thus a perfect gradation between the most basic diorite and the most acid granite can be found. The examination of thin sections of these rocks also shows a similar relation between them. Thus we believe that all the plutonic rocks, the diorites, grano-diorites and granites are the result of differentiation of one magma. In the solidification of this magma, the more basic rocks solidified first, the more acid last. Thus we find the acid rocks cutting the more basic. The intrusion of this magma will be treated in the paragraph, discussing the problems as a whole, under that topic.

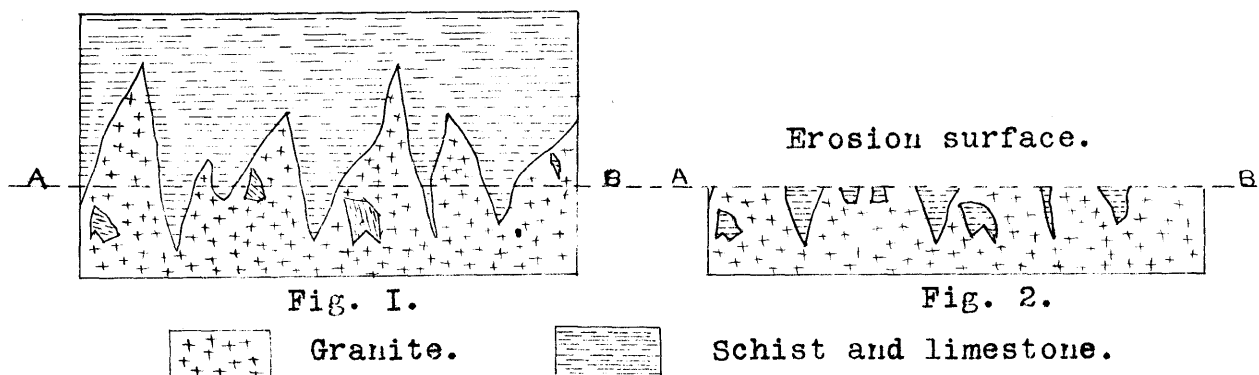
f. Deformation of the rocks:- The schists and limestones, which have been placed in the Lower Cambrian, were undoubtedly folded before the igneous intrusion. This is fully proved by the fact that the strike of the strata in the Highfield belt varies from $N 5^{\circ} W$ through the northwest quadrant to E. W. In the Devils Den there is a complete fold exposed. It is not certain as to whether the West Newbury formation was folded before the igneous intrusion or not, but its rather constant strike parallel to the general strike of the region, about $N 70^{\circ}$ to $80^{\circ} E$, would seem to prove that it was not.

Subsequent to the intrusion of the plutonics and their solidification, the region was strongly folded. The gneissic structure of the igneous rocks in many cases and the general blurred and sheared condition of the contacts of the igneous rocks definitely proves this. The folding of eastern Massachusetts has long been considered to be concomitant with the Appalachian revolution.

Prof. Shaler in his "Geology of Cape Ann" considers Cape Ann to represent an anticlinal axis, forming the northern boundary of the Boston Basin. This axis forms the southern boundary of a smaller synclinal basin, the northern boundary of which is the anticlinal axis represented by the belt of rocky hills extending from Georgetown to Newburyport. This northern anticline is not only well marked by the rocky ledges but by the gneissic character of the igneous rocks and the schistosity of the sedimentaries. In no other part of the area is the metamorphism so great as along this axis, but the contortion of the strata proves that some smaller folds exist in the basin. The lowest point in this basin occurs along the Parker River, for along this river is the largest development of what must have been at one time, whether it be in Cambrian or later Paleozoic times, a surface formation. Therefore this basin is properly called the Parker River Basin. The Merrimac River occupies a similar basin north of the Georgetown-Newburyport anticline.

g. The structural relations of intrusive rocks to all others:- The intrusive rocks following the Appalachian folding are all basic. They cut all other formations. They undoubtedly entered along preexisting fissures which trend in the northeast and northwest quadrants. Slight faulting has accompanied the formation of these fissures and larger faults probably exist which have not been traced out. These fissures are post-Appalachian as they cut the axial lines. The dikes are also, of course, post-Carboniferous but their definite age is uncertain, except that some resemble the north-south dikes of the Boston Basin, which are held to be Triassic. Therefore, the age of these dikes lies between Carboniferous and late Triassic or early Jurassic times.

h. History:- We consider therefore, that in Cambrian times the whole area was covered by sediments consisting of muds and calcareous deposits. As there is a profound unconformity between the Middle and Upper Cambrian, the strata or at least the known Lower Cambrian strata, were at the close of the Middle Cambrian, folded. Nearly all geologists who have worked in this area agree that sedimentation continued through a part of the early Paleozoic. In late Devonian time, these sediments were invaded by an acid magma possibly formed as Prof. Crosby suggests. This magma by differentiation formed a more basic peripheral layer. This batholite invaded the sediments, stopping off large and small blocks which sank into the magma. This basic interior is now represented by the quartz-hornblende diorite. The invasion progressed by a series of smaller irruptions, each successive one becoming more acid, giving the grano-diorite and the granites. The final contact of the batholite was extremely irregular, long apophysal tongues being sent into the sediments, in much the same manner as the granite in the Oriental Pyrenees, which is illustrated in the first of the accompanying figures.



A rough diagrammatic representation illustrating the very irregular contact between the schists and limestones and the granite, as it occurs in the district about L'Etang de Baxouillade, near the town of Ax-les-thermes in the Pyrenees.

Plate VI.



SUMMARY LEDGE.

In this ledge the diorite cuts the schist; the granite cuts both the diorite and the schist; and the diabase cuts all three. The head of the hammer rests on the schist and below the schist is the diorite. The handle of the hammer rests on the granite. The black tongue cutting the granite represents the diabase.

Long erosion has left the Cambrian sediments in isolated patches or blocks, as shown in figure 2.

Either before or after the intrusion of the batholite, probably in Cambrian or Carboniferous times, the volcanic rocks of the Parker River Basin were erupted. These represent surface flows and vary from rhyolites to basalts.

Subsequent to the formation and solidification of all the above rocks, the region was strongly folded producing the anticlines and synclines already spoken of, and metamorphosing the rocks in the post-Carboniferous times, concomitant with the Appalachian revolution.

Following this folding, the region was fissured and at least to some extent faulted. In some of these fissures trap dikes were injected. These basic dikes may represent the complementary dikes which were described by Prof. Daly as accompanying igneous intrusions.

In pre-Glacial times, this district suffered long continued erosion and has been worn down nearly to the sea-level. The rocky hills seldom reach an elevation of more than 100 feet. This elevation represents the level of the Tertiary peneplain at this point.

In glacial times immense deposits of drift were spread over the entire area. This drift is both stratified and unstratified, representing moraines and deposition from glacial streams. The topography of the area was greatly changed, all the oxidized zone being removed and all the rough and jagged surfaces were smoothed off. Fresh water swamps and ponds were formed in depressions in the drift, and the course of many streams was changed. Subsequent erosion has failed to change the topography to any extent.

The igneous intrusion:- We believe, as stated in a preceding paragraph, that the plutonic rocks are derived from one magma, and the different rocks represent the different phases of the intrusion. Of the various theories proposed to explain the intrusion of plutonic magmas, the two summarized by Prof. Daly in his "Geology of Ascutney Mountain" and his own, and the theory held by Prof. Crosby, as yet unpublished in full detail, which he has kindly allowed us to consider in this discussion, will be criticised in the light of the evidence seen in the area.

That the granites and diorites, which form the greater part of the bed rock in eastern New England covering thousands of square miles, were injected into preexisting cavities or potentially existing cavities, that is those which are opened *pari passu* with the invasion, is inconceivable. Such a catastrophic theory is hardly to be held to-day. There is in this area as well as in the Ascutney Mountains, as shown by Prof. Daly, "an almost entire lack of sympathy between the structural planes in the country rocks, and the form of each intrusive body". Therefore it is seen that this theory does not fit the facts as we have found them.

The second theory discussed by Prof. Daly is the one that "batholites have undergone their 'mise en place' as a result chiefly of the caustic and assimilating property of the igneous magma in contact with the country rock". That assimilation of the sediments and of the floor upon which the sediments originally rested, and occupied now by the plutonic rocks, took place, is not to be doubted. No other hypothesis, thus far suggested, can so satisfactorily explain the absence of the original floor and the base of the sedimentaries. But that assimilation took place along the contact, and very superficially, does not satisfactorily explain the extremely jagged con-

tacts of plutonic rocks. The contact of the batholite exposed in Newbury is extremely irregular and dove-tail-like. Neither does the composition of either the granite or diorite seem to change at their contact with the sedimentary formations. Thus we have granites in contact with both limestones and schists, and diorites in contact with the same, neither changing in character at the contact. Therefore we can again quote from Prof. Daly: "As in its usual form the assimilation hypothesis also will hardly fit the facts recorded for the Newbury area."

We have left then the assimilation theory as modified by Prof. Daly and Prof. Crosby. Both of these geologists agree that extensive rifting and fissuring of the "unfused cover" of the batholite accompanies its intrusion and that large and small blocks are stoped off. The tongues, dikelets and numerous inclusions along the contacts in our area fully support this conclusion. Prof. Daly believes that these rifted blocks sank downward into the lower depths of the magma in a more or less steady rain due to the greater specific gravity of the solid blocks. In abyssal regions he believes these rocks to undergo active solution, changing the original magma, which he considers at least as basic as the most basic phase of the igneous rocks, to a more acid one. This mixed magma undergoes abyssal differentiation, the acid sub-magmas floating on the heavier basic residues. The original outer magma, which is basic, having been solidified and fissured by solidification and expansion, is invaded by the differentiated granite.

Prof. Crosby on the other hand, lays no such stress on the rain of rifted blocks down into the lower depths of the magma. He holds that the invasion of the batholite is caused by the uprise of the isogeotherms, which is due to the accumulation of sed-

iments and the isoclinal folding of the Lower and Middle Cambrian strata. This rise causes a fusion of the pre-Cambrian floor and the base of the overlying sediments, thus producing an acid molten magma. While he holds "that the batholite was in the main developed in situ by a gradual elevation of the isogeotherms due to sedimentation and subsequent plication", he regards "the actual contacts as largely mechanical, the product of rifting and flowing. The acid magma thus formed he considers to be differentiated by fractional crystallization on cooling into a basic outer layer. This layer on solidifying is extensively fissured and becomes slowly invaded "under enormous pressure by the more acid and still more molten magma beneath, which on cooling formed the basic or dioritic granite. Under the conditions postulated this basic granite must grade into the diorite" Still later the granite is irruptive into this.

While we agree with Prof. Daly in that the original earth magma is basic, it must have, to be found in its present place, assimilated the pre-Cambrian floor and the base of the Cambrian sediments which probably reached a thickness of some miles. The pre-Cambrian was doubtless made up of crystalline schists and gneisses. Prof. Daly himself states that a differentiation working on the material of even limestones and schists might well give a granite with a low content of lime. Thus it seems probable that the original magma would have become, by the time it had reached its present position, acid. That a layer of basic magma should have continued over the more acid one formed by the assimilation of the sediments and progressed up in this condition for a distance of several miles seems more or less hypothetical.

It seems reasonable that differentiation would take place less readily in abyssal depths than in a cooling and more

superficial region. In the depths, one would think that chemical affinity would be the most active, and that uniformity of a magma over large areas would be the result. While in cooling zones one can more readily see how magmatic differentiation can take place by fractional crystallization.

The gradation between the diorite, which at one time was probably more basic than at present, possibly a gabbro, to the most acid granite, is better explained by Prof. Crosby's theory of differentiation from an original acid magma. The evidence of overhead toping and the subsequent sinking of the blocks in the magma is very striking in this area. These schist inclusions have already been spoken of, but it seems well to recall the large sheet-like inclusion of schist in the quarry opposite Carr's Island, for it is doubtless hundreds of feet below its original place. Thus it appears that Prof. Crosby's theory, although not considering these topped off blocks and their subsequent sinking, is more fully substantiated by our work.

E-2. Source and mode of deposition of ore.

The veins were evidently formed in preexisting fissures. Slight faulting along the veins and the accompanying shear zones prove this. The banded structure does not necessarily mean that the veins were formed in fissures which were originally open to the width of the present vein, but more probably represents successive additions to the vein. Thus for example, it is inconceivable how the massive quartz veins, such as that to the west of Crane Neck Hill, deposited in a fissure that was actually open to a width of 10 feet, or for example, 200 feet which is the width of a vein at Mount Hope, R.I. Such a vein probably represents successive openings and subsequent fillings. It is in this manner that we suppose the veins carry the ores to be formed. This explains the banded structure of the quartz and siderite. The walls of the vein, especially where the walls were limestone, were probably dissolved to some extent by the mineralized waters. This solution of the wall-rock would make room for such a development as that found in the upper workings of the Chipman Mine. Here the galena reached a thickness of 6 feet and was probably deposited *pari passu* with the solution of the walls. Thus we consider this abnormal width, which rapidly decreased to 8 inches, as a metasomatic replacement.

The limitation of the ore to the schist and limestone country rock suggests the derivation of at least some of these minerals, especially the valuable ones from the sedimentary formations. The patches of galena scattered through the limestone, even where there are no veins in the neighborhood, as at Devils Den, and the mineralization of the schists, confirm this theory. Whether or not these minerals are original in the sedimentaries or not is unde-

terminable. They may have been present originally as Chamberlain, Winslow and Van Hise believe the lead and zinc ores of the Silurian limestone of the Mississippi Valley to be original. Or they may be secondary, the sedimentaries being impregnated by them during the intrusion of the granites and diorites as Kemp believes to be the explanation of contact ore deposits. The ore deposits, as they exist to-day, were not formed during the intrusion of the granites or while the igneous magma was still hot or molten, because the fissures and quartz veins cut all rocks irrespectively. These fissures were formed either during the Appalachian revolution or later, because if formed before, they would have been disturbed by the folding and faulting which took place, and no such disturbance is found. At this time, the granite magma had, of course, solidified. Trap dikes are found in the area, but do not have any connection with the ore. The metamorphic condition of the sediments veil the primary origin of the ores, but that the sedimentary rocks played the all important part in the deposition of the ore deposits, is most probable.

The ferruginous character of the granite in the neighborhood of the mines and the increase of siderite in depth, indicate that the granite was the source of the siderite. Quartz and calcite are easily accounted for, as both are abundant in the country rock. Limonite, serpentine, agalmatolite and kaolin represent alteration and secondary products.

The veins were deposited by the deposition of minerals from solution in preexisting fissures. These fissures increased in width *pari passu* with ore deposition as described on page 74. The minerals composing the vein were probably leached from the surrounding country rock. Only where the veins cut the sedimentary

rocks, do they contain ore. Thus it is probable that the ore was leached from the sedimentary formations by meteoric waters and deposited by lateral secretion, superficial waters being the agent of deposition.

The localization of the ore in chimneys, such as the Chipman Lode, and the enlargement of the vein is not easily explained. The most probable origin is either that the chimney represents a more active water channel, or else the chemical reactions which precipitated the ore minerals were more efficient.

E-3. Economic future of Newbury.

a. Ores:- From the preceding work, it has been shown that the veins are limited to the sedimentary formations and are essentially superficial. It has also been noted that this area has suffered great erosion. This erosion has removed the greater part of the Cambrian sediments and those remaining being hardly more than large blocks in the enclosing igneous complex. Thus it is seen that these sediments are themselves superficial. Probably still more superficial are the ore deposits, so that the greater part of what may have been payable silver veins have been eroded. There may still be in the vicinity of Newburyport deposits of ore which have given rise to the abundant and attractive float specimens. But these ore deposits if found, will probably be only the roots of former veins, and will most likely last no longer than did the Chipman Lode. Granite seems to underlie these patches of schists and limestones, and judging by the present occurrences of ore, when the granite is reached, the values will diminish to nothing. These prospective deposits may be found, and if so, should be worked on a small scale until the extent of the deposit is fully known. The discovery of these veins, except where they may be uncovered from under the glacial drift, is, owing to the thoroughness with which the country has been prospected and examined, very doubtful.

b. Limestone:- Except as a source of minerals, there is little to be expected from the limestones of Newbury. The abundant fissuring makes the limestone impossible for use as a marble. And although the serpentine would make a good verde antique marble, the abundance of wollastonite with the serpentine makes

it too brittle for use. Considering the abundance of better and unmetamorphosed limestone throughout the country, its use as a source of lime is not to be considered. It is also very doubtful that these blocks of limestone continue to any great depth any more than they have great length or breadth.

c. Building stones:- Not many of the rocks are suited for building stones. The diorites are too friable, the granite is gneissoid and schistose, and both diorite and granite are broken into small fragments by many intersecting joints and fissures. The porphyritic granite is very weak and brittle, which unfits it for building stone. The schists and limestone are out of the question. The grano-diorite of Newburyport is, where the joints and fractures are not abundant, seemingly a good building stone. The quarry opposite Carr's Island contains large blocks suitable for quarrying. The rock here is acid, granite-like in texture, medium-grained, looks well and is probably a good, durable building stone.

The basalts or melaphyrs south of the Parker River, resemble the Rock Island and Brighton basalts, and like them would make good road metal. It is tough, elastic and durable. The schist and marble also would make good road metal. The basalts are more conveniently located and are probably better adapted for this use. The silicious and granitic texture of the granites and diorites make them unsuitable for this purpose.

d. Clays:- Little attention has been given to clays, but the large amount of glacial clays in the broad valley south of Newburyport and their accessible situation makes the attempt to work these clays advisable. They possess good plasticity, little iron, or other harmful impurities, and if a means of separating the

sandy particles by washing were found, there seems to be no reason why they should not make a good high grade clay.

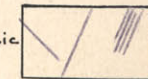
In summing up, there seems to be little prospect for Newbury or the surrounding towns in a mining way; but it is possible that the Newburyport grano-diorite and clays may be of some importance.


STRUCTURE SECTIONS




Age LEGEND


Age Volcanics.


Triassic
?  Trap Dikes
(all these dikes are very basic)


?  Effusive Types
(felsites, tuffs, agglomerates, andesites, and basalts.)


Plutonics


 Diorite
(quartz hornblende)


 Diorite gneiss

 Grano-diorite


Devonian?  Granite-Diorite Complex.
(a phase of the grano-diorite)


 Granite gneiss
(contains a little hornblende and plagioclase)

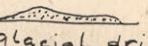
 Red Granite
(usually fine grained and binary)

 Porphyritic Granite

Sedimentaries

?  West Newbury formation.

L.E.  Lower Cambrian schists and limestones

 glacial drift

Older ↑

TOPOGRAPHICAL MAP

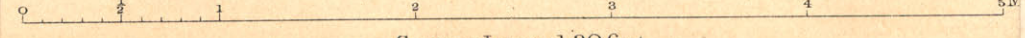


42° 60'

42° 35'

42° 40'

Scale 62,500

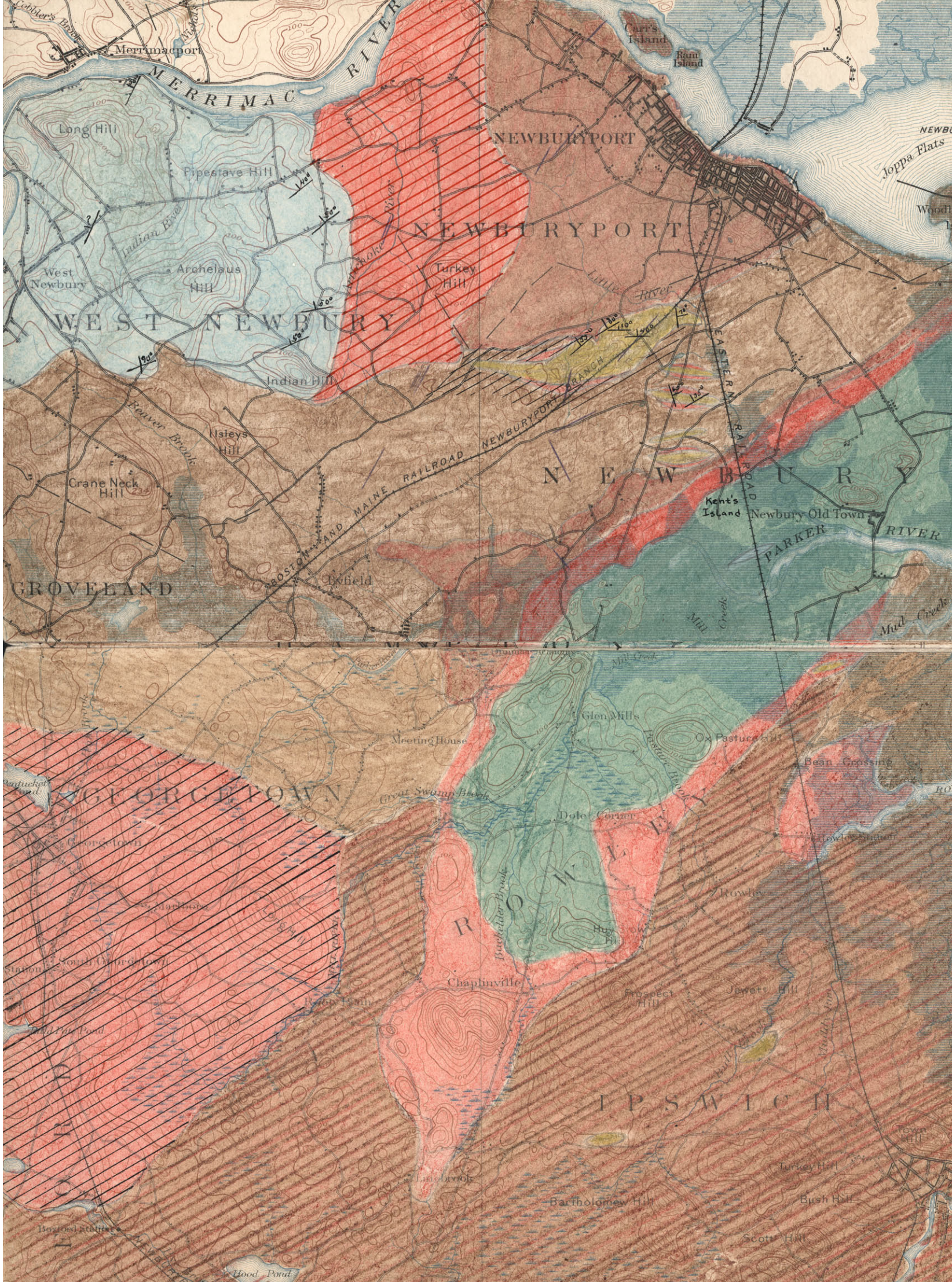


Contour Interval 20 feet

Datum is mean Sea level.

70° 30'


AREAL GEOLOGY




LEGEND


Age


Volcanics


Triassic ?  Trap Dikes (all these dikes are very basic)


?  Effusive Types (felsites, tufts, agglomerates, andesites, and basalts.)


Plutonics


 Diorite (avartz, horn blende) ← Younger


 Diorite gneiss.

Devonian ?  Grano-diorite


 Granite-Diorite Complex. (a phase of the grano-diorite)


 Granite gneiss (contains a little horn blende and plagioclase)

 Red Granite (usually fine grained and binary) ← Older

 Porphyritic Granite

Sedimentaries

?  West Newbury formation

L.E.  Lower Cambrian (Schists and Limestones.)