DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

GEOLOGIC ATLAS

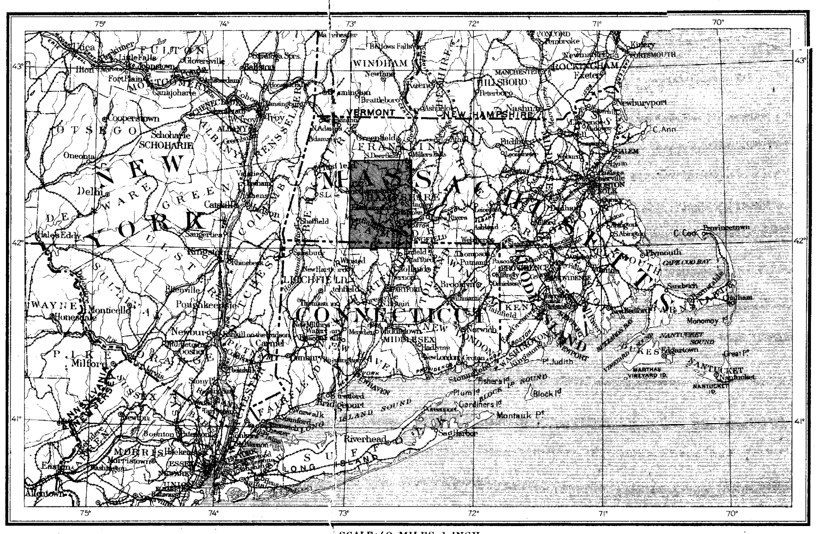
OF THE

UNITED STATES

HOLYOKE FOLIO

MASSACHUSETTS - CONNECTICUT

INDEX MAP



SCALE: 40 MILES - 1 INCH

AREA OF THE HOLYOKE FOLIO

LIST OF SHEETS

DESCRIPTION | TOPOGRAPHY | HISTORICAL GEOLOGY | SURFICIAL GEOLOGY | ECONOMIC GEOLOGY

STRUCTURE SECTIONS

FOLIO 50 | LIBRARY EDITION | HOLYOKE

WASHINGTON, D. C.

ENGRAVED AND PRINTED BY THE U. S. GEOLOGICAL SURVEY

BAILEY WILLIS, EDITOR OF GEOLOGIC MAPS S. J. KÜBEL, CHIEF ENGRAVER

1898

EXPLANATION.

The Geological Survey is making a geologic map of the United States, which necessitates the preparation of a topographic base map. The two are being issued together in the form of an atlas, the parts of which are called folios. Each folio consists of a topographic base map and geologic maps of a small area of country, together with explanatory and descriptive texts.

THE TOPOGRAPHIC MAP.

The features represented on the topographic map are of three distinct kinds: (1) inequalities of surface, called *relief*, as plains, plateaus, valleys, hills, and mountains; (2) distribution of water, called *drainage*, as streams, lakes, and swamps; (3) the works of man, called *culture*, as roads, railroads, boundaries, villages, and cities.

Relief.—All elevations are measured from mean sea-level. The heights of many points are accurately determined, and those which are most important are given on the map in figures. It is desirable, however, to give the elevation of all parts of the area mapped, to delineate the horizontal outline, or contour, of all slopes, and to indicate their grade or degree of steepness. This is done by lines connecting points of equal elevation above mean sea-level, the lines being drawn at regular vertical intervals. These lines are called *contours*, and the uniform vertical space between each two contours is called the *contour interval*. Contours and elevations are printed in brown.

The manner in which contours express elevation, form, and grade is shown in the following sketch and corresponding contour map:

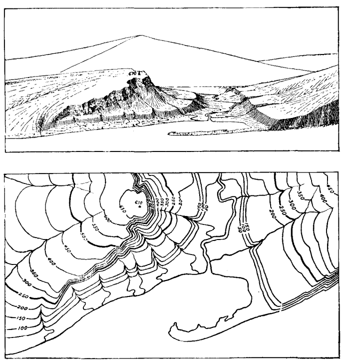


Fig. 1.—Ideal sketch and corresponding contour map.

The sketch represents a river valley between two hills. In the foreground is the sea, with a bay which is partly closed by a hooked sand-bar. On each side of the valley is a terrace. From the terrace on the right a hill rises gradually, while from that on the left the ground ascends steeply in a precipice. Contrasted with this precipice is the gentle descent of the left-hand slope. In the map each of these features is indicated, directly beneath its position in the sketch, by contours. The following explanation may make clearer the manner in which contours delineate elevation, form, and grade:

1. A contour indicates approximately a certain height above sea-level. In this illustration the contour interval is 50 feet; therefore the contours are drawn at 50, 100, 150, 200 feet, and so on, above sea-level. Along the contour at 250 feet lie all points of the surface 250 feet above sea; and similarly with any other contour. In the space between any two contours are found all elevations above the lower and below the higher contour. Thus the contour at 150 feet falls just below the edge of the terrace, while that at 200 feet lies above the terrace; therefore all points on the terrace are shown to be more than 150 but less than 200 feet above sea. The summit of the higher hill is stated to be 670 feet above sea; accordingly the contour at 650 feet surrounds it. In this illustration nearly all the contours are numbered. Where this is not possible, certain contours—say every fifth one—are accentuated and numbered; the heights of others may then be ascertained by counting up or down from a numbered contour.

2. Contours define the forms of slopes. Since contours are continuous horizontal lines conforming to the surface of the ground, they wind smoothly about smooth surfaces, recede into all reentrant angles of ravines, and project in passing about prominences. The relations of contour curves and angles to forms of the landscape can be traced in the map and sketch.

3. Contours show the approximate grade of any slope. The vertical space between two contours is the same, whether they lie along a cliff or on a gentle slope; but to rise a given height on a gentle slope one must go farther than on a steep slope, and therefore contours are far apart on gentle slopes and near together on steep ones.

For a flat or gently undulating country a small contour interval is used; for a steep or mountainous country a large interval is necessary. The smallest interval used on the atlas sheets of the Geological Survey is 5 feet. This is used for regions like the Mississippi delta and the Dismal Swamp. In mapping great mountain masses, like those in Colorado, the interval may be 250 feet. For intermediate relief contour intervals of 10, 20, 25, 50, and 100 feet are used.

Drainage.—Watercourses are indicated by blue lines. If the stream flows the year round the line is drawn unbroken, but if the channel is dry a part of the year the line is broken or dotted. Where a stream sinks and reappears at the surface, the supposed underground course is shown by a broken blue line. Lakes, marshes, and other bodies of water are also shown in blue, by appropriate conventional signs.

Culture.—The works of man, such as roads, railroads, and towns, together with boundaries of townships, counties, and States, and artificial details, are printed in black.

Scales.—The area of the United States (excluding Alaska) is about 3,025,000 square miles. On a map with the scale of 1 mile to the inch this would cover 3,025,000 square inches, and to accommodate it the paper dimensions would need to be about 240 by 180 feet. Each square mile of ground surface would be represented by a square inch of map surface, and one linear mile on the ground would be represented by a linear inch on the map. This relation between distance in nature and corresponding distance on the map is called the scale of the map. In this case it is "1 mile to an inch." The scale may be expressed also by a fraction, of which the numerator is a length on the map and the denominator the corresponding length in nature expressed in the same unit. Thus, as there are 63,360 inches in a mile, the scale "1 mile to an inch" is expressed by $\frac{1}{63,360}$. Both of these methods are used on the maps of the Geological Survey.

Three scales are used on the atlas sheets of the Geological Survey; the smallest is $\frac{1}{250,000}$, the intermediate $\frac{1}{125,000}$, and the largest $\frac{1}{62,500}$. These correspond approximately to 4 miles, 2 miles, and 1 mile on the ground to an inch on the map. On the scale $\frac{1}{62,500}$ a square inch of map surface represents and corresponds nearly to 1 square mile; on the scale $\frac{1}{125,000}$, to about 4 square miles; and on the scale $\frac{1}{250,000}$, to about 16 square miles. At the bottom of each atlas sheet the scale is expressed in three different ways, one being a graduated line representing miles and parts of miles in English inches, another indicating distance in the metric system, and a third giving the fractional scale.

Atlas sheets and quadrangles.—The map is being published in atlas sheets of convenient size, which are bounded by parallels and meridians. The corresponding four-cornered portions of territory are called *quadrangles*. Each sheet on the scale of $\frac{1}{250,000}$ contains one square degree, i. e., a degree of latitude by a degree of longitude; each sheet on the scale of $\frac{1}{125,000}$ contains one-quarter of a square degree; each sheet on the scale of $\frac{1}{62,500}$ contains one-sixteenth of a square degree. The areas of the corresponding quadrangles are about 4000, 1000, and 250 square miles, respectively.

The atlas sheets, being only parts of one map of the United States, are laid out without regard to the boundary lines of the States, counties, or townships. To each sheet, and to the quadrangle it represents, is given the name of some well-known town or natural feature within its limits, and at the sides and corners of each sheet the names of adjacent sheets, if published, are printed.

Uses of the topographic sheet.—Within the limits of scale the topographic sheet is an accurate and characteristic delineation of the relief, drainage, and culture of the district represented. Viewing the landscape, map in hand, every characteristic feature of sufficient magnitude should be recognizable. It should guide the traveler; serve the investor or owner who desires to ascertain the position and surroundings of property to be bought or sold; save the engineer preliminary surveys in locating roads, railways, and irrigation ditches; provide educational material for schools and homes; and serve many of the purposes of a map for local reference.

THE GEOLOGIC MAP.

The maps representing areal geology show by colors and conventional signs, on the topographic base map, the distribution of rock formations on the surface of the earth, and the structure-section map shows their underground relations, as far as known, and in such detail as the scale permits.

KINDS OF ROCKS.

Rocks are of many kinds. The original crust of the earth was probably composed of *igneous rocks*, and all other rocks have been derived from them in one way or another.

Atmospheric agencies gradually break up igneous rocks, forming superficial, or *surficial*, deposits of clay, sand, and gravel. Deposits of this class have been formed on land surfaces since the earliest geologic time. Through the transporting agencies of streams the surficial materials of all ages and origins are carried to the sea, where, along with material derived from the land by the action of the waves on the coast, they form *sedimentary rocks*. These are usually hardened into conglomerate, sandstone, shale, and limestone, but they may remain unconsolidated and still be called "rocks" by the geologist, though popularly known as gravel, sand, and clay.

From time to time in geologic history igneous and sedimentary rocks have been deeply buried, consolidated, and raised again above the surface of the water. In these processes, through the agencies of pressure, movement, and chemical action, they are often greatly altered, and in this condition they are called *metamorphic rocks*.

Igneous rocks.—These are rocks which have cooled and consolidated from a liquid state. As has been explained, sedimentary rocks were deposited on the original igneous rocks. Through the igneous and sedimentary rocks of all ages molten material has from time to time been forced upward to or near the surface, and there consolidated. When the channels or vents into which this molten material is forced do not reach the surface, it either consolidates in cracks or fissures crossing the bedding planes, thus forming dikes, or else spreads out between the strata in large bodies, called sills or laccoliths. Such rocks are called *intrusive*. Within their rock enclosures they cool slowly, and hence are generally of crystalline texture. When the channels reach the surface the lavas often flow out and build up volcanoes. These lavas cool rapidly in the air, acquiring a glassy or, more often, a partially crystalline condition. They are usually more or less porous. The igneous rocks thus formed upon the surface are called *extrusive*. Explosive action often accompanies volcanic eruptions, causing ejections of dust or ash and larger fragments. These materials when consolidated constitute breccias, agglomerates, and tuffs. The ash when carried into lakes or seas may become stratified, so as to have the structure of sedimentary rocks.

The age of an igneous rock is often difficult or impossible to determine. When it cuts across a sedimentary rock, it is younger than that rock, and when a sedimentary rock is deposited over it, the igneous rock is the older.

Under the influence of dynamic and chemical forces an igneous rock may be metamorphosed. The alteration may involve only a rearrangement of its minute particles or it may be accompanied by a change in chemical and mineralogic composition. Further, the structure of the rock may be changed by the development of planes of division, so that it splits in one direction more easily than in others. Thus a granite may pass into a gneiss, and from that into a mica-schist.

Sedimentary rocks.—These comprise all rocks which have been deposited under water, whether in sea, lake, or stream. They form a very large part of the dry land.

When the materials of which sedimentary rocks are composed are carried as solid particles by water and deposited as gravel, sand, or mud, the deposit is called a mechanical sediment. These may become hardened into conglomerate, sandstone, or shale. When the material is carried in solution by the water and is deposited without the aid of life, it is called a chemical sediment; if deposited with the aid of life, it is called an organic sediment. The more important rocks formed from chemical and organic deposits are limestone, chert, gypsum, salt, iron ore, peat, lignite, and coal. Any one of the above sedimentary deposits may be separately formed, or the different materials may be intermingled in many ways, producing a great variety of rocks.

Sedimentary rocks are usually made up of layers or beds which can be easily separated. These layers are called *strata*. Rocks deposited in successive layers are said to be stratified.

The surface of the earth is not fixed, as it seems to be; it very slowly rises or sinks over wide expanses, and as it rises or subsides the shore-lines of the ocean are changed: areas of deposition may rise above the water and become land areas, and land areas may sink below the water and become areas of deposition. If North America were gradually to sink a thousand feet the sea would flow over the Atlantic coast and the Mississippi and Ohio valleys from the Gulf of Mexico to the Great Lakes; the Appalachian Mountains would become an archipelago, and the ocean's shore would traverse Wisconsin, Iowa, and Kansas, and extend thence to Texas. More extensive changes than this have repeatedly occurred in the past.

The character of the original sediments may be changed by chemical and dynamic action so as to produce metamorphic rocks. In the metamorphism of a sedimentary rock, just as in the metamorphism of an igneous rock, the substances of which it is composed may enter into new combinations, or new substances may be added. When these processes are complete the sedimentary rock becomes crystalline. Such changes transform sandstone to quartzite, limestone to marble, and modify other rocks according to their composition. A system of parallel division planes is often produced, which may cross the original beds or strata at any angle. Rocks divided by such planes are called slates or schists.

Rocks of any period of the earth's history may be more or less altered, but the younger formations have generally escaped marked metamorphism, and the oldest sediments known, though generally the most altered, in some localities remain essentially unchanged.

Surficial rocks.—These embrace the soils, clays, sands, gravels, and bowlders that cover the surface, whether derived from the breaking up or disintegration of the underlying rocks by atmospheric agencies or from glacial action. Surficial rocks that are due to disintegration are produced chiefly by the action of air, water, frost, animals, and plants. They consist mainly of the least soluble parts of the rocks, which remain after the more soluble parts have been leached out, and hence are known as residual products. Soils and subsoils are the most important. Residual accumulations are often washed or blown into valleys or other depressions, where they lodge and form deposits that grade into the sedimentary class. Surficial rocks that are due to glacial action are formed of the products of disintegration, together with bowlders and fragments of rock rubbed from the surface and ground together. These are spread irregularly over the territory occupied by the ice, and form a mixture of clay, pebbles, and bowlders which is known as till. It may occur as a sheet or be bunched into hills and ridges, forming moraines, drumlins, and other special forms. Much of this mixed material was washed away from the ice, assorted by water, and redeposited as beds or trains of sand and clay, thus forming another gradation into sedimentary deposits. Some of this glacial wash was deposited in tunnels and channels in the ice, and forms characteristic ridges and mounds of sand and gravel, known as osars, or eskers, and kames. The material deposited by the ice is called glacial drift; that washed from the ice onto the adjacent land is called modified drift. It is usual also to class as surficial rocks the deposits of the sea and of lakes and rivers that were made at the same time as the ice deposit.

AGES OF ROCKS.

Rocks are further distinguished according to their relative ages, for they were not formed all at one time, but from age to age in the earth's history. Classification by age is independent of origin; igneous, sedimentary, and surficial rocks may be of the same age.

When the predominant material of a rock mass is essentially the same, and it is bounded by rocks of different materials, it is convenient to call the mass throughout its extent a *formation*, and such a formation is the unit of geologic mapping.

Several formations considered together are designated a *system*. The time taken for the deposition of a formation is called an *epoch*, and the time taken for that of a system, or some larger fraction of a system, a *period*. The rocks are mapped by formations, and the formations are classified into systems. The rocks composing a system and the time taken for its deposition are given the same name, as, for instance, Cambrian system, Cambrian period.

As sedimentary deposits or strata accumulate the younger rest on those that are older, and the relative ages of the deposits may be discovered by observing their relative positions. This relationship holds except in regions of intense disturbance; sometimes in such regions the disturbance of the beds has been so great that their position is reversed, and it is often difficult to determine the relative ages of the beds from their positions; then *fossils*, or the remains of plants and animals, are guides to show which of two or more formations is the oldest.

Strata often contain the remains of plants and animals which lived in the sea or were washed from the land into lakes or seas or were buried in surficial deposits on the land. Rocks that contain the remains of life are called fossiliferous. By studying these remains, or fossils, it has been found that the species of each period of the earth's history have to a great extent differed from those of other periods. Only the simpler kinds of marine life existed when the oldest fossiliferous rocks were deposited. From time to time more complex kinds developed, and as the simpler ones lived on in modified forms life became more varied. But during each period there lived peculiar forms, which did not exist in earlier times and have not existed since; these are characteristic types, and they define the age of any bed of rock in which they are found. Other types passed on from period to period, and thus linked the systems together, forming a chain of life from the time of the oldest fossiliferous rocks to the present.

When two formations are remote one from the other and it is impossible to observe their relative positions, the characteristic fossil types found in them may determine which was deposited first.

Fossil remains found in the rocks of different areas, provinces, and continents, afford the most important means for combining local histories into a general earth history.

Colors and patterns.—To show the relative ages of strata, the history of the sedimentary rocks is divided into periods. The names of the periods in proper order (from new to old), with the color or colors and symbol assigned to each, are given in the table in the next column. The names of certain subdivisions of the periods, frequently used in geologic writings, are bracketed against the appropriate period name.

To distinguish the sedimentary formations of any one period from those of another the patterns for the formations of each period are printed in the appropriate period-color, with the exception of the first (Pleistocene) and the last (Archean). the Pleistocene and the Archean, are distinguished from one another by different patterns, made of parallel straight lines. Two tints of the period-color are used: a pale tint (the underprint) is printed evenly over the whole surface representing the period; a dark tint (the overprint) brings out the different patterns representing formations.

PERIOD.	SYMBOL.	COLOR.
Pleistocene	P	Any colors.
Neocene { Pliocene / Miocene }	N	Buffs.
Eocene (including Oligocene)	E	Olive-browns.
Cretaceous	K	Olive-greens.
Juratrias { Jurassic / Triassic }	J	Blue-greens.
Carboniferous (including Permian) . .	C	Blues.
Devonian	D	Blue-purples.
Silurian (including Ordovician)	S	Red-purples.
Cambrian	€	Pinks.
Algonkian	A	Orange-browns.
Archean	Æ	Any colors.

Each formation is furthermore given a letter-symbol of the period. In the case of a sedimentary formation of uncertain age the pattern is printed on white ground in the color of the period to which the formation is supposed to belong, the letter-symbol of the period being omitted.

The number and extent of surficial formations of the Pleistocene render them so important that, to distinguish them from those of other periods and from the igneous rocks, patterns of dots and circles, printed in any colors, are used.

The origin of the Archean rocks is not fully settled. Many of them are certainly igneous. Whether sedimentary rocks are also included is not determined. The Archean rocks, and all metamorphic rocks of unknown origin, of whatever age, are represented on the maps by patterns consisting of short dashes irregularly placed. These are printed in any color, and may be darker or lighter than the background. If the rock is a schist the dashes or hachures may be arranged in wavy parallel lines. If the rock is known to be of sedimentary origin the hachure patterns may be combined with the parallel-line patterns of sedimentary formations. If the metamorphic rock is recognized as having been originally igneous, the hachures may be combined with the igneous pattern.

Known igneous formations are represented by patterns of triangles or rhombs printed in any brilliant color. If the formation is of known age the letter-symbol of the formation is preceded by the capital letter-symbol of the proper period. If the age of the formation is unknown the letter-symbol consists of small letters which suggest the name of the rocks.

THE VARIOUS GEOLOGIC SHEETS.

Historical geology sheet.—This sheet shows the areas occupied by the various formations. On the margin is a *legend*, which is the key to the map. To ascertain the meaning of any particular colored pattern and its letter-symbol on the map the reader should look for that color, pattern, and symbol in the legend, where he will find the name and description of the formation. If it is desired to find any given formation, its name should be sought in the legend and its color and pattern noted, when the areas on the map corresponding in color and pattern may be traced out.

The legend is also a partial statement of the geologic history. In it the symbols and names are arranged, in columnar form, according to the origin of the formations—surficial, sedimentary, and igneous—and within each group they are placed in the order of age, so far as known, the youngest at the top.

Economic geology sheet.—This sheet represents the distribution of useful minerals, the occurrence of artesian water, or other facts of economic interest, showing their relations to the features of topography and to the geologic formations. All the formations which appear on the historical geology sheet are shown on this sheet by fainter color-patterns. The areal geology, thus printed, affords a subdued background upon which the areas of productive formations may be emphasized by strong colors. A symbol for mines is introduced at each occurrence, accompanied by the name of the principal mineral mined or of the stone quarried.

Structure-section sheet.—This sheet exhibits the

In cliffs, canyons, shafts, and other natural and artificial cuttings, the relations of different beds to one another may be seen. Any cutting which exhibits those relations is called a *section*, and the same name is applied to a diagram representing the relations. The arrangement of rocks in the earth is the earth's *structure*, and a section exhibiting this arrangement is called a *structure section*.

The geologist is not limited, however, to the natural and artificial cuttings for his information concerning the earth's structure. Knowing the manner of the formation of rocks, and having traced out the relations among beds on the surface, he can infer their relative positions after they pass beneath the surface, draw sections which represent the structure of the earth to a considerable depth, and construct a diagram exhibiting what would be seen in the side of a cutting many miles long and several thousand feet deep. This is illustrated in the following figure:

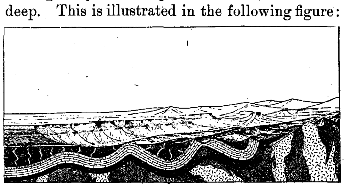


Fig. 2.—Sketch showing a vertical section in the front of the picture, with a landscape beyond.

The figure represents a landscape which is cut off sharply in the foreground by a vertical plane that cuts a section so as to show the underground relations of the rocks.

The kinds of rock are indicated in the section by appropriate symbols of lines, dots, and dashes. These symbols admit of much variation, but the following are generally used in sections to represent the commoner kinds of rock:

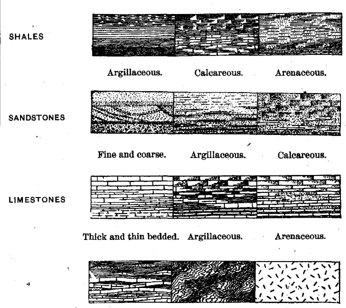


Fig. 3.—Symbols used to represent different kinds of rock.

The plateau in fig. 2 presents toward the lower land an escarpment, or front, which is made up of sandstones, forming the cliffs, and shales, constituting the slopes, as shown at the extreme left of the section.

The broad belt of lower land is traversed by several ridges, which are seen in the section to correspond to beds of sandstone that rise to the surface. The upturned edges of these beds form the ridges, and the intermediate valleys follow the outcrops of limestone and calcareous shales.

Where the edges of the strata appear at the surface their thickness can be measured and the angles at which they dip below the surface can be observed. Thus their positions underground can be inferred.

When strata which are thus inclined are traced underground in mining, or by inference, it is frequently observed that they form troughs or arches, such as the section shows. But these sandstones, shales, and limestones were deposited beneath the sea in nearly flat sheets. That they are now bent and folded is regarded as proof that forces exist which have from time to time caused the earth's surface to wrinkle along certain zones.

On the right of the sketch the section is composed of schists which are traversed by masses of igneous rock. The schists are much contorted and their arrangement underground can not be inferred. Hence that portion of the section delineates what is probably true but is not

In fig. 2 there are three sets of formations, distinguished by their underground relations. The first of these, seen at the left of the section, is the set of sandstones and shales, which lie in a horizontal position. These sedimentary strata are now high above the sea, forming a plateau, and their change of elevation shows that a portion of the earth's mass has swelled upward from a lower to a higher level. The strata of this set are parallel, a relation which is called *conformable*.

The second set of formations consists of strata which form arches and troughs. These strata were once continuous, but the crests of the arches have been removed by degradation. The beds, like those of the first set, are conformable.

The horizontal strata of the plateau rest upon the upturned, eroded edges of the beds of the second set at the left of the section. The overlying deposits are, from their positions, evidently younger than the underlying formations, and the bending and degradation of the older strata must have occurred between the deposition of the older beds and the accumulation of the younger. When younger strata thus rest upon an eroded surface of older strata the relation between the two is an *unconformable* one, and their surface of contact is an *unconformity*.

The third set of formations consists of crystalline schists and igneous rocks. At some period of their history the schists were plicated by pressure and traversed by eruptions of molten rock. But this pressure and intrusion of igneous rocks have not affected the overlying strata of the second set. Thus it is evident that an interval of considerable duration elapsed between the formation of the schists and the beginning of deposition of the strata of the second set. During this interval the schists suffered metamorphism; they were the scene of eruptive activity; and they were deeply eroded. The contact between the second and third sets, marking a time interval between two periods of rock formation, is another unconformity.

The section and landscape in fig. 2 are ideal, but they illustrate relations which actually occur. The sections in the structure-section sheet are related to the maps as the section in the figure is related to the landscape. The profiles of the surface in the section correspond to the actual slopes of the ground along the section line, and the depth of any mineral-producing or water-bearing stratum which appears in the section may be measured from the surface by using the scale of the map.

Columnar-section sheet.—This sheet contains a concise description of the rock formations which occur in the quadrangle. The diagrams and verbal statements form a summary of the facts relating to the character of the rocks, to the thicknesses of the formations, and to the order of accumulation of successive deposits.

The rocks are described under the corresponding heading, and their characters are indicated in the columnar diagrams by appropriate symbols. The thicknesses of formations are given under the heading "Thickness in feet," in figures which state the least and greatest measurements. The average thickness of each formation is shown in the column, which is drawn to a scale—usually 1000 feet to 1 inch. The order of accumulation of the sediments is shown in the columnar arrangement: the oldest formation is placed at the bottom of the column, the youngest at the top, and igneous rocks or other formations, when present, are indicated in their proper relations.

The formations are combined into systems which correspond with the periods of geologic history. Thus the ages of the rocks are shown, and also the total thickness of each system.

The intervals of time which correspond to events of uplift and degradation and constitute interruptions of deposition of sediments may be indicated graphically or by the word "unconformity," printed in the columnar section.

Each formation shown in the columnar section is accompanied by its name, a description of its character, and its letter-symbol as used in the maps and their legends.

CHARLES D. WALCOTT,
Director.

Revised June, 1897.

OUTLINES OF THE GEOLOGY OF WESTERN MASSACHUSETTS.

TOPOGRAPHY.

Quadrangles referred to.

In order to follow this general description, which is applicable to territory extending beyond the limits of the Holyoke quadrangle, the reader is referred to the following topographic sheets of western Massachusetts: Greylock, Hawley, Greenfield, Becket, Chesterfield, Northampton, Sandisfield, Granville, and Springfield, all on a scale of 1 mile to 1 inch.

Green Mountain range; location and description.

The Green Mountain range passes across the State of Massachusetts, between the valleys of the Connecticut River on the east and the Housatonic and Hoosic rivers on the west. It does not here include mountains of great height, as in Vermont, but is a broad plateau. On the west it is bounded by a high, steep, and continuous scarp; on the east it descends by a more gradual and undulating slope. The western crest has an elevation of about 2000 feet. The surface is deeply cut by narrow valleys, with a few rounded hills rising to inconsiderable heights above the average level.

Berkshire Hills, the western portion of Green Mountain plateau.

The western and more elevated portion of this plateau lies along the eastern edge of Berkshire County and forms part of the Berkshire Hills, but the greater part of the upland occupies the western half of Franklin, Hampshire, and Hampden counties. Its western edge is a continuous divide from which nearly all its drainage is into the Connecticut. Only at one place, in Hinsdale, does this line of watershed make a large bend to the east so as to throw a considerable area of upland drainage to the west into the Housatonic.

Principal stream systems of the plateau.

The plateau is traversed in deep and narrow valleys by the main streams and branches of two principal rivers, the Deerfield and the Westfield. The Deerfield River, entering from Vermont with a southwesterly course, turns abruptly eastward. At the bend is now the eastern entrance to the Hoosac Tunnel. The Agawam or Westfield River gathers its waters by three convergent streams: the Westfield River, flowing south from near the valley of the Deerfield; the Middle Fork of the Westfield, flowing south by east; and the West Fork of the Westfield, flowing southeast. The last-named stream rises in a gap in the crest of the plateau edge between Becket and Hinsdale. This gap is in fact a deep canyon, ample for the occupancy of a considerable river, in the swampy bottom of which the headwaters of the Westfield gather to flow east and those of the Housatonic to flow west. It is clear that this canyon was not made by the streams that now start there, but by a large river heading far to the west and flowing eastwardly.

Uniformity of slope; hills and valleys of the plateau.

The features of this plateau—its general uniformity of slope when considered as a whole, the hills rising above its surface, the valleys incised in its plain—these features and their relations record episodes in the development of the present landscape.

Restoration of former plateau surface—a plain.

For example, the canyon at the headwaters of the Westfield River stands like a broken aqueduct opening above the Housatonic Valley. The river which carved the canyon had its source in the west beyond the latter valley and flowed over a surface high above that valley's level. To restore this condition the Housatonic Valley must be supposed filled to the plane of the eastward-sloping plateau. The narrow valleys of the Deerfield, the Westfield, and their tributaries may be conceived to have been filled in like manner. Thus there is restored an extensive plain, the original form from which the dissected plateau of the present time has been worked out. The greater breadth and depth of the Housatonic Valley, which is carved in limestone, as compared with the narrow Deerfield and Westfield valleys, which are cut in gneiss, are due to the fact that limestone offers much less resistance to erosion than does gneiss. It is the habit of streams to adjust their courses to lines of least resistance, along which the deeper channels are excavated. The relations of the Housatonic and Westfield rivers afford a striking illustration of this habit.

Dissection of elevated plain.

The plain in which these valleys are carved is being destroyed because it is elevated. The streams, having fall, are able to carry away loosened rock material, and they also use it as a tool with which to cut their channels deeper. It is obvious that these existing conditions under which the plain is being destroyed are not those under which it was formed.

Evolution of the former plateau.

To gain an idea of the manner of development of the once level surface of the plateau, we may conceive the present process of gradual wearing down carried to completion. When the streams shall have carved away the elevations now existing, the plateau and hills will be reduced to a surface of very gentle slope, rising gradually from sea level. Such a plain is called a *peneplain*, or, when worn to a uniform surface at the lowest altitude above sea, a *base-level*. In the course of development of such a peneplain the sea may encroach upon its area. To the limits of the encroachment the waves cut away all low hills and fill hollows, producing a plain which is even more uniform than any stage of the peneplain of erosion, except perhaps the extreme case of a base-level. Such a wave-smoothed surface is called a plain of *marine gradation.*

The former plain of the Green Mountain plateau may still be recognized by one who stands upon its surface and scans the horizontal sky line which represents it on a level with his position. It extended evenly westward from the Berkshire Hills over the now deep Housatonic-Hoosic Valley, to touch the crest lines of the Taconic Mountains, which lie along the western boundary of Massachusetts. Down this surface flowed the rivers which cut the upper canyon of the Westfield Valley in Washington and the Farmington Valley in Otis. Those who have most carefully studied the aspects of the plateau are agreed that it was once a peneplain, worn down by frost, rains, and streams. They differ as to what part marine gradation may have played in modifying its surface. In any case it formerly extended from the sea by a gentle slope to moderate altitudes. It has been raised to its present elevation by earth movements, and these were no doubt as gradual as they were extensive and mighty.

Landscapes of earlier geological periods.

To follow the history of the landscape of western Massachusetts still further back into the past, we must appeal to the rocks as guides. Their record is transcribed under the next head, "General geology," but something of it may appropriately be sketched here.

The carving of the old peneplain of the Green Mountain plateau occurred during and before the so-called Cretaceous period of geological history. This period was, relatively speaking, only a short portion of the later history of the earth. In the process of leveling, elevations of some amount were removed. We are interested to know what was their magnitude. From this Cretaceous land and from that of the preceding period, the Juratrias, sediments were carried down to the seas and deposited in extensive beds, of which some part still remains as sandstones and shales. The volume of these deposits indicates that the hills which were destroyed in the process were of great bulk; perhaps they were mountains. But there is another line of evidence. The rocks of the Green Mountain plateau contain minerals and are characterized by fissile structures that develop only under great pressure, such as exists deep in the earth. Hence it is known that these rocks which are now at the surface were buried several thousand feet at least. The upward movement of the earth's crust which raised them, as the old peneplain was being carved, was the growth of a mountain range. That range was destroyed in making the peneplain, and the present range of the Green Mountains has grown on its site by renewed elevation and subsequent erosion. Thus two generations of mountains are recognized, and it may be that they were preceded by earlier ranges. Moreover, the history of the rocks themselves goes still further back, to periods when the sea prevailed over the region.

GENERAL GEOLOGY.

The rock masses which make up the structure of the Green Mountain plateau are of many varieties. They have been brought into their present relations by repeated action of physical and chemical forces, and the resulting architecture is very intricate. In the following paragraphs the general relations of the rock masses and the outlines of geological history will be stated. The details of fact which constitute the record are described in the essay relating to each quadrangle.

Origin of the rocks.

The great Cambrian transgression.

The greater portion of the rocks of the Green Mountains in Massachusetts were once horizontal beds of gravels, sands, clays, and marls, which became consolidated into conglomerates, sandstones, shales, and limestones. They began to accumulate at a time remote in the geological past, when the region was invaded by the sea. There had been land of an extent not now known. It subsided and the sea spread over it. During the occupation of the district by the waters, which was prolonged, there were changes in the height of the land and the position of the shore line about the submerged area, and the sediments deposited in the sea varied accordingly. In these deposits were doubtless buried, as fossils, some of the early forms of life of the Cambrian and Silurian types. Eruptions of igneous rocks also occurred and caused the intercalation of various lavas with the sediments.

Chemical and physical changes of Cambrian and Silurian rocks.

In adjustments of the earth's form during subsequent ages, down to and including the Carboniferous period, the Cambrian and Silurian rocks were subjected to chemical reactions and to pressures sufficiently powerful to disguise or obliterate the original structure of the rocks.

Changes of attitude in sheets of sediment.

The sheets of sediment changed form in a manner which can best be compared to the crumpling of sheets of paper. The pressures to which the beds were subjected were greatest from east to west. They therefore forced the beds into folds running north and south. The folds developed as alternate arches and troughs; as the compression continued they were pinched together, so that many of the beds which had previously extended in a horizontal attitude came to stand vertical or nearly so. From such positions they were pressed over westward, overturned, and many of the folds laid in an eastward-sloping attitude. The folds were of various sizes, ranging from microscopic plications to arches several miles across. In the deeper portions of the whole mass the rocks were so confined, yet forced to move by such pressures, that they were squeezed and thrust one fold upon another. Where this occurred on a minute scale, as it did throughout the Green Mountains, the rocks are divided into thin laminæ, which sometimes differ from the original layers in the sand and clay, and are therefore called schists.

Growth of new minerals.

In the course of this process fresh minerals crystallized everywhere. In the more clayey sediments the growth of minerals gave character to the schist, which is now called by the name of the distinctive mineral, as mica-schist. The more purely quartzose deposits were cemented by quartz, forming the dense rock called quartzite. Limestones crystallized to marbles, or, when they were clayey, into schists containing pyroxene, hornblende, and other silicates. The volcanic rocks have been altered into hornblende-schist and chlorite-schist, serpentine, and soapstone; and they may have furnished the iron for small beds of hematite and magnetite. All this is expressed in saying that the rocks are metamorphic rocks or crystalline schists.

Evidences of folding.

In the processes of mountain growth and removal, portions of the folded rocks which were deeply buried have come to form the surface. The upper parts of the greater folds have been worn off. Thus the cut edges of the upturned beds are now exposed, and any one bed appears at the surface repeatedly. An illustration of folded and partially eroded beds in simple relations is given in fig. 2 of the Explanation on the inside pages of the cover. The more complex relations of the schists of the Green Mountain region are illustrated in the Structure-Section sheet of the accompanying folio. The greater folds have been traced by observing the dips of the beds and by identifying the recurrence of such beds as the amphibolite in the Hawley schist. The minor folds are too numerous to be made out, and the original thickness of the strata can not be determined with accuracy.

In the accompanying columnar section, fig. 1, is given the full column of the geological formations in the area here described. On comparing with this list the legend on the border of each sheet, the distribution and relative importance of each formation will appear clearly. In this table the formations stand in their proper relative positions, the oldest at the bottom.

ALGONKIAN PERIOD.

The most ancient rocks of this region, pre-Cambrian, probably not Archean.

In the usage adopted in this atlas the term "Archean" is applied to those most ancient crystalline rocks which form part of the original crust of the earth and which antedate and underlie the oldest sedimentary rocks. Used in this sense there may not be any Archean rocks in the region. The name "Algonkian" is applied to all sedimentary rocks up to the base of the Cambrian, which rocks are at present without known distinctive fauna and are usually highly crystalline. The Algonkian period, as here used, is therefore equivalent to the later portion of the Azoic of Lyell, the Eozoic of Dawson, and the Archæan of Dana.

Oldest sedimentary rocks—gneisses and limestones.

Washington gneiss.—The oldest rocks of this region appear at the surface in oval areas surrounded by younger strata. They have been laid bare by erosion of the beds which once deeply covered them. The line of these ovals extends south from the Hoosac Tunnel along the crest of the plateau. The rocks belong to the oldest sedimentary system, the Algonkian, and are highly crystalline. They consist of firm, coarse gneisses which contain minerals and possess structures not formed in the later rocks, and thick beds of coarse and highly crystalline limestones with many minerals, some of which are rarely found in later limestones, as chondrodite, wernerite, dark pyroxene and hornblende, and coarsely crystallized graphite. Considerable beds of pyrrhotite, magnetite, and graphite also occur.

Because of the presence of these heavy limestones, which were probably of marine organic origin, we may assume that the whole series, except possibly the hornblende-gneiss of East Lee, was sedimentary, but we know nothing of the limits of the sea in which the strata were spread.

CAMBRIAN PERIOD.

Transgression of Cambrian sea and resultant deposits of sediment.

Becket gneiss and Cheshire quartzite.—The rocks of the Algonkian period had grown old; they had assumed a highly crystalline texture, had been strongly folded and deeply eroded, and through many ages had stood as dry land, while the atmospheric waters had softened and disintegrated them to a very great depth. Then the land sank and the waters of the Cambrian sea advanced rapidly over it, coming apparently from the southwest. All the Algonkian rocks of this region were submerged, and beyond a shore line much farther east the dry land of the period extended where are now the waters of the north Atlantic. Such a broad advance of the waters upon the land is called technically a *transgression.* These waters in their progress over the sinking land washed the softened rocks into clean quartz beach sands, clayey and feldspathic sands, and pebble beds, and these became consolidated into sandstones, feldspathic sandstones, and conglomerates. They are now metamorphosed, the first into quartzite, and the other two into a gneiss in which, in many places, the traces of pebbles can still be seen. These rocks, part gneiss, part conglomerate, can often be seen to rest on the upturned edges of the older Algonkian gneiss. The coarse deposits formed near the eastern shore grade westward with considerable rapidity into the Stockbridge limestone, which indicates that the shallow water became deeper and clearer a short distance to the west, where the calcareous deposits gathered. Just beyond the limits of the region under consideration the rock has furnished fossils belonging to the first assemblage of organic forms yet discovered.

SILURIAN PERIOD.

Hoosac schist.—Beneath a sea which was probably still expanding beyond the shores which bounded it in Cambrian time, fine-grained sediment accumulated during the early part of the Silurian period. As compared with the older Becket gneiss, the finer grain of the sediment and the absence of iron and potash indicate more perfect sorting of the materials derived from adjacent lands. Such sorting is accomplished by waves and by currents which carry the finer material farther from shore. The resulting sandstone has now become a hydrated mica-schist, which often contains newly formed feldspathic minerals, particularly albite. It has received the name Hoosac schist, as most appropriate for its whole extent in Massachusetts, but it corresponds to the Green Mountain gneiss of C. B. Adams, in the Vermont Survey. This schist is probably of about the same age as the upper portion of the Stockbridge limestone to the west, and is partly upper Cambrian and partly lower Silurian, though the rock is so uniform throughout from top to bottom that no dividing line can be drawn.

Hydrated mica-schist, derived from clayey sediments.

Rowe schist.—By a gradual transition from one kind of rock to another, the uppermost bed of the Hoosac schist changes in a few feet into the overlying Rowe schist. This is the rock that occurs in the region around the east portal of the Hoosac Tunnel and extends south across the State in a broad band which crosses the Boston and Albany Railroad between Middlefield station and the Chester town line.

The Rowe schist is a monotonous rock made up of quartz and a white mica called muscovite. It is usually nearly all quartz, though the mica seems the more important mineral because it is spread in thin scales on the surfaces of the layers. The mica easily becomes hydrated, changing to the variety called sericite or hydromica, which feels greasy, like talc. The rock is then a sericite- or hydro-mica-schist, and, like the Hoosac and Savoy schists in a similar condition, has been called talcoid or talc-schist. In some occurrences the Rowe schist contains garnets and chlorite, and then can not be distinguished from the Savoy schist above. The fact that the rock is largely free from feldspathic and iron-bearing minerals, which develop from the clayey portion of a sediment, and is composed chiefly of quartz, indicates that its materials had originally been more thoroughly waterworn and sorted even than those of the preceding deposits. It may be that during the Rowe epoch the broader expanse of the sea gave the waves more efficient action on the sands of that ancient shore, or that the materials had more than once passed through the line of breakers during fluctuations of the shore line before they came to rest in the Rowe deposits.

Gradual transition to quartzose, talc- or sericite-schist derived from well-sorted sediments.

The Hoosac and Rowe schists represent a great thickness of sediments which accumulated not very far from shore, and therefore in waters that were comparatively shallow. We must then suppose that the bottom of the sea in which these deposits were gathering was steadily sinking a little faster than the sediments accumulated, and, from the gradual transition, that this sedimentation went on without interruption at the time of passage from the older to the newer formation.

Chester amphibolite.—In the sequence of strata the Rowe schist is followed by a formation which is peculiar in its character and mineral associations. It is a thin-bedded, greenish-black, heavy rock, consisting of matted needles of hornblende in a ground of quartz and plagioclase-feldspar grains. Such a rock is called an amphibolite or hornblende-schist. It is a formation generally of no great thickness, and, being tilted on edge in the present position of the rocks, it appears as a narrow band. It is named from the unique emery bed at Chester, which occurs in it.

Characteristics of amphibolite.

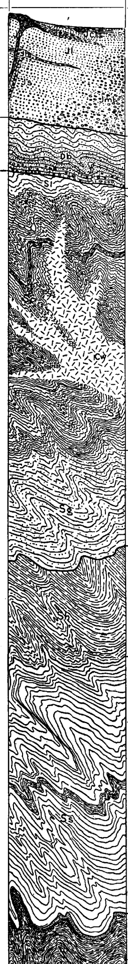
The mineral character of this formation is variable. As it is followed southward the amphibolite changes several times locally into a serpentine, abounding in dolomite. In the great bed in Middlefield the serpentine retains the amphibolite structure, and there is an abrupt change from serpentine to amphibolite. In Chester the eastern border of the amphibolite is skirted by a bed of emery. From Blandford southward the amphibolite gradually gives place to enstatitic dolomite, serpentine, and steatite.

Alteration products and associated minerals of the amphibolite.

These mineral associations may have had their origin partly in lavas and volcanic fragmental deposits or in beds of ferruginous magnesian limestone. It would appear that they were derived chiefly from impure limestone, with a possible admixture of basic eruptives, but the relative importance of these factors is undetermined. As a limestone occupying a place between the sandy Rowe and Savoy deposits, the formation testifies to the presence of deeper waters over the area and the existence of conditions favorable to calcareous deposition.

Savoy schist.—The Savoy rock is a sericite-schist like the Rowe schist. It is usually of finer grain and more micaceous, and it more generally carries large garnets, which are surrounded by films of green chlorite. Blotches of chlorite formed from garnets are also common in the rock. Beds of hornblende-schist appear more abundantly than in the Rowe schist. The Savoy schist stretches in a broad band eastward from the Chester hornblende zone, and is crushed into many folds, which in this wooded country covered with glacial clays can rarely be unraveled. The thickness of the formation can therefore not be determined definitely, but the deposit was of great volume and, like the material of the Rowe schist, consisted of well-sorted sediment.

Quartz-mica-schist like the Rowe schist, but more ferruginous.



Period.	Description of the Formations and their Estimated Thickness.
Juratrias.	The deposits of the Juratrias comprise four sediments, which formed during the same epoch, namely: the Mount Toby conglomerate (Jmt), a very coarse basal conglomerate of slate and crystalline rocks, along the eastern shore; the Sugarloaf arkose (Js), a coarse, feldspathic sandstone and conglomerate (4660 feet), on the western shore; and the Longmeadow sandstone (Jl), a medium-grained, feldspathic, ferruginous sandstone (1000 feet), and Chicopee shale (Jc), a sandy, carbonaceous shale (200? feet), which accumulated in the central channel of the bay. These were cut through by volcanic eruptions of three distinct periods, the earlier two represented by the interstratified lava beds (350 feet) of Holyoke diabase (Jh) and the Granby tuff (Jg), an agglomerate of diabase (580 feet) interstratified with the sandstone, and the latest by the volcanic cores and dikes of Blackrock diabase (Jb).
	UNCONFORMITY
Dev.	The Bernardston series (Db) consists of a dark mica-schist, which is spangled with biotite and contains several beds of amphibolite (1300 feet). This rests on quartzite (650 feet) containing a bed of highly crystalline limestone (20? feet) full of Devonian fossils.
	UNCONFORMITY
Silurian.	The Leyden argillite (Sl) is a black, fine-grained, fissile slate. (300 feet.)
	The Conway schist (Sc) is a fine-grained muscovite-schist, darkened by coaly matter, containing garnet, biotite, and staurolite, and is much contorted. It is represented on the east of the valley by the Amherst schist (Sa), a rusty mica-gneiss, at times fibrolitic and greatly impregnated with granite, and farther east by the Brimfield fibrolite-schist. (5000? feet.) The granite occurring in this area (Cw) was probably erupted during the Carboniferous period, and cuts through all the Silurian and older formations.
	The Goshen schist (Sg) is a dark, flaggy schist containing garnet and staurolite, and is spangled with biotite. It has beds of gneiss interstratified. (2000? feet).
	UNCONFORMITY
	The Hawley schist (Sh) is a green sericite-chlorite-schist with beds of amphibolite and manganese silicates. (2000? feet.)
	The Savoy schist (Ss) is a chloritic, quartzose sericite-schist with beds of amphibolite, changing toward the south to a feldspathic mica-schist with many intrusions of granite. (5000? feet.)
	The Chester amphibolite (Sch) is an epidotic hornblende-schist with beds of magnetite and emery near the top. It contains beds of pyroxene rock, enstatite rock, and dolomite, and is frequently replaced by serpentine and steatite. (3000? feet.)
	The Rowe schist (Sr) is a quartzose sericite-schist. Toward the south it is indistinguishable from the Hoosac schist and is included with it. (4000? feet.)
	The Hoosac schist (Shc) is a feldspathic mica-schist with numerous granite masses, which extend also into the Rowe schist. (1500 feet.)
	UNCONFORMITY
Cambrian.	The Becket gneiss (€b) is a white biotite-gneiss, at times grading into conglomerate. (2000? feet.)
	UNCONFORMITY
Algonkian.	The Washington gneiss (Aw) is a rusty biotite-gneiss carrying blue quartz. (2000? feet.)

FIG. 1.—GENERALIZED SECTION OF THE ROCKS OF WESTERN MASSACHUSETTS, SHOWING THEIR SEQUENCE AND PRESENT COMPRESSED STRUCTURE.

Hawley schist.—A formation consisting of highly ferruginous minerals is distinguishable above the Savoy schist. The prevailing rock is a soft, chloritic schist abounding in carbonates of iron and magnesia, and in black hornblende needles, which are often gathered in sheaves on the faces of slabs. These sheaves are called *fasciculite*. Many bands of hornblende-schist, some of great thickness, can be traced for long distances. The abundance of iron contained in this formation suggests the possibility that it represents a period of volcanic activity, but no trace of a distinctly volcanic rock can be found in it. A concentration of iron in sediments may have been due to conditions favorable for the separation of iron carbonate as a constituent of calcareous deposits. It may be, also, that a part of the ferruginous Chester formation had become subject to erosion and thus furnished the material for these well-bedded iron-bearing strata of the Hawley schist.

Chlorite-schist and associated ferruginous minerals.

An interesting similarity may be traced between the sequence of formations of Cambrian and Silurian age thus far described and the succession of formations of the Juratrias period in the Connecticut Valley. The later history can be more accurately read and serves to suggest the events of the earlier. In the Juratrias period a rapidly encroaching sea spread the coarse débris of granite, forming a feldspathic conglomerate, which if metamorphosed would resemble the Becket gneiss. Finer feldspathic sandstones followed in the Juratrias sequence, and these would readily be altered to rocks like the Hoosac and Rowe schists. The trap sheets and broad-spread tuff beds of the Connecticut Valley may have had their earlier representatives in the Chester amphibolite. The ferruginous formation in each of the two periods is followed by light-colored rocks—light-buff sandstones in the Juratrias and the Savoy schist in the Silurian; but later the iron of the traps affected the color of the upper sandstones of the Juratrias, coloring them dark red; and similarly the Hawley schists may be rich in iron because the ferruginous rocks of the Chester contributed to their deposit. Suggestive as this correspondence of characteristics in the two periods is, it is not to be supposed that history repeated itself very closely. Diverse processes under different conditions may produce similar results, and the facts described are not so peculiar as to admit of one interpretation only.

Comparison of sequence of Juratrias and Silurian strata.

Goshen schist.—The schists described above, from the Hoosac upward, have been called the talcose schists by the earlier geologists. The Goshen and succeeding formations were called by them the calciferous mica-schist. They are much less metamorphosed than the older strata. This is indicated by the presence of abundant carbonaceous material, by the smaller size of the newly formed minerals, and by the retention in good degree of the original structure of the clayey sandstones from which they were formed.

Calciferous mica-schists, less metamorphosed than the talc-schists.

The Goshen schist is altered from its original condition by the abundant growth of a white mica among the sand grains of which it was at first mainly composed, and the whole is darkened by a fine, coaly dust. In this are thickly spread small garnets, staurolites, and spangles of black mica set across the bedding. It breaks in flags a few inches thick, which are much used for sidewalks. Many beds are almost purely quartzose and are used for scythestones.

Conway schist.—This formation is distinguished from the one below by the intense corrugation of the schists and by abundant beds of a black, coaly and micaceous limestone, which have changed at the top and bottom into hornblende-schist for a few inches in depth. Blocks of this limestone weather into peculiar forms, like anvils and plowshares, the top and bottom being the resistant schist, the central shaft the easily dissolved limestone. Several thick beds of hornblende-schist are also found in this formation. The limestone and hornblende-schist distinguish it from the Goshen, in which these rocks are wanting. Eastwardly the rock changes into a coarse, rusty muscovite-biotite-schist, often somewhat feldspathic. In the extreme south it maintains this character and assumes the aspect of a bedded granite or gneiss. This is due to the prevalence of true eruptive granite, from which, while it was still hot, alkaline solutions penetrated the schist,

Calciferous mica-schist and associated limestone beds.

producing feldspars. The rock here becomes comparatively barren of accessory minerals, though cyanite occurs near the base of the bed in fine crystals.

The Goshen and Conway schists occupy an area wider than that of all the other formations combined, but the two contract suddenly and do not reach the southern border of the State.

Carbonaceous clay deposits altered to argillite.

Leyden argillite.—This slaty rock is widely spread in Vermont, and enters Massachusetts in Leyden, occupying the whole of the town. It passes south beneath the Juratrias sandstones in Greenfield and Deerfield, and reappears in Whately, where it is cut off on the south by the eruptive tonalite. It is the least altered rock of the Paleozoic column. Originally a black mud rock, it is now a black slate composed of a felt of microscopic scales of mica inclosing small grains of original quartz and much coaly matter, derived from the organic bodies it once contained. When most changed small pustules indicate the beginning of garnets or black mica crystals, and it is often netted with quartz veins. It is highly corrugated, and where by pressure a cleavage structure was produced it makes good roofing slate. At its contact with the eruptives it is changed into a chiastolite-schist, or even a chlorite-gneiss.

Goshen and Conway schists and Leyden argillite a continuous series.

The deposits of the Goshen and Conway schists and Leyden argillite make a continuous series, separated from formations below and above by considerable unconformities. They doubtless were laid down in a sea having boundaries and history different from those before and after it. Their limits on the south and west are successively narrower, the Leyden, the latest of the three, lying within the Conway, and the Conway within the Goshen, the oldest. Hence it may be inferred that the sea had shrunk northeastward, or that the land had expanded in that direction, during the corresponding epochs.

DEVONIAN PERIOD.

Transgression of the Devonian sea indicated by basal conglomerate.

Bernardston formation.—Next above the Leyden argillite occurs a conglomerate composed in part of pebbles derived from that formation and deposited upon it near their source. Such a bed is called a basal conglomerate. In order that they should produce such pebbles, the Leyden strata must have hardened and been raised to form a shore line against which broke the waves of the Devonian sea. Quartz veins also had developed in the argillite. These changes imply the lapse of considerable time between the Leyden epoch and that during which the sedimentary deposits were continued by the return of the sea over this area. The pebble beds mark the fourth unconformity in the Paleozoic history of the province, the Cambrian transgression having been the first, the break at the base of the Silurian the second, and that separating the Hawley and Goshen schists the third. The basal conglomerate and the deposits succeeding it were spread over Bernardston and Vernon and are known as the Bernardston formation. They are now greatly altered; the pebbles have been mashed as if they had been soft metal, and the whole conglomerate is locally changed to gneiss. The gneiss grades up into thick beds of quartzite, upon the faces of which there is much newly formed mica. Beds of limestone inclosed in these quartzites still contain upper Devonian corals, crinoids, brachiopods, and other shells, although the rock is so coarse-grained that cleavage pieces of calcite more than an inch across can sometimes be split from it.

Character of the Devonian rocks.

Above these altered sandstones and limestones comes a series that was once composed of clayey beds with interposed limestone beds. The former have been changed into mica-schists and the latter into thick strata of hornblende-schist.

CARBONIFEROUS PERIOD.

Sedimentary rocks of Carboniferous age not present.

There are no sedimentary rocks of Carboniferous date known in western Massachusetts, although they occur in the eastern part of the State about Narragansett Bay and near Worcester. If such beds were deposited here they have been entirely removed by erosion. It is more probable that the region had been raised above sea after the deposition of the Bernardston Devonian formation, and formed part of the extensive Carboniferous continent.

Culmination of earth movements in the Carboniferous period.

In tracing the history of the Paleozoic age from the Cambrian period to the Carboniferous, it has been noted that the older Algonkian rocks were more metamorphosed than the succeeding Cambrian deposits; that the Cambrian and early Silurian formations, including the Hawley schist, had suffered more disturbance than had the strata of later Silurian age; and that the Devonian beds were less altered than any of the older rocks. The degree of metamorphism serves to distinguish these several groups of formations, and marks the fact that the earlier ones were repeatedly disturbed, folded, and mashed in successive earth movements. Such movements raised land areas, possibly to mountainous altitudes, at several epochs during the Silurian and Devonian periods. During or near the close of the Carboniferous period, however, occurred the culminating movements which, to a still higher degree, folded and metamorphosed all the older rocks. It is associated in time and effect with movements which affected the entire Appalachian mountain system and in New England were followed by intrusions of granitic igneous rocks among the sedimentary formations. The granites are composed of quartz, potash feldspar, and mica or hornblende. On account of the proportionately large amount of quartz which they contain they are called acid rocks. They are thus contrasted with the so-called basic igneous rocks, which contain little or no quartz and much iron, such as the Juratrias diabase described below.

Granitic intrusions.

The acid granitic rocks, while intensely heated, melted or forced their way up through the already folded strata in huge domes several miles across, which sent out a multitude of dikes, like branches, into the surrounding schists. The rocks now at the surface were probably intruded at considerable depth, but have been since uncovered by deep denudation. Their domes extend along the eastern border of the valley from near the Deerfield River to the south line of the State.

The central portion of one of them, extending from near Whately to Northampton, is more basic than the others and is called tonalite. Bordering this is a granite containing black mica, and outside this is a granite containing both black and white micas. These extensive areas of granite and the bordering rock have been greatly cracked and the fissures occupied by coarse granite or pegmatite veins, which have been formed largely by the intervention of water, and around the edge of the whole complex mass these veins carry many fine and rare minerals. Still farther out is a zone of immense quartz veins.

JURATRIAS PERIOD.

Development of Connecticut embayment.

The events of the Paleozoic age, constituting a prolonged history of geographic changes, had come to a close, and a land not greatly unlike the present in general configuration had been established, when a new sedimentary record was begun in a bay occupying the position of the Connecticut Valley in Connecticut and Massachusetts. The shores of the bay were the west scarp of the Worcester County plateau on the east and the east scarp of the Green Mountain plateau on the west, and extended from near Brattleboro, Vermont, to New Haven, Connecticut. The sea waters rose to a considerable height above the present level of the bordering plateaus, and spread sediments brought in from these elevated regions on either side of the bay. The shoreward sediments on the east are represented by the Mount Toby conglomerates, and the Sugarloaf arkose is the synchronous deposit formed along the western shore. The Longmeadow sandstone was deposited in the shallower and quieter off-shore area, and in the central zone of this latter area, where the basin was widest, the still finer Chicopee shale was laid down. All these deposits are partly contemporaneous sediments, differing as the strength of the current and the character of the shore rocks affected them. Strong tides, like those of the Bay of Fundy, seem to have swept up the west side of the bay, carrying the material of the granitic shore rocks far north, to rest against a shore made of the dark schists, and the return currents ran along the east shore, carrying the eastern shorewash south, while quieter waters and shifting currents spread the sediments in the central area.

Relations of conglomerates and brown sandstones.

Volcanic activity and records of animal life.

The accumulation of sediments was interrupted by an eruption of lava through a fissure in the earth's crust, which opened along the bottom of the basin. The lava flowed east and west on the bottom of the bay, as tar oozes and spreads from a crack, and solidified in a sheet which may have been 2 or 3 miles wide and about 400 feet thick in its central part. This is the main sheet or Holyoke diabase. The sheet was soon covered with sand layers, but its thickness was such that it had shallowed the waters to near tide level, and thus occasioned extensive mud flats. This was an area suitable for the formation and preservation of unique records of the life of the time. The curiously shaped and often huge reptiles of that age wandered over the mud exposed at low tide, and their footprints, being covered by the deposit of the next flood tide, constitute the so called "bird tracks" which have been found in such great numbers and perfection.

The sands had reached a considerable thickness over the first trap bed when a second outflow of the trap followed, represented by the posterior bed or Hampden diabase. Immediately after the outflow of this sheet an explosive eruption took place, and blocks of diabase and pulverized lava were spread by the waters over a broad area, forming the Granby tuff bed. A third period of volcanic activity followed, during which a line of small volcanoes broke out along the old fissure beneath the bay. The area was next the scene of dislocations or faults, by which the mass of sedimentary and volcanic rocks was divided into great blocks, often extending north and south. The blocks slipped one past another along nearly vertical planes. In these dislocations the strata were generally tilted eastward.

Faulting of sedimentary and volcanic rocks.

Upon the map the faults which bound these blocks are clearly indicated where they cross the trap ridges. They are approximately parallel, and run about N. 20° E., crossing the trap ridges at very small angles. They are doubtless equally abundant over the rest of the district, but the sandstones include no peculiar bed which can be identified for long distances, and are so largely covered that the faults can not be traced. Because of the unequal tilting of these blocks the outcrop of the main sheet has a peculiar, lobed appearance, and the eastern sheet is broken into parts widely separated from each other. In these movements, associated perhaps with general uplift of the area, the bay became land and the rocks were exposed to erosion.

Landscapes of post-Juratrias periods.

The subsequent history of the region, during the later part of the Juratrias, the Cretaceous, Eocene, and Neocene periods, is recorded only in the aspects of the landscape. In Cretaceous time the heights of the Juratrias uplift were eroded to an extensive peneplain, which now forms the level of the Green Mountain plateau, as has already been explained. This plain is also represented in the crests of the trap ridges in the Connecticut Valley, the trap rock having maintained the level, while the soft sandstones surrounding it were worn away. In consequence of the elevation of the region after Cretaceous time and the activity of the ordinary atmospheric agents, the surface had been engraved nearly to its present relief of valleys and hills when the unusual conditions of the Glacial epoch were brought about. The history from the beginning of glaciation is described under the next heading.

PLEISTOCENE PERIOD.

Advance of the continental glacier.

Glacial epoch.—The landscapes of New England owe their generally rounded profiles to the effect of an ice sheet or continental glacier which spread over the region in recent geological time. The ice expanded from a center of accumulation in the Canadian Highlands, and the phenomena of ice erosion and deposition are widespread. Before the expansion of the ice sheet the relief of the region was essentially what it is now, but the rocks were deeply decayed and buried beneath clay and partly decomposed minerals. This layer the ice ground off and carried forward, distributing it as a peculiar stiff clay, or hardpan, containing a heterogeneous variety of bowlders. Such a deposit, characteristically developed only under glaciers, is called *till*. Till extends as a thick sheet very generally covering the rocks of all the region of western Massachusetts. This deposit often thickens into very regular hills, which are elongate in the direction of the motion of the ice. They are called *drumlins*, or locally "hogbacks." They are marked features of the landscape in the valley, especially near Northfield and Northampton. They are formed beneath the ice as bars are formed beneath water. Where bare bosses remain the rocks are rounded and smoothed. They were also frequently scratched by stones dragged along in the bottom of the ice, and from these striæ the direction of the movement can be ascertained. The ice flowed over the plateau in a general course S. 35° E., and down the Connecticut Valley from north to south. Although this course lay across hills and valleys which present irregularities of several hundred feet, the ice was turned aside only locally by the most marked heights and depressions. Hence it is inferred that it must have been of very great thickness.

Deposits beneath the ice.

The till and glaciated rock surfaces in the Connecticut Valley are broadly covered by later sand and clay deposits formed during the epoch of glacial retreat, from flood waters of the Connecticut River. In the upland valleys similar deposits accumulated locally in lakes dammed by the ice.

Lakes and streams occasioned by the ice sheet.

Deposits of the epoch of glacial retreat.—After the ice had so far shrunk that parts of the ground were no longer covered, the abundant waters from its continued melting were drained off to the southeast, down the slope of the plateau.

The broad valley of the Connecticut was the main outlet of this drainage, and as the country then stood nearly 200 feet lower than now, the fall was slight and the waters spread in a succession of lakes. The central trap ridges divided the waters into three separate bodies, which I have called the Montague, Hadley, and Springfield lakes. The tributaries sent great sand and gravel deltas out into these lakes, and fine thin-laminated clays, in which arctic leaves are found, collected over their bottoms.

The fact that the drainage west of the Connecticut Valley was southeast, while the ice front of the great glacier retreated toward the northwest, favored the clearing out of the main channels of drainage and allowed the waters generally to flow off freely. Therefore, there were in that region few glacial lakes or streams emptying in directions now abandoned, but some such transient bodies of water have left the evidence of their former presence in flat-topped deposits of well-sorted sands and gravels over the surface of the plateau and at high levels along the valleys of the main streams. Thus by the damming of the Deerfield River near Shelburne Falls the waters of this stream were sent south across Buckland, Ashfield, and Williamsburg to join the Mill River and enter the Connecticut at Northampton, and the damming of the Westfield Little River sent the waters south across Granville and formed the broad sand flats that occupy that township. When the ice resting in the Housatonic Valley formed a dam across the Hinsdale, East Lee, and Tyringham valleys, glacial lakes were formed whose heavy sand beds are still thrown across these valleys. Many similar instances are mentioned in the description of the separate quadrangles.

Changes since the Glacial epoch.

With the disappearance of the ice from the drainage area of the Connecticut, the system of lakes shrank suddenly to the present river. The old shore lines of these lakes are now 380 feet above sea on the north line of the State, 300 feet at Northampton, 180 feet at the south line of the State, and down near sea level at New Haven. As fine clays were deposited over all the bottoms of the lakes, there can then have been but little current through them, and therefore little fall. Since then the land must have risen in the latitude of Northampton nearly 200 feet. This has given the Connecticut new power of erosion, and it has cut down through the lake beds and swung east and west, forming the beautiful terraces which border the stream and make much of the charm of the valley scenery. These terraces are the sites of many of the most attractive towns along the river. As the river has swung to and fro, it has built up the broad, rich meadows which make the best farming land of the district. The great deltas of Mill and Chicopee rivers had reached clear across the lake, so that when the lake gave place to the river the latter could not regain its pre-glacial bed, which is far east of and much lower than its present one. It therefore soon cut through the lake beds and came to the rock. Thus the waterfalls at Turners Falls and Holyoke were formed and the water power of the river was concentrated at these points. This has determined the sites of the largest industries in the valley.

DESCRIPTION OF THE HOLYOKE QUADRANGLE.

GEOGRAPHY.

Extent.

General relations.—The quadrangle represented by the Holyoke atlas sheet is bounded by the parallels of 42° and 42° 30′ and the meridians 72° 30′ and 73°. It embraces therefore, a quarter of a square degree of the earth's surface, measuring 34.51 miles from north to south and 25.64 miles from east to west, and containing about 884.85 square miles. It extends two-thirds the distance across the State of Massachusetts from its southern boundary, covering the greater portion of Hampshire and Hampden counties and going over on the north into Franklin County and on the south into Connecticut. At its northwest corner it touches Berkshire County. The adjacent fifteen minute quadrangles are, on the north the Hawley and Greenfield, on the east the Belchertown and Palmer, on the south the Hartford and Granby, and on the west the Sandisfield and Becket.

Political divisions and adjacent quadrangles.

TOPOGRAPHY.

The western upland.

Two distinct topographic types are represented on this sheet, an upland and a valley. The upland is the larger, western part, and it varies in general altitude from 1200 to 2000 feet above the sea. The summits of most of its hills, and many broad flat areas which rise gradually higher toward the northwest, represent an ancient plain, which sloped southeastward from the Housatonic River toward the Connecticut Valley. This ancient plain, which is otherwise well preserved, is now deeply notched by the picturesque transverse valley of the Westfield River and by the wild gorge of the Westfield Little River. On the south the tributaries of the Farmington River drain the area by longitudinal valleys. Farther north a watershed running north 2 or 3 miles from the east border of the plateau separates the streams that run directly into the Connecticut from the many branches of the Westfield River. The southeastward slope of the ancient plain controls in the main the direction of the streams, though the East Branch of the Westfield flows south across the towns of Goshen and Chesterfield, following the trend of the rock bands. South of Shack Street in Chesterfield this brook turns sharply west, at a point from which it seems formerly to have run southeast into North Branch of Manhan River, and so directly into the Connecticut. It appears to have been diverted into the Westfield River by a tributary which cut back from the deeper valley.

Among the summits which rise above the general level of the ancient plain are High Ridge and Merritt Hill in Williamsburg, and More Hill in Goshen, all of resistant granite; and farther west Gobble Mountain and Round Top, in Chester, composed of hornblende-schist, are conspicuous landmarks. A deep depression has been eroded in the upland in Goshen and Chesterfield towns, over a circular area of softer rocks.

The Connecticut Valley.

The western upland or plateau ends with an exceptionally steep descent to the low sand-covered plain which extends east beyond the limits of the quadrangle. This escarpment, which runs from longitude 72° 40′ on the north to 72° 50′ on the south, forms the western boundary of the Connecticut River Basin.

The Northampton section of the valley.

The section of this basin in the vicinity of Northampton and Amherst covers the most picturesque portion of the Connecticut Valley and of the State. The broad and beautiful meadows bordering the river are bounded on the north by table mountains of sandstone and conglomerate—the Sugar Loafs and Mount Toby—and walled on the south by the trap bluffs of the Holyoke and Mount Tom ranges. The granite mountains which make the eastern rim of the uplands overlook the meadows from the west and form the western border of the Connecticut Valley, in the wider topographic sense, while beyond the limit of the quadrangle the gneiss ridges of Pelham shut it in on the east.

The sandstone hills which form the northern boundary are separated from the crystalline rocks on either side by deep depressions—the Leverett gorge, occupied by the New London Railroad, on the east, and the low plain of South Deerfield on the west—while the river cuts through the middle of the sandstone hills.

The trap ranges on the south are isolated by exactly similar depressions—the narrow gorge of the Belchertown ponds on the east, beyond this quadrangle, and the broad depression followed through Easthampton by the Canal Railroad on the west—while here again the river cuts through the trap range at its center.

Across Amherst and Northampton the rounded hills of glacial stony clays called drumlins, or in homely phrase "hogbacks," form an important element in the scenery. Finally, the winding Connecticut, with its many bends and oxbows, and the rich bottom lands or meadows in Hadley, Hatfield, and Northampton, form an appropriate center and foreground of a region as varied in beauty as it is diversified in geological interest.

The Westfield sand plain.

Next southwest is the Southampton-Westfield plain, underlain by sandstones and leveled up by sands which were deposited after the retreat of glaciers that once occupied the area. Upon this plain the streams run north and south from a low divide, which is not marked at all in the topography. The great mass of Mount Tom dominates the valley, and the trap ridge of which it is a part is continued southward at a lower level. The ridge is deeply notched at several points, and each notch corresponds to a break, or fault, in the rocks. It rises to considerable elevation in Proven Mountain, and has always a sharp western and a more gradual eastern slope. This range bounds the Westfield plain on the east.

The country east of this ridge may be divided into two portions. That west of the Connecticut and north of the Westfield River is an undulating area of red sandstone and glacial clay. That south of the Westfield and the larger area east of the Connecticut form part of a flat sand plain, the bottom of an ancient lake, broken rarely by a reef of trap or a drumlin, and extending east beyond the limit of the quadrangle up to the foot of the Wilbraham Hills. The Connecticut River and its tributaries have cut deep trenches in these sands, forming the meadows which border the streams and the fine terrace scarps which flank them.

GENERAL GEOLOGY.

SEDIMENTARY ROCKS.

Geological subdivisions.

The rocks occurring in the Holyoke quadrangle consist of: 1. The very old crystalline schists of the western plateau, which are assigned to the Algonkian, Cambrian, and Silurian systems. These schists are penetrated by great stocks and dikes of acid intrusives. 2. The much later Juratrias sandstones, conglomerates, and basic intrusives of the Connecticut Basin. 3. The relatively modern surface deposits of Glacial and post-Glacial age.

ALGONKIAN.

Dark, micaceous, and fibrolitic gneiss.

Washington gneiss.—A band of ancient gneiss enters the quadrangle at its southwest corner and runs up across Tolland, narrowing to a point near Black Pond. It is distinguished by its highly micaceous and fibrolitic character. Its beds dip on either side beneath the white Cambrian gneiss. Just beyond the quadrangle in Riverton, it includes a large bed of limestone containing chondrodite, and to the west the gneiss grades into the blue quartz-gneiss so common in this formation.

CAMBRIAN.

Light-gray, friable biotite-gneiss.

Becket gneiss.—A broad band of light-gray, friable biotite-gneiss surrounds the Washington gneiss last described, and dips out from it beneath the newer rocks. It is thin bedded, and the thick-bedded granitoid gneiss, like the fine quarry stone in Becket, does not appear here. In places it is somewhat rusty and contains large garnets, becoming much like the feldspathic schist above, so that in the next quadrangle south the distinction between the two is hard to trace in the field.

The gneiss of Pelham, so commonly used as a building stone, forms the eastern border of the Connecticut Basin just beyond the limits of the quadrangle on the east, and its great sheets can be seen on any of the western roads of Pelham or Shutesbury, dipping westward toward the valley, but the rock is not present at the surface in this quadrangle except in Granville, Tolland, and adjoining towns in Connecticut. These sheets resume this westward dip and, extending under the area to the west, form the platform upon which all the younger rocks rest and come up to form the crest of the Berkshire Hills along the western edge of the plateau in Peru.

SILURIAN.

Feldspathic mica-schist.

Hoosac schist.—The distinction between the albitic mica-schist (Hoosac schist) and the sericite-schist (Rowe schist), which is so marked in the northern and central part of the State, fades out gradually in the southern part of this quadrangle, both beds losing some of the characteristics which separate them farther north. The small porphyritic albites of the former gradually become inconspicuous, and the feldspathic constituent comes to be mainly potash feldspar, apparently as a result of granitic impregnation, as granite becomes abundant and appears in large masses. The Hoosac schist is generally a coarse muscovite-biotite-schist, showing on foliation faces broad plates of muscovite and biotite regularly intergrown and containing often garnet, staurolite, and gray cyanite. Toward the base is a peculiar rock. In a limpid granular quartz mass, distinct scales of silvery muscovite, red biotite, and pyrite are compressed into parallelism, producing a bright silvery luster. It contains much plagioclase. This is a part of the Hoosac schist, but is an inconstant bed. Rarely hornblende-schist beds and a pale-green actinolite-garnet rock derived from limestone occur.

By the development of three folds in these schists, two of which bring the Becket gneiss to the surface, and by the pinching out of the overlying hornblende-schists between these folds, the Hoosac schists come to occupy a broad area in the southern portion of the quadrangle.

Green, quartzose sericite-schist.

Rowe schist.—This formation barely skirts this quadrangle on the west, and is best exposed on the road going west from Chester, at the second bridge. The Rowe schist north of North Blandford is a barren sericite-schist of pale-green color, often spotted with chlorite plates, quartzose, and greasy to the feel, but in the vicinity of Blair Pond it becomes also feldspathic and more coarsely crystalline, and loses its tendency to hydration, apparently from the influence of the granite. South of North Blandford the rocks are wholly covered for a long distance. The boundary is drawn so as to let the Rowe schist taper to a point, and farther south the distinction between the Rowe and the Hoosac schists is not carried out.

East of the Juratrias.

A series of rocks which seems to represent the whole Silurian succession west of the river, but in simpler form and with less thickness of individual beds, extends west from the gneiss of Pelham and occupies the narrow bottom of the valley from the point where the railroad crosses Locks Pond Brook south past Leverett Center. The series goes beneath Mount Toby, and south of the mountain extends west to underlie Amherst and Hadley. It is so greatly faulted and crushed and impregnated with granite that its mapping has been very difficult.

The basal bed of the series, resting upon the Cambrian biotite-gneiss of Pelham, is an altered conglomerate, now a feldspathic mica-schist or a gneiss with black and white mica, which may be correlated with the Rowe schist. Its description is based wholly upon the beds in Northfield Mountain, in the Warwick quadrangle, and it touches only the extreme northeast corner of this quadrangle as it passes from Locks Pond Brook to the west entrance of Rattlesnake Gutter in the Belchertown quadrangle, next east of this.

Hornblende-schist, in part replaced by serpentine and soapstone.

Chester amphibolite.—By far the most interesting series within this quadrangle is the band of hornblende-schist (amphibolite) and soapstone beds mapped as the Chester amphibolite. The unique magnetite and emery bed at Chester is situated along the eastern border of this hornblendic band. The band crosses the area from north to south, inclosed between sericite-schists on either side, and standing always nearly vertical. Details of its distribution and mineral associations are as follows:

The band is narrow where it enters the quadrangle from the north. It is locally changed to soapstone on the river road in Windsor, and carries a great bed of serpentine and soapstone and some emery at H. Smith's in Middlefield. Two miles south it widens suddenly to 200 rods, and much the larger half on the east becomes serpentine, derived largely from the hornblende-schist and retaining its structure, but possibly partly derived from an olivine or olivine-enstatite rock. This serpentine continues more than a mile, to the bed of the Westfield River, on the south bank of which the rock changes back suddenly to hornblende-schist, and continues, with the above width, several miles to the south, making the mass of Gobble and Round Top mountains. Fine pseudomorphs in serpentine were formerly found in the serpentine north of the river, and were supposed to be flattened quartz crystals. They prove on measurement to be olivine.

In the river, opposite the railroad bridge at the west line of Chester, the north end of the remarkable emery vein is beautifully exposed, and it continues to border the hornblende-schist on the east for a distance of 3 miles.

Steatite (soapstone) appears on the east of the bed in Gobble Mountain, and both steatite and serpentine occupy the same position in the old mine. The emery is disseminated in magnetite, and the bed reaches in places a thickness of 16 feet and is estimated to average 4 feet.

Minerals accompanying the emery.

A great number of beautiful and rare minerals accompany the emery, and in the list below they are arranged in the order of their age:

Stage 1. Magnetite, emery, corundophilite, bordering an olivine-enstatite rock.

Stage 2. Corundophilite (in veins in magnetite), tourmaline, pyrite, epidote, corundum (white and blue in veins), and oligoclase.
2a. Corundophilite (in incrusting layers on Stage 2), margarite, diaspore, rutile, epidote, chalcopyrite, calcite, menaccanite.
2b. Menaccanite, margarite, diaspore, brookite, calcite.

Stage 3. Specular iron, aragonite, pyrite, chalcopyrite.
3a. Calcite, malachite.

Stage 4. Corundophilite altered to amesite, margarite, and diaspore bleached. The enstatite rock changed to serpentine, and this to talc.

In North Blandford is a great development of steatite which seems to have been derived from a coarse radiated actinolite, and near this an extensive bed of serpentine containing much chromite and a trace of nickel, probably derived from an olivine rock. On the old maps this locality is called the Crater.

Farther south in Blandford, at the Osburn soapstone quarry, is a thick bed of black enstatite-serpentine with much soapstone, derived from a coarse radiated actinolite, itself derived from the enstatite.

At the bottom of the brook gorge to the west of the quarry is a remarkable serpentine derived from a coarse pyroxenite. The pyroxene can be traced in the change into actinolite, and this into serpentine and talc. Farther south, in Liberty Hill, West Granville, the amphibolite band widens greatly, and, sending off a long spur to the south, bends sharply and turns north for 3 miles; then turning abruptly south again, it extends to a point south of the cemetery in East Granville. Here it again bends north and runs 8 miles northeast to Atwater's serpentine quarry in Russell. Thence it runs south again for some distance, to disappear below the sands of the valley, south of Munn Brook in Southwick. At the cemetery in East Granville a remarkable change takes place in the bed. The amphibolite becomes quite subordinate and the series is represented by great beds of black serpentine of a very peculiar structure. It is made up often of large interlaced prisms, formerly enstatite, and still showing at times a core of this mineral surrounded by bastite. More often these prisms are completely altered to a black serpentine. The interstices between these prisms are usually filled with a transparent dolomite, the solution of which gives the rock a peculiar ragged surface. This is best studied east of H. Cooley's, in a pasture a mile southeast of Sweetman Mountain, where the prisms of enstatite are sometimes a foot long; or east of J. Downey's in East Granville, where the bed graduates into a nephrite-like tremolite-schist, and that into a great bed of white granular limestone; or at Atwater's, at the northern elbow of the band, where the enstatite remains only in the green foliated bastite found in the multitude of great bowlders scattered over Granville and Southwick. The most important place for the study of this band is the newly opened quarry of the Hampden Marble Company. South of Little River, on the Westfield-Russell line, the bed is 150 feet thick in cyanite-bearing mica-schist and is cut by granite. The western third is enstatite-serpentine. The remainder is a dolomitic marble, shot through with long serpentinized enstatites in beautiful stellate arrangement.

Traces of the presence of enstatite appear in the serpentine at Hubbard Brook just over the State line and at Osburn's quarry. Whenever this occurs the rock was probably once enstatite or enstatite-olivine rock. Yet the only certain proof of the presence of olivine found in following this band across the State was the occurrence of olivine pseudomorphs in the serpentine in Middlefield, which have been described as quartz pseudomorphs.

Northward from Munn Brook, then, all the serpentine beds are enstatite-serpentines to Osburn's quarry, where the eastern bed and the steatite have this origin; the western is a pyroxenite-serpentine. In North Blandford the somewhat peculiar "Crater" serpentine is probably derived from an olivine rock. The soapstone, like that at Osburn's, may have been derived from an enstatite rock through actinolite.

The Chester amphibolite a metamorphosed dolomitic limestone.

In earlier publications the Chester amphibolite band was described as being composed of altered eruptives. In Monograph XXIX, on the Geology of Old Hampshire County, later discoveries have led me to present the view that the band is an altered limestone or dolomite, possibly contemporaneous with the Bellowspipe limestone in western Berkshire. The first view was based on the fact that many amphibolites are altered eruptives and that enstatite is commonly an eruptive mineral and emery a possible contact mineral. The finding of great beds of dolomitic limestone in the series and the passage of these limestones into enstatite limestones, the fact that the Naxas emery is found in limestone and that many amphibolites are derived from limestones, together with the great extent of the series as it passes across Connecticut, Massachusetts, and Vermont, lead me now to believe it to have been mainly a calcareous sedimentary formation, with possibly some very basic eruptives associated therewith. It was a broad band of limestone, and waters leaching through the superincumbent schists deposited a great bed of limonite and gibbsite on it, like the West Stockbridge ores on the Stockbridge limestone. This was then altered to the magnetite-emery bed, while the rusty dolomites changed into enstatite-limestone and amphibolite.

Savoy schist.—This broad formation is, in its passage across the quadrangle, a very monotonous mass of quartzose mica- or hydromica-schists, generally quite barren of all accessories.

Quartzose mica-schist with intercalated amphibolite.

In the central portion, about Chester, many amphibolite beds are intercalated, and large garnets occur in highly micaceous, coarse biotite beds, also beautiful hornblende in black blades penetrating a white quartzite. This facies of the formation is well exposed in the cuttings west of the Chester railroad station.

Farther south this formation consists of a quartzose hydromica-schist, more or less chloritic, often barren over large areas, frequently carrying much pyrite and garnet, the latter changed more or less into chlorite. Its vertical beds present a very monotonous aspect.

Beds of black hornblende-schist are not infrequent around North Blandford, but as the Savoy schist widens to the east in a broad anticline, this becomes less common and the rock is cut by great granite masses and loses the greasy feel of hydromica.

In the northeast corner of the quadrangle the Savoy schist is a micaceous quartzite, generally containing a green chloritic mineral, which is at times certainly derived from garnet. Sometimes it may be called a whetstone-schist. It is exposed all along the road east of Mount Toby, beginning a little north of the railroad crossing, and in the cuttings of the railroad and in the brooks coming down from the mountain just south of the Mount Toby station. In Roaring Brook the Mount Toby conglomerate is seen resting upon it 50 feet above the railroad. The rock was very greatly contorted and crushed, and then cemented by quartz and hematite, and at a later time jointed, so that it falls easily into small pieces.

A bed of hornblende-schist crosses the northeast corner of the quadrangle, south of the great mass of granite which lies west of the road extending north from Leverett Center, and a second broad strip of hornblende-schist stretches southwest from A. Field's on the road to Leverett Center west of the railroad. It is often biotitic, and is generally a thin fissile rock, stretched by pressure It has a dark-green color, and is made up of quartz, hornblende, feldspar, and magnetite.

Hawley schist.—This formation runs south across the northern half of the quadrangle, with southerly strike and nearly vertical dip, and in Chester is overlapped by the Goshen schist. It is exposed also in an oval area around Burnell Pond by a dome-shaped uplift. It is a ferruginous formation, consisting of hornblende-schists with soft chlorite- and sericite-schists. In the two latter rocks black hornblende needles arranged in sheaves appear abundantly on the slabs, whence is derived the name, fasciculite-schists.

Hornblende-, chlorite-, and sericite-schists.

The whole slope on the eastern side of the valley that separates Middlefield and Worthington is occupied by these rocks, with a width of about a third of a mile. The rocks abound in large garnets, superficially changed into chlorite, which with the fasciculite form fine cabinet specimens.

Goshen schist.—This formation includes the lower portion of the Calciferous mica-schist of Hitchcock. It is almost wholly free from limestone and is a dark-gray graphitic muscovite-schist, often arenaceous and splitting into flags 2 to 3 inches thick, which are much used in the large towns in the Connecticut Valley for sidewalks. It is abundantly crowded with small red garnets, especially where micaceous, and spangled with small shining black mica plates set across the bedding where it is more arenaceous. Staurolite is generally rare in the central portion of the quadrangle, and is wanting in the northern part.

Graphitic muscovite-schist.

The typical region is that surrounding the oval of Hawley schist in Goshen, and dipping out from it in all directions. A band identical in lithological character and of the same thickness crosses the western portion of Worthington. In Goshen occur bands of light-gray biotite-gneiss, with massive texture and fine grain, which resembles the Cambrian gneiss, but under the microscope proves to be much more like the schists with which it is associated.

The schists run across the southern half of the quadrangle in a narrow band, and are well exposed at Salmon Falls (Fairfield), where their thickness, much diminished from that seen farther north, can be clearly determined. In the rest of the area this is not so clear, as, being caught up in the broad anticline, the rock is about as much corrugated as the next formation above, and the only criterion by which it can be distinguished is the smaller quantity of graphite and other accessories. The distinction is here comparatively unimportant, and is carried out partly for the sake of uniformity with adjoining sheets and partly because in the great mass of these graphitic schists any distinction is important in unraveling the structure and expressing it on the map.

Conway schist.—A large portion of the quadrangle is covered by this formation, which is also very extensive northward beyond its limits. The finely corrugated muscovite-schist, which is the principal rock, is often so contorted that no strike can be made out. It is dark from the abundance of coaly matter; small garnets and staurolites are usually abundant in it, but they grow rare to the north; and zoisite and blue cyanite are common.

The rock is generally spangled with many small, elongate, shining, black mica scales, set transversely to the foliation. There are many beds of a sandy quartzite with small scales of red mica regularly disseminated. These make excellent scythestones. Beds of a black limestone full of nodules of graphite and dark mica appear north of the middle of the quadrangle, and increase in number northward. These beds are often changed above and below for 2 or 3 inches into hornblende-schist, and when blocks are separated from the ledge they weather in swampy places into forms like plowshares, anvils, etc., from the solubility of the limestone.

Mica-schist, with beds of limestone, whetstone, and hornblende-schist.

In the western portion the schist is very fine grained and of the type described above. In the eastern portion it is greatly cut by large masses of granite and becomes itself coarser grained, barren of all accessories mentioned above and much impregnated with quartz and pegmatite veins. It is a rather coarse muscovite- or muscovite-biotite-schist, rendered dark by graphitic dust. The fine and regular corrugation common farther west gives place to an irregular contortion, and the whole is greatly changed from the normal dark-spangled and corrugated schist farther west by the intrusion of the granite.

The thickest bed of limestone starts at Whately Glen and runs south across the town of Whately. Parallel to this runs a thick bed of hornblende-schist, and abuts against the great mass of granite which occupies so much of the quadrangle. Fragments of the three rocks, the mica-schist, the limestone, and the hornblende-schist, can be found for many miles south included in the granite in the line of their strike and in parallel positions. This fact proves that these rocks once extended together across the granite and have been removed by erosion. The granite is largely hornblendic in the area of the hornblende-schist, biotitic in the area of the biotite-limestone, and muscovitic in the part covered by the muscovite-schists This indicates that the granite melted up into the schists, and incorporated much of them into its mass.

Amherst feldspathic mica-schist.—The equivalent of the Conway schist on the east side of the river is the Amherst feldspathic mica-schist, which is coarser and more ferruginous. Where these schists are exposed in Mount Warner and across Amherst by the erosion of the Juratrias sandstone, they are cut in every direction by numberless dikes of coarse pegmatite, and are much more metamorphosed than those west of the river. The schists are impregnated with granitic material from the pegmatite, and thus become feldspathic. Fibrolite is a rather common constituent, linking them with the Brimfield schists of Worcester County. They form a disturbed syncline in Mount Warner and extend east across Amherst, dipping west—that is, away from the lower portion of the series along the eastern border of the quadrangle.

Fibrolitic mica-schist impregnated with granitic material.

Leyden argillite.—Back of Whately village is a most interesting band of extremely fine-grained mica-schist or phyllite, almost too coarsely crystalline to receive the name of argillite, by which it has usually been known. It is greatly corrugated, and this structure is brought out by distinct sandy layers. It is often perfectly cleaved, as a result of pressure, and this structure expresses itself by a parting which separates the rock into thin parallel plates. Many irregular veins of white quartz cut the rocks where the road crosses the brook west of Whately, and the limestone of the Conway schist appears beneath it, showing that the argillite is newer than the Conway schist. Along its contact with the tonalite it is greatly altered by the latter into a greenish gneiss, and farther outward into a chiastolite-schist. These chiastolites are further altered, while retaining the black cross in section, into a mass of muscovite scales in which minute staurolites in twin crystals are embedded, and the latter are superficially changed into a fibrous mineral.

Very fine-grained mica-schist or phyllite.

CARBONIFEROUS.

As has been stated on an earlier page, there are no sedimentary rocks of Carboniferous age known in this part of the State. A description of eruptive granites of Carboniferous age occurring in this quadrangle may be found under the heading "Igneous rocks."

JURATRIAS.*

The map shows that the Juratrias red sandstones enter the quadrangle from the north with a width of about 8 miles, are greatly constricted where they pass west of Mount Warner, and expand toward the south. This narrow zone in Hatfield is due to extensive erosion, which has worn away the sandstones down to the schists and left a sheltered remnant of sandstone isolated in the village of Amherst. This erosion was aided in exposing the crystalline rocks by the irregular surface of the latter and by faulting, which has raised the eastern portion of the basin and depressed the western portion. The eastern border of the sandstone was doubtless high up on the slope of the Pelham ridge, beyond the eastern border of the quadrangle.

Extent of the Juratrias red sandstone.

The southern part of the quadrangle presents a wide section of the "Connecticut River sandstone," as these beds have been called, because of their typical character in the valley; they are widely known among geologists on account of the "bird tracks" which occur here in abundance and beauty unequaled elsewhere, and they have been fully described by President Edward Hitchcock, in a magnificent work published by the State of Massachusetts.

The steep walls of the valley, the series of faults which bound it on each side, and the great thickness of the sandstones, or, what is the same, the great depth of the basin in which these sandstones are gathered, are best explained on the hypothesis that the basin is a "graben," or rift valley, formed by the sinking of a great block of the crystalline substratum between faults. These faults have a certain symmetry with the curved outcrops of the Holyoke and Greenfield trap sheets, projecting on the east into their concavities and on the west preserving a marked parallelism with the lobes of the trap.

The Connecticut Valley possibly a rift valley.

Mount Toby conglomerate.—The Mount Toby conglomerate is composed of coarse materials varying from pebbles 2 inches in length to masses with dimensions of from 2 to 4 feet. The rock is very largely, and often wholly, made up of comminuted argillites, quartz-schist, and vein quartz, with larger pebbles of the same material. In many cases, as along the eastern slope of Mount Toby and in Gill, rocks from 1 to 2 feet long are set as closely as they can lie in a coarse gravel from which all sand has been washed. A partial arrangement of the pebbles with their flat surfaces parallel to a common plane and the rude stratification in the coarser and the finer beds is the only structure.

Coarse conglomerate of argillite, quartz-schist, and vein quartz.

In the bed of Roaring Brook, and of the next brook to the north on the east flank of Mount Toby, about 50 feet above the level of the New London Northern Railroad, the conglomerate can be seen resting upon the contorted quartzites. As we go westward from this point the whole mass of the main ridge of Mount Toby is found to be made of this coarse rock, but following any of the "sugar roads" into the mountain from the western side we find several bands of the Longmeadow sandstone, which penetrate the horizontal beds of the coarser rock and thin out under the main ridge. These indicate successive oscillations of level, during which the finer-grained sandstone extended east across the conglomerate several times and then gave place to the coarser material again.

Sugarloaf arkose.—This rock, which is a coarse, buff to pale-red sandstone, and which often becomes so coarse that it can be called a fine conglomerate, is made up largely of the débris of the granite and coarse pegmatite veins of the high ground to the west. The flesh-colored cleavage pieces of the feldspar and the shining scales of white mica give character to the rock. At the surface it is generally softened by the solution of the cement and often spotted green by the reduction of the iron rust by decomposing organic matter. This process is in places carried so far that the surface is white from the leaching out of the reduced iron salts, thus showing the kaolin resulting from the decomposition of the feldspar.

Coarse sandstone of granite débris.

In the northern part of the quadrangle the rock extends from the Connecticut River westward, including the isolated area in Amherst village, and farther south occupies the whole width of the plain west of the Holyoke Range. It is synchronous with the Mount Toby conglomerate, which is the eastern shore deposit, now raised between two great faults above its former level. Its western limit is along the foot of the bluffs, where it seems to meet them by a nearly continuous series of faults across the State; but the junction is deeply covered by the terrace sands, so that the coarsest western shore deposits are mostly concealed. Just south of Whately village, near the western border, it becomes a coarse granitic conglomerate, which represents a part of the western shore bed. It is also a decided conglomerate at Mount Tom station in the center of the basin and just beneath the Holyoke trap, and it may have been brought up here by faulting.

The low ground of the Westfield-Southwick plain is underlain by this formation, which is there a coarse feldspathic sandstone, whose material has been largely derived from the granites of the hills to the west. Along the western border it becomes a granitic conglomerate. Its red or buff color comes from the iron rust, which forms a large part of the cement by which the ancient gravels were solidified.

Longmeadow sandstone.—The Longmeadow sandstone represents an offshore facies of the sediment spread over the bottom of the Juratrias bay. South of Titans Pier, where the Holyoke trap projects into the river, the coarse Sugarloaf arkose grades into the buff or brown sandstones, which have been quarried on both sides of the river in Larrabee's quarries. This is the north end of a broad band which extends south down the center of the broadened bay. It is a quartzose brownstone, oftentimes somewhat feldspathic, and cemented mainly by iron oxide. It suffers the same superficial change as the preceding rock. It abounds in branching tubes of sandstone about the size of a pencil or smaller, which are of the same material as the rock itself, but separate easily from the rest of the rock. They have been thought to be the remains of seaweeds and have been called fucoids, but they are ferruginous concretions. Many layers of the rock are covered with the tracks of animals of every size, ripple marks, mud cracks, raindrop impressions, and a multitude of markings which have not been explained but which prove that the waters were shallow and that the deposits were often laid bare by the tide. The valuable building stone of the region comes from exceptional beds in this series.

Brown sandstone abounding in animal tracks and other markings.

Chicopee shale.—This is a central band, which begins at Holyoke and is best exposed along the railroad cutting near the Holyoke dam, where it is a thin dark-gray shale or shaly sandstone, coaly, and showing many minute impressions on the laminæ, some of which have been formed from salt and gypsum crystals which have been dissolved out. The beds appear at the mouth of the Chicopee River, and in the bed of the Connecticut River at Mittineague, where the rock consists of red shales with many nodules and narrow beds of concretionary limestone and casts of skeleton salt crystals in calcite. It also appears in the beds of brooks in Agawam and Thompsonville, near the Connecticut, but the rock in place is so covered that it is not possible to draw a boundary for it with accuracy.

Gray and red shales containing casts of salt crystals.

Granby tuff.—This consists of heavy-bedded black tuff and tuffaceous sandstones varying from fine-grained volcanic sandstones to coarse breccias and agglomerates; from rocks made up wholly of volcanic débris to such as contain abundant fragments of granitic and gneissoid rocks. The finer-grained varieties contain the materials of granite, especially white mica, on the lamination faces, and grains of quartz in the mass of the rock.

Black massive tuff and coarse volcanic breccia.

The roadside a mile or two south of Smith Ferry and the railroad cuts adjacent furnish fine outcrops of this bed, and enable one to study it near the center of eruption and distribution.

The great angular blocks of diabase a mile north of Smith Ferry, by the cemetery, can be seen to have fallen into and to have bent down the layers of the mud, now turned to sandstone. The blocks grow gradually smaller southward, and above Larrabee's quarry on the north line of Holyoke a few scattered fragments of trap, an inch or two long, in the feldspathic sandstone are all that remain. More easterly, on the road going south from The Notch, at a small brook, the cross section of the bed is very instructive. Here the fragments are from half an inch to an inch in size. The transition from the tuff to the feldspathic sandstone above and below is very sudden. The tuff itself is deep brown from rust.

In tracing the outcrop, one finds portions of it wanting, apparently faulted out of sight; and on the other hand, portions of it are found far beyond these limits, having been let down from above during the time of faulting, and now being exposed by the great erosion which the sandstone has suffered.

The striking cases of this kind are: (1) In the bluff overlooking the Middle Belchertown Pond, and (2) a mile and a quarter north of the cemetery in Granby and a mile east of The Notch, and thus far up the mountain side and far north of the present outcrop of the bed. Here a mass projects from the ground and is shaped like the rude model of a great telescope on its stone pedestal. This shows that the tuff extended far north and east of its present outcrop.

*See paper on the Triassic of Massachusetts, by the writer: Bull. Geol. Soc. Am., Vol. II, p. 451, 1891.

IGNEOUS ROCKS.

CARBONIFEROUS.

ERUPTIVE MASSES.

Williamstown granite, Belchertown tonalite, and Middlefield granitite.—The granitic igneous rocks which were erupted in Massachusetts about the close of the Carboniferous period occur on both sides of the Connecticut Valley, and their distribution in this quadrangle is very interesting. The central core is the great block of tonalite or hornblende-biotite-plagioclase rock in Hatfield which is mapped as the Belchertown tonalite. The High Ridge dome of granite, the Mount Pomeroy and Mount Tekoa masses, and a string of smaller batholiths lie west of the tonalite. They are great and monotonous stocks of biotite-muscovite-granite, occasionally carrying black tourmaline. Whatever masses may occur to the east are to a great extent hidden by the later Juratrias rocks. In a bordering band about 3 miles wide, west of the great domes, smaller but considerable stocks of similar granite are abundant. Farther west comes a bordering area, stretching from Granville north to Cummington, and beyond to Northfield, that has numerous veins of coarse pegmatite which carry subordinate veins abounding in spodumene, colored tourmalines, cleavelandite, cassiterite, zircon, uranite, triphylite, beryl, etc. Beyond this is a series of great quartz veins, often quarried for crushing. Outside of this area, to the west, the country is for a long way free from intrusive rocks, until near the western border the unique Middlefield dike of peculiar porphyritic biotite-epidote-granite appears.

Biotite-muscovite-granite masses.

Pegmatite and great quartz veins.

In Blandford, 3 miles west of Huntington village, at the quarry above the Pontoosic Mills, is a remarkable pegmatite vein, 12 to 15 feet thick. A selvage of coarsest mica, 3 feet thick, is attached to the schist walls and is followed inwardly by two bands of feldspar crystals, well formed and 1 to 2 feet across, mixed with the coarse mica, and this grades, by the disappearance of the feldspar, into a central smoky quartz mass several feet thick. A similar vein of coarse pegmatite, wholly decomposed to kaolin and preserved from the erosion of the Glacial period, is now extensively worked near Blandford Center, for the finer kinds of brick and terra cotta.

JURATRIAS.

BEDDED DIABASES.

Three great trap sheets were poured out upon the sea bottom while the Mount Toby conglomerate was gathering over the eastern border, the Sugarloaf arkose was forming over the broad bottom of the bay and in coarser varieties fringing the western border, and the Longmeadow sandstone was being deposited in the wider reaches of the bay.

Talcott diabase.—The Talcott diabase is important in its extension across Connecticut, but barely crosses the line into the Holyoke quadrangle. In Percival's account of the geology of Connecticut it was called the anterior sheet, as it lies in front of the main or Holyoke sheet, which dips east and faces west.

Holyoke diabase.—The Holyoke diabase is a typical diabase of monotonously uniform character. It is a dark-gray, very dense, fine-grained rock, with broad conchoidal fracture. Under the microscope it is seen to consist of a network of elongate triclinic feldspars inclosing shapeless masses of augite. This quadrangle includes the transverse portion of the great Holyoke bed from near its east end to the apex of Mount Tom, beyond which it drops to a lower level and continues south. It commences with southerly dip and swings round to an easterly dip of about 30°. At its east end it is thinner and more weathered than farther west, and more amygdaloidal. The rock is generally very fine grained, but at Titans Pier it is coarser, the flat blades of augite being nearly an inch long. It often shows a rude columnar structure, generally on a large scale. Titans Piazza, south of Mount Holyoke, is much visited because of the fine columnar wall. The great columns are here 30 to 40 feet long and 3 to 4 feet wide. They are underworn so that one, and in some places two, rows are retained in place solely by their lateral connection with adjacent columns and their bottoms are hemispherical. They form thus a curious cave or rock shelter, with its ceiling formed of the rows of great hemispheres of the column ends. The thick bed rises above the sandstones because erosion has removed these from its flanks. Its own shape depends locally upon the angle at which it is truncated by erosion. Where its eastern slope agrees pretty closely with the upper surface of the bed and the western slope coincides with the columnar structure, which is at right angles to the surface of the bed, it runs in a bold hill with precipitous western face, as in Mount Tom and Proven Mountain. Where erosion has worn off the trap sheet more nearly horizontally the ridge is less elevated, but the trap covers a broader surface.

The main trap sheet.

The columnar structure at Titans Piazza.

To the north, in Sunderland and Deerfield, a bed of trap similar to the main Holyoke sheet rests on the Mount Toby conglomerate, extends northwest across the river on the Sugarloaf arkose, and stretches north far beyond the limits of the quadrangle. Slightly inclined to the east, its mass forms the core of Deerfield Mountain just beyond the border of the quadrangle, and seems formerly to have capped South Sugar Loaf and North Sugar Loaf. This is apparently the reason why they still retain a mesa form. The rock is a dark, fine-grained trap, full of steam holes and thoroughly rotted where it occurs in the conglomerate, dark and compact in the arkose. The bed shows a superficial and two intermediate sheets full of steam holes, indicating three immediately successive flows.

Where the Holyoke Branch Railroad first touches the main trap sheet at the south end of Ashley Pond, a cutting exposes the upper surface of the trap, which is full of small fragments of a compact, dove-colored limestone.* These are frequently angular, but they are also often so kneaded up with the trap as to give the impression that both must have been plastic when they were thus mixed. The trap is full of rounded holes filled with clayey limestone. With the microscope the material can be seen to have flowed as a fine calcareous mud into the steam holes which open on the surface of the trap fragments. In other cases the drops of mud were inclosed in elongate swarms in the solid trap and seem to have flowed with the liquid material. Other cavities are filled by a later infiltrated crystalline calcite. The broad surface of the trap for 5 miles shows this structure. While the lava incased in a thin solid layer was flowing over the bottom of the bay, heated waters rising from its surface caused convection currents which swept the fine mud out onto the hot bed in sheets which were then enveloped by still liquid trap where the surface layer was broken up and were blended with the rest. All along the base of the trap sheet within the same limits the same structures occur inverted, and are to be explained as having been formed on the surface of the trap, as already described, and then underrolled by its slow and continuous advance westward, and brought into a position at the base of the bed. The scoriaceous structure in such great thickness and completeness, the fine brecciation, and the intimate mixture with the limestone can have been effected only at the surface.

Inclusions of limestone in the trap; underrolling of the bed.

Beginning with the east end, the trap bakes the sandstone on which it rests, as may be seen at the few places where the contact can be observed—in the northwest shoulder of Mount Norwottock, just north of the "Devils Garden," and a few feet north of Titans Piazza. From Titans Pier south to a point near the Westfield River it does not bake the rocks on which it rests, but is amygdaloidal and kneaded full of limestone and more or less brecciated. These structures, having been formed on the surface of the lava stream and underrolled by its advance, so that they come to lie on the bottom, have thus protected the underlying beds from the heat.

Hampden diabase.—The Hampden diabase forms the strong foothill ridge east of the Mount Tom Range, which extends from a point south of Mount Nonatuck to the south line of the quadrangle and beyond. By Percival it was called the posterior sheet. At the north end it is interrupted by an intrusive dike, to be described later. The great tongue projecting east from the Blackrock boss on the east side of the river may be its eastward prolongation, but this seems to be an intrusive offshoot from the boss itself. The Hampden sheet can not be followed farther east. It is well exposed at the Tatham cutting in West Springfield, and at the Holyoke Branch Railroad east of Ashley Pond. It is thinner than the main sheet, being 50 feet thick in West Springfield, and identical with it in character and composition.

The trap sheet east of the Mount Tom Range.

The bold hill east of Mount Tom and north of the Holyoke reservoir (Little Mountain) seems to be the site of the vent up through which the lava of the posterior sheet came. It is possible, however, that the hill is composed of a volcanic core of later date, thrust up through the Hampden sheet itself as well as through the sandstones. The outcrops, though abundant, do not quite settle the matter, but the weight of the evidence is strongly in favor of the first supposition.

Place of outflow of the Hampden sheet.

Starting at Smith Ferry, the Hampden sheet forms the crest of the ridge nearest the river for a long way south, and can be seen to rest upon the sandstones as a normal contemporaneous sheet. At Little Mountain it is suddenly prolonged downward as a great core, a third of a mile across, which sends out horizontal dikes into the sandstone to the west, south, and east, and overflows to form the trap sheet. The latter extends north and east, while the parts which formerly extended west and south have been eroded away. This core is represented on the surface by the sudden widening of the diabase sheet.

*See paper on diabase, pitchstone, and mud enclosures of the Triassic trap of New England, by the writer: Bull. Geol. Soc. Am., Vol. VIII, p. 59, 1897.

If the sandstones were removed from beneath, the trap would stand like a great toadstool, the core being its stem and the top being broken away on the west and south. If the portion of this top which extends in an easterly direction be followed a half mile southeast to the steep hill just north of Larrabee's quarry by the railroad, the sheet is seen to rest on the sandstone, which is baked. Just south, in the quarry, at a much lower level, the trap appears in mass beneath the sandstone and tuff. The sheet is covered by a tuff bed throughout its length from Smith Ferry, and the mass in the quarry lying beneath the same tuff is doubtless the same sheet. A fault of about 100 feet downthrow has caused the difference in level. This trap in the brook bed just north is amygdaloidal at its surface and the sandstone rests normally upon it, but in the quarry the sandstone rests upon an exceedingly irregular surface of the scoriaceous trap, and the sand was manifestly carried out over the still melted trap, since the two are kneaded together in a very irregular way. The sand extends down in long filaments and disconnected shreds into the trap for 1 or 2 feet, and small fragments of the trap are in other places included in the sandstone above. This sandstone shows abundantly the influence of the heated trap. It is very ferruginous, and is for a foot or two above the trap made up of small flattened concretions. All its fissures for several feet up are coated with broad sheets of the finest drusy specular iron, in coarse crystalline plates, and large cavities both in the trap and in the sandstone are filled with calcite in crystals of considerable size. The most remarkable mineral found here is anhydrite, which occurs in large, bluish-white, finely crystallized masses, coarsely foliated and slightly radiate, exactly resembling the Chesterfield cleavelandite. It is found in masses as large as one's fist inclosed in the trap a foot or two below its surface. It was formed by the action of sulphuric acid, derived from pyrite in the trap, upon calcite, which is found in the same cavities as the anhydrite.

Interesting minerals in the trap.

INTRUSIVE DIABASES.

Blackrock diabase.—Parallel with the Holyoke Range and about a mile southeast of it is a line of volcanic cores, rounded masses of various sizes filling probably the throats of ancient volcanoes removed by erosion. One of these plugs, north of Moody Corner, is a quartz-diabase. The others differ only slightly from the bedded traps. They are fresher and contain a little olivine. They baked the sandstones strongly and sent many dikes into the surrounding rocks. The larger of these masses resist erosion and stand out strongly as great domes. Black Rock, south of Mount Holyoke, is a type, and one well exposed for study. The core at the Burnt Mill, a mile north of Smith Ferry, is well dissected by the brook.

Cores of ancient volcanoes.

SURFICIAL ROCKS.

PLEISTOCENE.

EPOCH OF GLACIAL OCCUPATION.

Glacial striæ.—The area covered by this quadrangle being one-half high plateau and one-half lowland underlain by soft sandstone, and these two sections being separated by a very steep escarpment, while the low ground is bisected by the sharp trap ridge, the directions of ice movement, so far as they were controlled by topographic features, were very complicated and exceptional. The general direction was S. 35° E. over the highlands and south over the valley plain, but the striæ indicate that the ice was deflected more to the east down the main branch of the Westfield River, and that the direction was almost due east down the Westfield Little River and the brooks to the north and south of Granville and Russell. The movement was even a little north of east where deep gorges have that course. On the other hand, on the low flat valley bottom in Westfield opposite these gorges, and up the side of the Mount Tom Range, the striæ run southwest, and thus the ice at one time moved almost directly into the mouths of the gorges. This occurs in the Pochassic Hills, west of Westfield village, and north of the Westfield River. To the north the striæ have the normal southerly direction. This seems to be explained by the widening of the valley, which caused the valley lobe of the retreating ice to fan out here and move southwest on its western flank.

Direction of ice movement.

Glacial gorges and potholes.—The main trunk of the Westfield River seems to have been occupied by a body of water during and at the close of the Glacial epoch, and fine potholes have been left at Salmon Falls and below Russell. The gorge of the Westfield Little River is the wildest, most picturesque, and most inaccessible canyon in central Massachusetts, and here also potholes occur in great numbers and of the largest size.

Glacial deposits.—The coarse upland till or bowlder clay covers all the plateau. Over the valley bottom the till is also thick and continuous, and is for the most part made up of the débris of the red sandstone, but the ubiquitous bowlders of the Vermont Cambrian quartzite are found everywhere, and down to the south line of the State bowlders of the Belchertown tonalite occur, showing that the due-south movement of the ice in the valley was persistent and long continued. The upland area presents few points of special interest in respect to glacial accumulations.

Over Ashfield and Plainfield and the depressed area in Goshen the till is especially thick. A marked bowlder train of the porphyritic granite occurring in place near Middlefield, extends southeast across Chester, the rock being easily identified by its peculiar character. When first discovered the emery bed on top of Round Top was finely ice-polished. The main valleys all run with the former direction of the ice. They are overlarge for the present streams occupying them, but only narrow gravel flats border them. On Mores Brook above Searsville great delta-like accumulations of sand occur at several points where the valley widens suddenly, but these seem to have been formed rather by the dropping of its sand by the overloaded stream as it expanded in the widened valley than by ice obstruction forming a glacial lake.

A marked bowlder train.

All the settled portions of Amherst and Northampton are underlain by till, and the difficulties of drainage, wet cellars, and bad roads are largely due to this fact. The road north of College Hall in Amherst and in front of the Forbes Library in Northampton are illustrations. The till is a tough clay, often requiring blasting in deep digging, so compact that it will sometimes trim into specimens with conchoidal fracture like porphyry.

In the valley near either side the hardpan is molded into great trains of drumlins, which are wanting in the central portion. Castor and Pollux at South Amherst are fine typical specimens, as well as Sunset Hill and Round Hill in Northampton. Extensive layers of sand are found inclosed in the till, formed probably by sub-glacial streams, and, when frozen, blocks or even broad sheets of this sand were moved along with the rest of the material beneath the ice.

Linear arrangement of drumlins.

Such a layer extends 12 to 20 feet below the surface from the Agricultural College grounds in Amherst south beneath Prospect street to the Central Railroad cutting. It caused the unfailing wells of the region and the brook that ran formerly across the common. Amherst was formerly covered by great conglomerate bowlders from Mount Toby, and Northampton by granitic rocks from the north. Sunset Hill is still covered by them, except where cleared within the Asylum grounds.

In the south part of the district, except in Southampton, Holyoke, and West Springfield, the till or ground moraine of the ice is deeply buried beneath the post-glacial sands. A continuous series of large drumlins east of the main trap ridge runs across Holyoke and West Springfield, and farther south across Agawam the larger drumlins rise out of the sands in a few cases, as in Liswell Hill and Buck Hill.

Ice erosion.—The broad, deep, sand-filled depression in the sandstones extending west along the north foot of the Holyoke Range and continuing south along the western foot of the Mount Tom Range, is explained by the recoil of the ice as it rose over the Holyoke Range, and by the southward deflection of the ice as it impinged against the obstructing Mount Tom Range. In the same way a deep depression was caused in the sandstone at the west foot of the Deerfield Mountain, from Cheapside to South Deerfield.

The depression is shallower where the range at the south end of Mount Tom drops suddenly to a much lower level. This harmonizes with the explanation advanced as to the cause of the depression. The sandstones occur high on the slopes of White Top Mountain and form a low watershed between the Manhan and Westfield rivers.

The Deerfield trap ridge has protected Mount Toby and the Sugar Loafs from the ice attack. In the lee of the Holyoke-Mount Tom Range the sandstones are preserved 200 feet higher than to the west and north of the range, while between these ridges nearly all the sandstone has been removed in the latitude of Amherst.

EPOCH OF GLACIAL RETREAT.

Glacial lake deposits west of the Connecticut Valley.—The configuration of the upland west of the Connecticut is such that over most of the area the glacial melting was not attended by obstructed drainage, and the waters escaped eastwardly with freedom and have left few large deposits of post-glacial sands.

An exceptional deposit occurs in Granville south of the Westfield Little River. Flowing northward between Russell and Westfield this stream was dammed by the Connecticut Valley ice lobe, extending south across Westfield, while its upper drainage area was still occupied by the melting ice. The drainage off the ice in the Westfield River Valley may thus for a time have been directed southwestward up the lower reach of the Westfield Little River to the bend north of Granville. The waters then flowed southward from this great bend, east of Cobble Mountain past the site of Granville village, and into the valley of the east branch of Salmon Brook. They spread broad areas of sand at the base of Cobble and Sweetman mountains and all down the central part of Granville and into Granby. The Connecticut Valley ice lobe, which dammed the mouth of Little River, must also have rested against Sodom Mountain and dammed the gorge of Munn Brook, because the sands east of Granville spread to the upper entrance of the gorge of this brook, and look down unsupported upon the open valley several hundred feet below. Considering the great volume of sand and the southwestern direction of the lower part of the Little River gorge, it is probable that the glacial waters, deflected by the ice lobe which rested against Mount Tekoa, flowed up this portion of the gorge from the lower valley of the Westfield River. These broad, flat-topped sand flats have a fixed shore line against the rocks, but they are deeply trenched by brooks that run out from them north, east, and south, and their gathering is hardly explicable except on the assumption that all these outlets but one were closed by ice during the filling of the basin.

High glacial lake beds.

Lakes of the Connecticut Valley.—As a result of the melting of the glacial ice, the Connecticut

Basin in Massachusetts was occupied by three confluent lakes, whose extent within this quadrangle is shown in fig. 2. The northwest corner of the Springfield lake, between South Hadley and Springfield, extends into this quadrangle. The contrast in temperature north and south of the Holyoke Range was great, and the ice melted south of the mountain while it lingered north of it. Thus the Springfield lake was formed while the basin of the Hadley lake was still filled with ice. Waters flowed over the ice and through the notches, sweeping with them bodies of coarse sand, which were deposited in the northwestern part of the Springfield lake.

The Springfield lake.

The great sand bar that stretches from Titans Pier to the north of Bachelor Brook, east of the Connecticut, is composed of sands that must have come through the Holyoke notch and over the surface of the ice covering the region north of Mount Holyoke. The reason for believing that the sands came over the ice is because they commence in the notches at levels above that reached by the Connecticut lakes, and because the plains north and west of the range are underlain at low level by fine clays, showing that in the Hadley lake there was no current able to move coarse sands southward through the notch.

Extensive sand plains stretch west from the old mouth of the Chicopee River at Collins station and cover almost the whole area across Chicopee, Springfield, and Longmeadow. The great plain now sinks from about 260 feet above sea in South Hadley to 200 feet in Longmeadow and Agawam, and its sands grow finer in the same direction because the distance from the center of supply increases in this direction. The Westfield plain just west of the notch of the Westfield River in the trap range stands 70 to 80 feet higher than the Agawam plain just east, because it stands nearer its source of supply—the Westfield River—which entered the lake west of Westfield, and was therefore filled to a higher level; and because there was small transfer of sediment through the narrow notch in the trap ridge.

These great lakes received fine sediments as well as coarse, and clays were deposited over all the central portions while the deltas advanced from the shores. Growing into the lake the deltas covered the clays, and the later erosion by the river discloses buff sands underlain by clay which rests on till. These clays are at least 160 feet thick in Northampton. They are in layers two-fifths of an inch thick, the lower portion of the finest clay, grading into very fine sandy clay in the upper part. The lower portion was deposited when the lake was frozen over, in winter; the upper, during the floods from the melting ice, in summer. Beneath the till are the Juratrias sandstones. Thus the beds of thin-laminated clays, which are worked for brick from Chicopee to Greenfield and in the Westfield basin, have been exposed in the bluffs formed by the wear of the rivers in the edge of the old lake deposits.

Succession of clays and sands.

The slope of the lake beds across Springfield from Collin's bridge in the next quadrangle east down to the plains of Agawam is slight and gradual, and the surface is not divided by any scarp or marked slope. This indicates that the conditions of deposition were nearly uniform throughout the lake, and not, as in the Hadley lake, markedly different according to the material brought in by different streams.

The eastern shore bench of the Hadley lake lies along the flank of the Pelham Hills, just beyond the limits of the quadrangle.

The Hadley lake.

The shore line was at the level of the post-office steps in Amherst. The College grounds and the Prospect street ridge formed an L-shaped island in the lake.

The eastern bench enters the quadrangle with the plains around North Amherst, which are the delta of Cushmans Brook, which entered the lake near the upper Cushman mill. The great Florence plain, extending north into Hatfield and south into West Farms and Loudville and east to underlie all the settled portion of Northampton, is the delta of the Mill River. Its great size is due to the fact that it received the floods from the melting ice over the western hills, after the broad valley had become an open lake.

One must restore in imagination the sand worn away by the Mill River to form alluvial meadows, and think of the Florence plain continuous with the plain west of the deep river bottom. Looking west across the plain, the bowlder-covered shore hills rise suddenly from the sand level; looking east, the restored plain descends from 300 feet in Florence to 200 feet in Northampton, as it projected out into deeper waters. The material of this delta is yellow, sorted and stratified sands and gravels, coarser near the mouth of the incoming stream at Leeds, finer toward the border from Northampton to Loudville. Many bowlder-strewn islands rise above its level.

A great spur of land extends southeast from Mount Warner. It was once a long, curved bar, which sloped gently into the deeper waters of the lake. The conditions along the Bay road on the north slope of Mount Holyoke are peculiar. As the ice melted back from the Holyoke Range, temporary lakes formed and filled with sand at a high level. The shore bench of the lake was worn at a lower level into these sands, and they were partly removed and spread by undertow in a long northward slope into the deeper waters of the lake.

Because of the greater width of the Hadley lake in its central portion, and because the north, east, and south sides received no considerable tributaries, the lake basin was much less filled than the others.

The Southampton-Westfield Valley is occupied by a part of the south lobe of the Hadley lake, which is separated from the northern basin by islands of Juratrias sandstone. Sands brought into the lake by the Manhan River were spread at the highest water level and joined with the great delta of the Westfield River. Thus the broad Hampden plains were formed. In the most sheltered part of the basin the sands surround the large depression of Hampton Pond.

The Hampden and Poverty plains.

Imagine the sands restored to the old level in the area subsequently eroded by the Westfield River and a great plain formed by the union of the Hampden plain north of the river and the Poverty plain south of the same. The plain, if thus restored, would now slope gradually southward from 290 feet above sea level to about 280 feet in the latitude of The Notch, and then rise again southward where the delta sands of the Westfield River extended across to abut against Proven Mountain. The name "Poverty plain" is an expressive one for these extensive and desolate reaches of coarse sand.

The shore bench of the Hadley lake adjoins the low lake bottom by a steep scarp along delta fronts, and by a long, easy slope where deltas did not form, as along the north foot of the Holyoke and Mount Tom ranges, or around the drumlins.

FIG. 2.—THE CONFLUENT GLACIAL LAKES OF THE CONNECTICUT VALLEY.

A MAP OF THE HOLYOKE QUADRANGLE, SHOWING THE POSITION OF THE THREE GLACIAL LAKES WHICH OCCUPIED THE CONNECTICUT VALLEY DURING THE RETREAT OF THE ICE. THE TOPOGRAPHY OF THE LAND AREAS IS THAT OF THE PRESENT SURFACE, REPRESENTED IN CONTOURS OF 200-FOOT INTERVAL, REFERRED TO THE PRESENT SEA LEVEL AS A DATUM PLANE.

The stratified gravels, coarse near the mouth of the old streams, as at the head of the South Leverett plain, at Cushman's mills in North Amherst, and at Leeds, grow gradually finer away from the head of the delta, as across the Florence plain. In passing into the deeper and quieter waters of the lake the sand layers grade into the delicate sand films which part the clay layers.

The Hadley lake bottom.

With the rise of each spring flood a new layer of sand and gravel was carried across the delta flat, and the finest sand was spread in a thin layer far out across the lake bottom, dwindling in size of grain and thickness. In the winter the stagnating waters clarified themselves, and the layer of fat clay resulted. It is on the surface of these exceedingly thin sand layers that fossil leaves of *Viola palustria* L., *Vaccinium* like *oxycoccus* L., *V. uliginosum*, *Rhododendron lapponicum* Wahl., *Arctostaphylos alpina* Spr., *A. uva-ursi* Spr., *Oxyria digyna* Campd., *Salix cutleri* Tuck., and *Lycopodium selago* L., occur in the clays exposed along the river bank below Hadley, in the clay pits near the asylum in Northampton, at the Central Railroad station, and at the clay pits near Kellogg's plane factory in Amherst.

Oscillations of the ice front.—The advance and retreat of the glacial ice in the Connecticut Valley were not a single event. Between the first advance marked by the lowest till, and the final retreat occurred several episodes of retreat and advance of greater or less extent and duration. These events are recorded in alternating beds of till and sands, which may vary from place to place and are not often completely exposed.

In the long cutting of the Canal Railroad extension near the Camp Meeting grounds on the north line of Northampton, the interlocking of the till and sand deposits showed clearly that the ice after receding from this point in the valley twice readvanced over it. The section indicated that the flat-topped shore bench may elsewhere also have a structure of unexpected complexity. The peak of a fine drumlin was uncovered, and from its south end a great morainic talus of coarse bowlders extended, the drumlin having been molded beneath the ice and the moraine being made afterward of coarse, loose material as the ice withdrew. Above these a layer of pink beach sands, at times 12 to 15 feet thick, was spread. These sands were wholly unlike the rapidly gathered angular glacial sands, being perfectly rounded and sorted. This represented the first period of recession of the ice, which may have been of considerable duration. A fine layer of till 4 or 5 feet thick was carried over this sand, contorting and eroding it for a long way south of the drumlin, and this marks the first readvance of the ice.

Glacial details exposed near Northampton.

This was covered by heavy sands of the common high terrace type, 22 feet in thickness exposed, dipping southward 20 to 30 degrees in great sheets with strong cross bedding, and traceable south in unbroken exposure a quarter of a mile. Each great inclined sheet becomes horizontal and extends south, gradually thinning, and being continued as a film of sand between layers of fat clay, into which the sand grades.

This was covered by a layer of till, 8 feet thick, deposited by ice, which wore down so as to rest on the drumlin, and then rode out on the sands and clays, wrinkling them up into complex patterns, pressing its bowlders down into the sands, combing filaments of the sand up into the till, and producing by pressure a slaty cleavage in both the sands and clays, which was curiously brought out in the cutting when frozen by the etching of the wind and the sun. This third till was covered by a third series of coarse, cross-bedded sands of the common type, which had been planed down by the waters to the horizontal surface of the lake bench.

The last advance of the ice over the sands and clays was of wide extent. The clays are finely contorted a few rods west of the Hatfield Hotel, in Hatfield village. The fine sands show the most remarkable convolutions through 40 feet of thickness and for half a mile from north to south in the railroad cuttings whch extend from the south border of the Deerfield basin nearly to South Deerfield. Much farther south, a few rods east of the electric lighting building in Leeds, the till with a thickness of 20 feet rests upon the sands, which have a great but unknown thickness. The last of these cases seems to have been caused by an ice lobe coming down the Mill River gorge and pushing out into the open valley. The others, caused by a longer lobe coming down the Deerfield gorge, extended far south, to fill the whole deep valley from old Deerfield to South Deerfield and on into Northampton.

POST-GLACIAL EPOCH.

Alluvial terraces.—When the confluent lakes of the Connecticut Valley had been drained, the deposits of sand and clay accumulated in them were exposed to erosion by rains, brooks, and the Connecticut River. The Connecticut adopted a course along the lowest line of the lake bed, and cut into the soft deposits. Being in consequence loaded with sediment, it cut into its banks, first on one side and then on another, and thus meandered in increasing curves from side to side of the valley. In thus sweeping across the plain the river cut level benches, upon which its floods spread deposits of sand and silt.

Terraces of the Connecticut River.

The terrace sands are medium, buff sands, delicately cross-bedded by the fine variations of the current that spread them. A rich layer of loam or loess, often 8 feet thick, is spread over the surface of the completed meadow. It is the aggregate contribution of many floods, its bedding destroyed by wind, weather, and frost, and it forms the most fertile soil in Massachusetts. The river has swung far to the west, forming the broad Hatfield and Northampton meadows, and to the east building up the rich meadows of Sunderland and Hadley.

Above Holyoke the river quickly cut down to rock, and runs in a narrow rock-bordered channel. South of this it has built up the Willimansett meadow, swinging east to form the high, steep scarp that bounds the broad sand plain to the east, built by the lake. The Crowfoot Brook at the foot of this scarp is a good illustration of what is called below the repulsion of tributaries. In swinging westward from the foot of the scarp the river built the meadow up as a series of islands, and the tributaries found their way round the lower ends of these islands to join the river as far down stream as possible. The river then swung east to form the meadow south of Ashleyville, but was not able to go farther east because of rock near the bridge over Chicopee River.

The Willimansett meadow.

South of Brightwood the terrace system is broader, more complicated, and more interesting. The highest terrace made by the river on the east side follows the 100-foot contour line from Brightwood through the thickly settled parts of the city of Springfield, running just beneath the armory grounds and ending near the mouth of the Pecowsic Brook. When formed the terrace was bounded outwardly by a smoothly curved scarp, which is now cut back by many small notches caused by springs and more deeply indented by the depression in which the Boston and Albany Railroad reaches the plain and by the Mill River. Each of the three principal streets running parallel to the river, Chestnut, Main, and Water streets, occupies the flat of a terrace formed by the Connecticut; and Round Hill, north of the Memorial Church, is a remnant of the 100-foot terrace which the stream has not worn away. The most probable explanation of this hill is that the Connecticut formerly flowed east of it, and bent westward toward Riverdale on the north and toward West Springfield on the south, forming an oxbow around this hill and then cutting off the oxbow in the neighborhood of the upper bridge and running west of the island.

In order to understand the complex and beautiful system of terraces around Springfield, one must suppose the old lake bottom restored. The 200-foot plain east of Liswells Hill in Agawam was then continuous with the 200-foot plain north of Mittineague, and the whole was continuous eastward at the same level over all the low ground of Agawam and West Springfield with the 200-foot plains north, east, and south of Springfield. It was an unbroken area of the same coarse sands found in the remnants that are left, and underlain by the same clays that now crop out everywhere from beneath these sands. The Connecticut, on the disappearance of the lake, ran down over the lowest part of the plain, not very far perhaps from its present course. It swung east, lowering its bed meanwhile, to its most easterly limit. It then ran at the 120-foot level from Riverdale south to the headwaters of Threemile Brook, and then southeastward to its present bed opposite Longmeadow station. It swung east again, building up the plain at the 120-foot level. This, as the oldest plain of the series, has suffered most from later erosion, but is well preserved about the head waters of Threemile Brook. The Westfield River then entered the Connecticut just east of Mittineague.

Origin of the terraces around Springfield.

The stream then swung east until it formed the scarp east of Chestnut street from Brightwood to Pecowsic Brook, and swinging west again it formed the plain along the west edge of which this street runs and then deepened its channel to the 65-foot level to form the depression east of Round Hill. Then, as noted above, it seems to have swung westward on the north and south of Round Hill until the bends touched to the west of this hill and the stream transferred its bed suddenly to the west, leaving the hill an isolated portion of a plain at the 100-foot level of nearly the same age as the Chestnut street plain. At the time when the river flowed east of this hill, however, the plain of which its surface is a part stretched westward continuously, forming part of the plain on which Riverdale stands. The Connecticut, after forming this oxbow, moved west as far as Agawam village, and then bore east again to its present position, while the Westfield River lengthened eastwardly to keep in touch with the main stream, and swung north and south, carving its own terraces in the deposits formed by the Connecticut.

The southward course of Threemile Brook, as well as the peculiar course of the Westfield River below Mittineague, are cases of the repulsion of tributaries as described below.

A few rods north of the mouth of the Freshman River in the bank of the Connecticut south of Hadley, where a fresh exposure is maintained by the erosion of the river, two projections appear in the bank, marked by bluish-gray color in place of the buff of the sands. There are here exposed two cross sections of the old bed of the Freshman River, deeply covered by the valley loam, and they contain old leaf beds with many softened and flattened logs of wood. The following flora and fauna have been found there, which represent the climate of southern Canada:

The old bed of the Freshman River.

Ranunculus aquatilis L.	Quercus alba L.
Acer saccharinum Wang.	Quercus coccinea Wang. var. ambigua.
Prunus virginiana L.	Fagus ferruginea Ait.
Platanus occidentalis L.	Betula alba L.
Juglans cinerea L.	
Carya amara Nutt.	

Five species of Coleoptera have been found, of which four have been described as new by Mr. S. H. Scudder in Monograph XXIX, Geology of Old Hampshire County.

The repulsion of tributaries.—The very great suddenness of the lowering of the lake waters to form the present river is most clearly marked in the unfilled Hadley lake. The deep slopes of the delta scarps

Peculiarities of drainage in the Hadley lake area.

are quite intact down to the low clay flats, but a few feet above the modern terraces of the river and not notched by any terraces marking intermediate water stands. The streams along the whole eastern side of the lake from Mount Toby to the Holyoke notch run down across the old lake bottom in accordance with its slopes, but when they reach the edge of the scarp formed by the Connecticut River in its most easterly swing they bend south and take a course often for a long distance almost parallel to the Connecticut, as if repelled by the latter, and at last bend suddenly and enter the main stream at right angles. The reason for this is found in the mode of formation of the terrace flats of the Connecticut. As an island is formed across the mouth of a tributary by the receding river, the tributary lengthens downstream and occupies the groove between the island and the former bank, and when with the continued westward swing of the main stream another island is made outside of the first the stream flows still farther south between this and the bank. In this way the tributary is sometimes deflected several miles. This is especially true of the Long Plain Brook and the two brooks south, and of the Fort River. In the latter case the stream once ran much farther south than its present mouth, to the landing place of the Mount Holyoke steamer, and it was tapped at its present mouth by an eastward swing of the Connecticut. The meadow flats show in broad undulations the many islands by whose confluence they have been built.

Turners Falls and Holyoke Falls.

Contrast between the Montague and Springfield lakes and the Hadley lake.—As detailed above, the sandstones were worn down by the ice to a low level in the Hadley lake and, protected by the trap ridges, remain at a much higher level in the other two. As a result the latter are "filled-up" lakes, while all the deposits were insufficient to fill the deep depressions of the Hadley lake. As a second result the Connecticut, on the decline of the waters, was pushed to the extreme western border of the former lakes by deltas, but found a low-water line down the center of the Hadley lake. As a third result, on commencing to lower its bed by erosion, the stream quickly struck rock in the two lakes, forming the Turners Falls in the Montague lake, and the Holyoke Falls in the Springfield lake, while in the Hadley lake it flows over clays far above the rock bottom. This agency has located all the water powers in the district. As a last result, the oscillations of the Connecticut were quickly ended by striking rock in the two lakes, and therefore only narrow meadows were formed and the sands have been left intact, while in the Hadley lake the swing has been $3\frac{1}{2}$ miles to the east and 4 miles to the west, and the broad Northampton and Hatfield meadows have been formed on the west and the Hadley meadows on the east of the river. For this reason the terraces proper—that is the terraces formed by the swing of the river—are more extensive in Hadley lake than elsewhere, while the outward bounding scarp is lower and less impressive. The steep scarps west of Northfield street or east of Turners Falls in the Montague lake area, or the great scarp that bounds Crescent Hill in Springfield, are sharply contrasted with the low slope south of Bridge street in Northampton, or that halfway between Northampton and Amherst.

Oxbows.—The stream, swinging thus broadly in fine and perfectly homogeneous sediments, across the Hadley lake has been so nicely balanced that it has obeyed Ferrel's law that bodies in the northern hemisphere tend to be deflected to the right by the revolution of the earth. It has thrown out and cut off seven great oxbows to the right, and formed two great bends in the same direction. In the same way the Freshman River, flowing over the same plain, has formed five times as many oxbows on the right side as on the left.

Dunes.—Where the prevailing west wind strikes the scarp which forms the east border of the meadows, the sands have been carried east in a marked line of dunes which stretch from the Northampton road in Hadley north to Sunderland, and a similar line extends west of Hatfield.

MINERAL RESOURCES.

Granite building stone.

Granite.—The fine granite worked by the Chester Granite Company at Chester comes from Becket, in the next quadrangle west of this. The Pomeroy Mountain granite, along the east border of the plateau, is generally too coarse grained for a building stone. Much fairly good rock of light color can be obtained, and is quarried considerably in Williamsburg and Florence. It is all, however, too far from the railroad. In the western part of the quadrangle there is only one outcrop of granite. This is the great Middlefield dike. The rock is blotched with white spots from the feldspar, and so would not give an even color, and is of rather coarse grain. It would furnish large blocks and is probably a durable rock. The dark tonalite of Hatfield has been quarried to a considerable extent for bridge work, especially for the railroads. It will furnish fine large blocks of durable stone, which, if the lighter shades were chosen, might be used for darker trimmings in connection with the Florence stone. This rock is used in Northampton for macadamizing. The quarry is located where the rock is considerably decomposed, and it is a rather poor road material.

Flagstone.—The quarries around Goshen, situated in the Goshen schist, formerly furnished many flagstones, which were used in Northampton and the other large towns in the valley. Large slabs can be obtained, which consist of mica-schist, with the surface slightly roughened by small garnets and staurolites.

Whetstone.—The rock marked "Whetstone" on the map is a gray, crisp, and gritty schist, with scales of red biotite scattered evenly through the mass and not parallel to any common plane. It was a sandstone in which the biotite scales have crystallized. Only a small part of the whetstone will furnish good scythestones. The best quarries are at the southwest base of Walnut Hill in Huntington, and at B. Shaw's in Cummington. The quarries have been worked at intervals since 1830. The scythestones are sold as "Quinnebaug stones" and are highly prized.

Feldspar and mica.—A series of dikes of a very coarse granite forms the outer fringe around the great granite areas which occupy the eastern edge of the plateau and just enter the quadrangle on the east. This series runs up the middle of the quadrangle and furnishes the rare minerals for which the region is noted. Around Knightsville the region has been worked for feldspar, and several dikes along this range may furnish merchantable feldspar and mica. The dikes on the north line of Blandford above the Pontoosic Flint Mills have been much worked, and the quartz and feldspar crushed at the mills. The mica is abundant but not of the largest size.

Quartz.—The same coarse granite veins have been worked for quartz, which is extensively crushed at the Pontoosic Mills and the mill in Chester, and is sold for polishing, making sandpaper, filtering, use in the manufacture of explosives, etc. The quartz is now more frequently obtained from large veins of pure quartz, which accompany and are of the same origin as the granite. These are found of great size between the two roads running south from Chester Center and about a mile east of Round Top.

The Chester mine.

Emery.—The great emery-magnetite bed in Chester has been mined for many years, first for iron and since 1864 for emery. The bed runs 6 miles along the east of the hornblende-schist, with a thickness much of the way of 4 to 16 feet. The magnetite, which is separated from the emery, after crushing, by batteries of magnets, does not seem to be utilized. Much of the time the mine has been allowed to lie idle, and emery from Asia Minor and corundum from the Southern States have been used in the mill instead. Recently the old mine has been reopened and supplied with new machinery.

Chromite.—Many small openings have been made in the search for chromic iron in the serpentine in Middlefield, especially a mile north of the point where the east boundary line of the mass crosses the river, and in the serpentine, at the "crater" in the north part of Blandford. There is much disseminated ore in the latter serpentine, but no indication of any considerable concentration of the ore.

Serpentine.—Nearly all the serpentines in the quadrangle are black and hard. That at the "crater" in the north of Blandford is pale green, compact, takes a fine polish, and could be used for ornamental work. The dolomitic limestone, filled with black spots and bars of black serpentine, often in stellate arrangement, which is quarried by the Westfield Marble Company mentioned above, promises to be of great value as a unique and attractive stone for interior decoration.

The Loudville mine.

Lead and barite.—The mine at Loudville was opened before the Revolution, and was worked again in the second decade of this century. It was reopened during the Civil War by a new company, and a very expensive plant was brought together. The company soon failed, and the machinery was sold to the Chester Emery Company. The mine furnished galena with a good percentage of silver, zinc blende, and copper ores, the latter in small quantity in a gangue of quartz and barite. It is perhaps a greater object of interest to the mineralogist, because of the rare and interesting minerals it has furnished, than to the investor. The vein at Hatfield has been extensively worked by rude methods in a long line of deep pits. It is a barite-lead vein of the same character as the Loudville vein, but the barite is purer and more abundant, and it has been mined for this substance more than for the metals. The two veins in Leverett, which have been worked largely in the same rude way, are of the same kind as the others, but they are less promising.

Road material.

Trap.—The great ranges of trap that pass across this quadrangle will furnish in inexhaustible quantities the best road material, and it is hoped that the recent interest in better roads may create here an important industry. Springfield obtains stone for the city streets from a quarry in the main trap ridge, on the line between West Springfield and Westfield. It is only a question of transportation, and the four places where the railroads come nearest to the supply of good material are at the city quarry mentioned above, at Tatham station, where the Holyoke branch of the New York, New Haven and Hartford Railroad crosses the two trap sheets, and near the Connecticut River below Mount Tom station. At the last place the material could be conveniently quarried and shot down to the level of the railroad, and this would furnish the city of Northampton with a better material than the rock now in use. Crushing plants have recently been erected in Easthampton at the foot of Mount Tom, and on a very extensive scale by the New England Trap Rock Company in the north of West Springfield, where the Holyoke branch of the New York, New Haven and Hartford Railroad crosses the main trap ridge. The works have a capacity of 700 tons a day, and can deliver the rock at 75 cents a ton on the cars.

The Longmeadow building stone.

Sandstone.—The line of quarries extending down the eastern border of the quadrangle from Indian Orchard southward represents an important industry. The Juratrias sandstones quarried here are extensively used for the finest buildings under the name of Longmeadow brownstone. East Longmeadow has grown to be a considerable town under the stimulus of this industry. The State was reported sixth in the production of sandstone in 1889, with an output of $649,097, of which $563,179 came from Hampden County, and practically all from the quarries mentioned above. The Saulsbury and Kibbe quarries, near East Longmeadow, furnish the greater portion of the product, and with the Carlisle quarry, near Sixteen Acres, sell their stone at 50 to 70 cents per foot at the quarry. The massive beds suitable for quarrying are about 10 feet thick and are followed above and below by thinner-bedded sandstones. The whole dips 10 or 15 degrees a little south of east. The Juratrias rock is generally of too coarse grain for use as a building stone. A quarry was opened a few years ago in the north part of South Hadley, on a buff sandstone of good grain and color and firm texture, and the town hall in Easthampton was in part constructed of it; but the rock owed its firmness to the proximity of a great mass of intrusive trap, which had baked it somewhat, and the useful stone was soon all quarried.

White pipe clay from Blandford Center.

Clays.—Brick clays are so abundant upon this quadrangle that they have no value when they are situated away from the larger towns. All around Westfield and Greenfield basins and in the bluffs bordering the Connecticut River, the thin-bedded clays crop out in great force and are extensively worked, especially near Springfield and Chicopee Falls. At Amherst, Westfield, Easthampton, and Northampton are extensive brick kilns. The superincumbent sands are everywhere of a quality which renders them suitable to be used with the clay for brick making. An interesting deposit, apparently of considerable importance and value, has been opened at Blandford Center, a white pipe clay suitable for the finer kinds of brick and terra-cotta work. It seems to have been formed by the decomposition in pre-glacial times of the feldspar of one of the beds of very coarse and very feldspathic granite, like those worked for feldspar in the northern part of the town. It has been sheltered from the general erosion of the ice by the hills north of Blandford. An extensive plant has been built at Russell to work the clays. The product is of the first quality and has come into extensive use. The fine new high-school building in Northampton was constructed of the buff brick from this deposit.

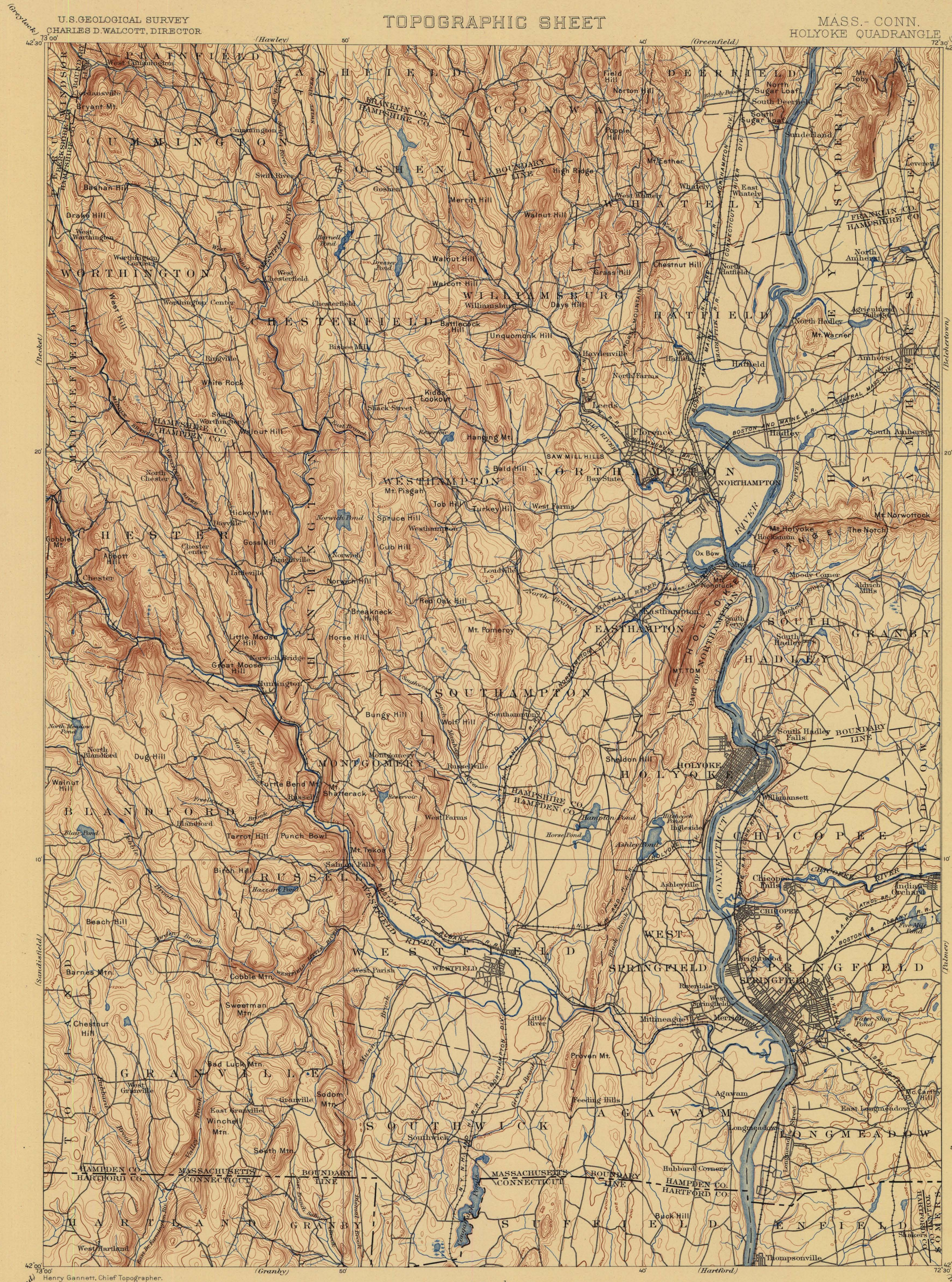
B. K. EMERSON,
Geologist.

May, 1897.

U.S.GEOLOGICAL SURVEY
CHARLES D.WALCOTT, DIRECTOR

TOPOGRAPHIC SHEET

MASS.- CONN.
HOLYOKE QUADRANGLE



LEGEND

RELIEF
(printed in brown)

Contours
(showing height above sea, horizontal form, and steepness of slope of the surface)

DRAINAGE
(printed in blue)

Rivers

Rivers and brooks

Intermittent streams

Canals

Ponds and reservoirs

Springs

Sinks

Marshes

CULTURE
(printed in black)

Cities and towns

Villages and roads

Railroads

Bridges

Ferries

State boundary lines

County boundary lines

Township boundary lines

Boundary lines and roads coincident

Names of adjoining published sheets are printed on the margin.

Henry Gannett, Chief Topographer.
Marcus Baker, Geographer in charge.
Triangulation by U.S.Coast and Geodetic Survey.
Topography by C.Arrick, C.C.Bassett, L.F.Cutter, A.Karl, and H.L.Smyth.
Surveyed in 1884-87.

Scale 1/125000

1 ½ 0 1 2 3 4 5 Miles

1 ½ 0 1 2 3 4 5 Kilometers

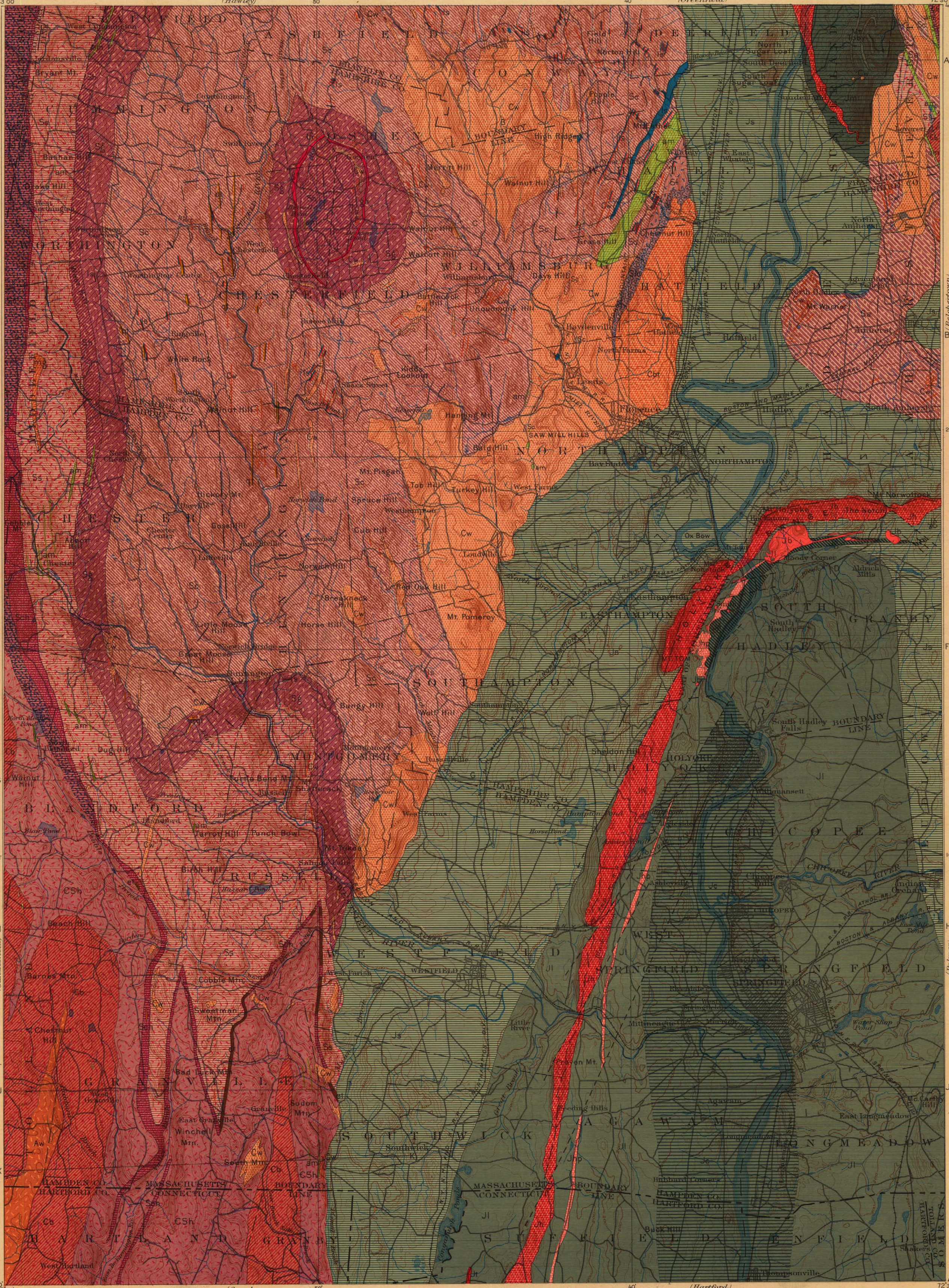
Contour Interval 40 feet.
Datum is mean Sea level.

Edition of July 1897.

U.S. GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

HISTORICAL GEOLOGY SHEET

MASS.-CONN.
HOLYOKE QUADRANGLE



LEGEND

SEDIMENTARY ROCKS

(Areas of Sedimentary rocks are shown by patterns of parallel lines. Metamorphism is indicated by short dashes combined with the parallel lines.)

JURATRIAS

- Jc — Chicopee shale *(black and red sandy shale)*
- Jl — Longmeadow sandstone *(reddish-brown sandstone with shore and shallow water markings)*
- Jg — Granby tuff *(coarse agglomerate of fragments of diabase, graduating into tufaceous sandstone)*
- Js — Sugarloaf arkose *(coarse felspathic sand stone, composed of the angular debris of granite,)*
- Jmt — Mt. Toby conglomerate *(very coarse conglomerate composed largely of slate fragments)*

SILURIAN

- Sl — Leyden argillite *(dark, coarse slate or fine-grained mica-schist)*
- Slc — Leyden argillite *(chiastolitic contact zone)*
- Sc — Conway schist *(dark, graphitic mica-schist with biotite, garnet, staurolite, and zoisite, and many beds of dark impure limestone and sandy quartzite)*
- Sa — Amherst schist *(coarse, fibrolitic and feldspathic schist, probably the equivalent of Conway schist)*
- Sg — Goshen schist *(dark, graphitic, flaggy mica-schist, with biotite and garnet)*
- Sh — Hawley schist *(sericite- and chlorite-schists with many beds of hornblende-schist)*
- Ss — Savoy schist *(sericite-schist with garnet and chlorite locally developed)*
- Sch — Chester amphibolite *(dark, flaggy hornblende-schist, in places changed to serpentine, and emery)*
- Sr — Rowe schist *(quartzose sericite-schist)*

- €Sh — Hoosac schist *(albitic sericite-schist)*

CAMBRIAN

- €b — Becket gneiss *(light-gray biotite-gneiss, at times a conglomerate; contains intrusive masses of saxonite altered to serpentine and asbestos)*

ALGONKIAN

- Aw — Washington gneiss *(dark, compact gneiss slightly fibrolitic)*

ROCK MASSES
(in various formations)

- ls — Limestone *(in Conway and Goshen schists)*
- qt — Quartzite *(in Conway and Goshen schists)*
- gn — Gneiss *(fine-grained biotite-gneiss in Goshen schist, possibly bedded granite)*
- am — Amphibolite *(in Conway, Hawley, Savoy, and Hoosac schists)*
- et — Enstatite rock, pyroxene rock, and dolomite *(in Chester amphibolite)*

Legend is continued on the left margin.

LEGEND
(continued)

IGNEOUS ROCKS

(Areas of Igneous rocks are shown by patterns of triangles and rhombs.)

JURATRIAS

- Jb — Blackrock diabase *(intrusive)*
- Jh — Holyoke diabase *(main sheet of Percival, interbedded)*
- Jt — Talcott diabase *(anterior sheet of Percival, interbedded)*
- Jhp — Hampden diabase *(posterior sheet of Percival, interbedded)*

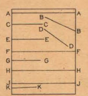
CARBONIFEROUS

- Cw — Williamsburg granite *(coarse muscovite-biotite-granite, with pegmatite and albitic granite veins)*
- Cbt — Belchertown tonalite *(granitoid quartz-plagioclase-hornblende-rock)*

- mg — Middlefield granitite *(porphyritic biotite-granite)*

Probable faults - - - - - -

Sections



Henry Gannett, Chief Topographer.
Marcus Baker, Geographer in charge.
Triangulation by U.S. Coast and Geodetic Survey.
Topography by C. Arriok, C.C. Bassett, L.F. Cutter, A. Karl, and H.L. Smyth.
Surveyed in 1884-87.

Scale $\frac{1}{125000}$

1 ½ 0 1 2 3 4 5 Miles

1 ½ 0 1 2 3 4 5 Kilometers

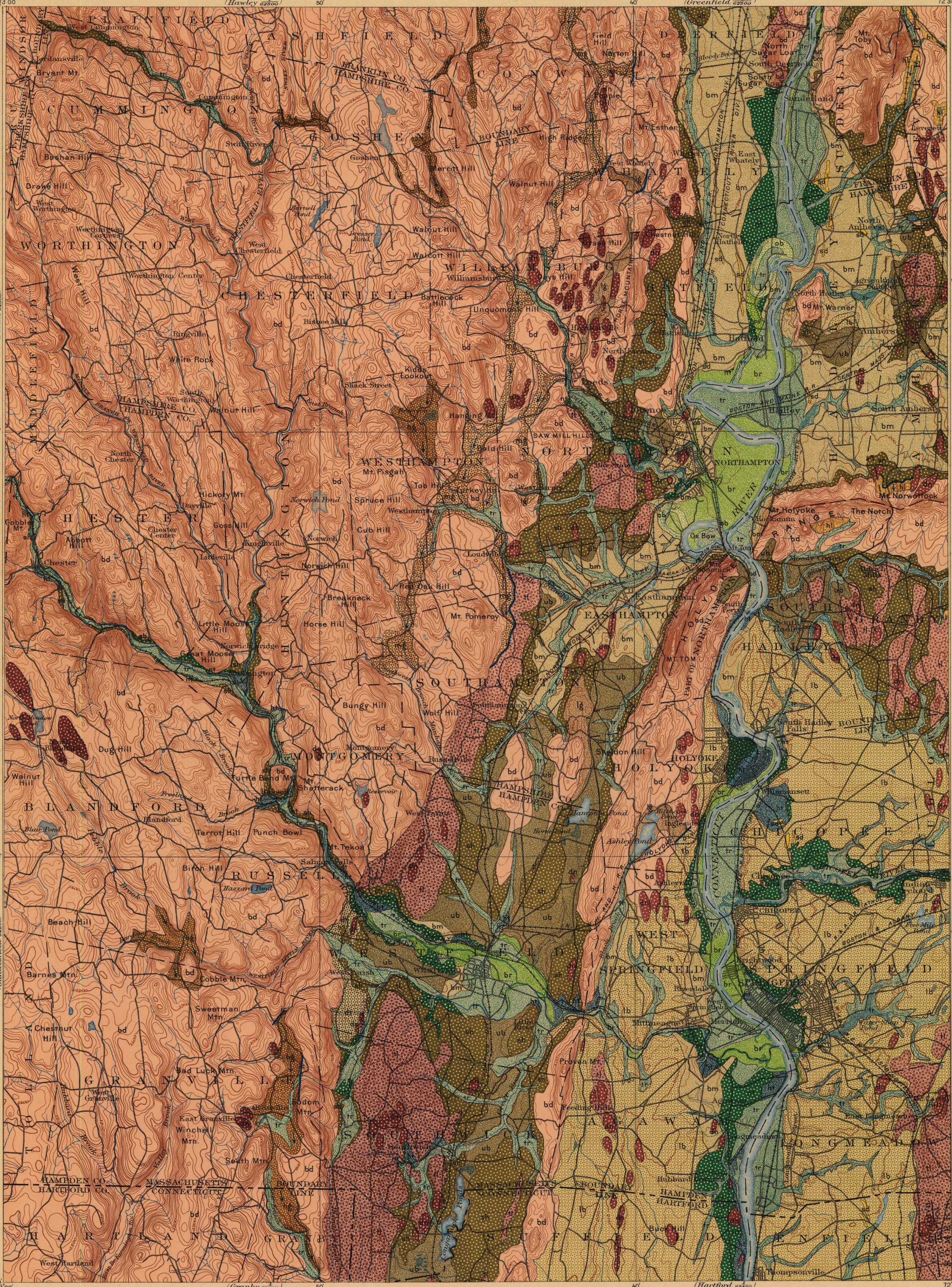
Contour Interval 40 feet.
Datum is mean Sea level.
Edition of July 1898.

Geology by B.K. Emerson.
Surveyed 1875—1896.

U.S. GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

SURFICIAL GEOLOGY SHEET

MASS.-CONN.
HOLYOKE QUADRANGLE



LEGEND

SURFICIAL ROCKS

(Areas of Surficial rocks are shown by patterns of dots and circles.)

POST-GLACIAL EPOCH

sd — Sand dunes *(wind blown sand derived from older deposits)*

Terraces of Erosion *(benches cut in older deposits and paved with sand by the receding waters of the Connecticut and its tributaries)*

br — Bars and incomplete terraces

ob — Old oxbows

os — Old stream beds

tr — Lowest complete terrace of the present level

ht — Higher terrace

nt — Highest normal terrace

EPOCH OF GLACIAL RETREAT

Terraces of Construction *(deposits of sand and clay in the confluent lakes of the Connecticut valley)*

bm — Lake bottom *(clay and fine sediment of the deeper portions of the lakes)*

lb — Lower bars and river flats *(sand at a lower level than the shore terrace)*

ub — Upper bars and river flats *(deposits on the sloping surface beyond the shore formation)*

sh — Lake shore beds *(normal high terrace)*

dt — High delta sands *(above the normal lake level)*

Glacial Lake and River Beds *(lakes and streams west of the Connecticut dammed by ice on the east)*

hg — Highest glacial lake beds

mg — Medial glacial lake beds

lg — Lowest glacial lake beds

(lakes and streams east of the Connecticut dammed by ice on the west or north)

hl — High lake deposits and moraine terrace *(kettleholed gravels)*

ic — Ice barriers *(showing the probable position of the ice front)*

Direction of glacial streams

EPOCH OF GLACIAL OCCUPATION

Glacial Deposits

tl — Till *(shown only in the valleys)*

dn — Drumlins

PLEISTOCENE

SEDIMENTARY AND IGNEOUS ROCKS

bd — Bed rock *(in greater part covered by till)*

PRE-PLEISTOCENE

Henry Gannett, Chief Topographer.
Marcus Baker, Geographer in charge.
Triangulation by U.S. Coast and Geodetic Survey.
Topography by C. Arrick, C.C. Bassett, L.F. Cutter, A. Karl, and H.L. Smyth.
Surveyed in 1884-87.

Scale $\frac{1}{125000}$

1 ½ 0 1 2 3 4 5 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 40 feet.

Datum is mean sea level.

Edition of Oct. 1898.

Geology by B.K. Emerson.
Surveyed in 1875-1896.

U.S. GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR.

ECONOMIC GEOLOGY SHEET

MASS.-CONN.
HOLYOKE QUADRANGLE

LEGEND

SEDIMENTARY ROCKS

(Areas of Sedimentary rocks are shown by patterns of parallel lines. Metamorphism is indicated by short dashes combined with the parallel lines.)

JURATRIAS

Jc — Chicopee shale *(black and red sandy shale)*

Jl — Longmeadow sandstone *(reddish-brown sandstone with shore and shallow water markings)*

Jg — Granby tuff *(coarse agglomerate of fragments of diabase, graduating into tufaceous sandstone)*

Js — Sugarloaf arkose *(coarse felspathic sandstone, composed of the angular debris of granite,*

Jmt — Mt. Toby conglomerate *(very coarse conglomerate composed largely of slate fragments)*

SILURIAN

Sl — Leyden argillite *(dark, coarse slate or fine-grained mica-schist)*

Slc — Leyden argillite *(chiastolitic contact zone)*

Sc — Conway schist *(dark, graphitic mica-schist with biotite, garnet, staurolite, and zoisite, and many beds of dark impure limestone and sandy quartzite)*

Sa — Amherst schist *(coarse, fibrolitic and feldspathic schist, probably the equivalent of Conway schist)*

Sg — Goshen schist *(dark, graphitic, flaggy mica-schist, with biotite and garnet)*

Sh — Hawley schist *(sericite-and chlorite-schists with many beds of hornblende-schist)*

Ss — Savoy schist *(sericite-schist with garnet and chlorite locally developed)*

Sch — Chester amphibolite *(dark, flaggy hornblende-schist, in places changed to serpentine, and emery)*

Sr — Rowe schist *(quartzose sericite-schist)*

CAMBRIAN

ЄSh — Hoosac schist *(albitic sericite-schist)*

Єb — Becket gneiss *(light-gray biotite-gneiss, at times a conglomerate; contains intrusive masses of saxonite altered to serpentine and asbestos)*

ALGONKIAN

Aw — Washington gneiss *(dark, compact gneiss slightly fibrolitic)*

ROCK MASSES
(in various formations)

ls — Limestone *(in Conway and Goshen schists)*

qt — Quartzite *(in Conway and Goshen schists)*

gn — Gneiss *(fine-grained biotite-gneiss in Goshen schist, possibly bedded granite)*

am — Amphibolite *(in Conway, Hawley, Savoy, and Hoosac schists)*

et — Enstatite rock, pyroxene rock, and dolomite *(in Chester amphibolite)*

Legend is continued on the left margin.

LEGEND
(continued)

IGNEOUS ROCKS

(Areas of Igneous rocks are shown by patterns of triangles and rhombs.)

JURATRIAS

Jb — Blackrock diabase *(intrusive)*

Jh — Holyoke diabase *(main sheet of Percival, interbedded)*

Jt — Talcott diabase *(anterior sheet of Percival, interbedded)*

Jhp — Hampden diabase *(posterior sheet of Percival, interbedded)*

CARBONIFEROUS

Cw — Williamsburg granite *(coarse muscovite-biotite-granite, with pegmatite and albitic granite veins)*

Cbt — Belchertown tonalite *(granitoid quartz-plagioclase-hornblende-rock)*

mg — Middlefield granitite *(porphyritic biotite-granite)*

Probable faults

Sections

A — A; B — B; C — C; D — D; E — E; F — F; G — G; H — H; J — J; K — K

Mines and quarries

- EM — Emery and magnetite
- SDS — Sandstone for building
- SER — Serpentine, verd-antique, etc.
- SPS — Soapstone
- SPM — Spodumene for lithia
- GR — Granite for building
- WHS — Whetstone
- LEAD — Barite and lead
- IRON — Chrome iron
- TRAP — Diabase for road ballast
- CLAY — Brick-clay
- KLN — Kaolin
- MF — Mica and feldspar
- FGS — Flagstone
- WELL — Artesian well
- X — Prospects

Known productive formations

Jl — Brownstone *(reddish-brown Longmeadow sandstone, used for building)*

EM — Emery and magnetite *(in Chester amphibolite)*

p — Soapstone and serpentine *(including black serpentine and verd-antique; occurs in Hoosac and Savoy schists and Chester amphibolite)*

Єb — Monumental granite *(Becket gneiss, used for architectural and monumental purposes)*

Cw Cbt — Building granite *(Williamsburg granite and Belchertown tonalite, used for work not requiring a high finish)*

Sg — Flagstones *(Goshen schist, used for flagging)*

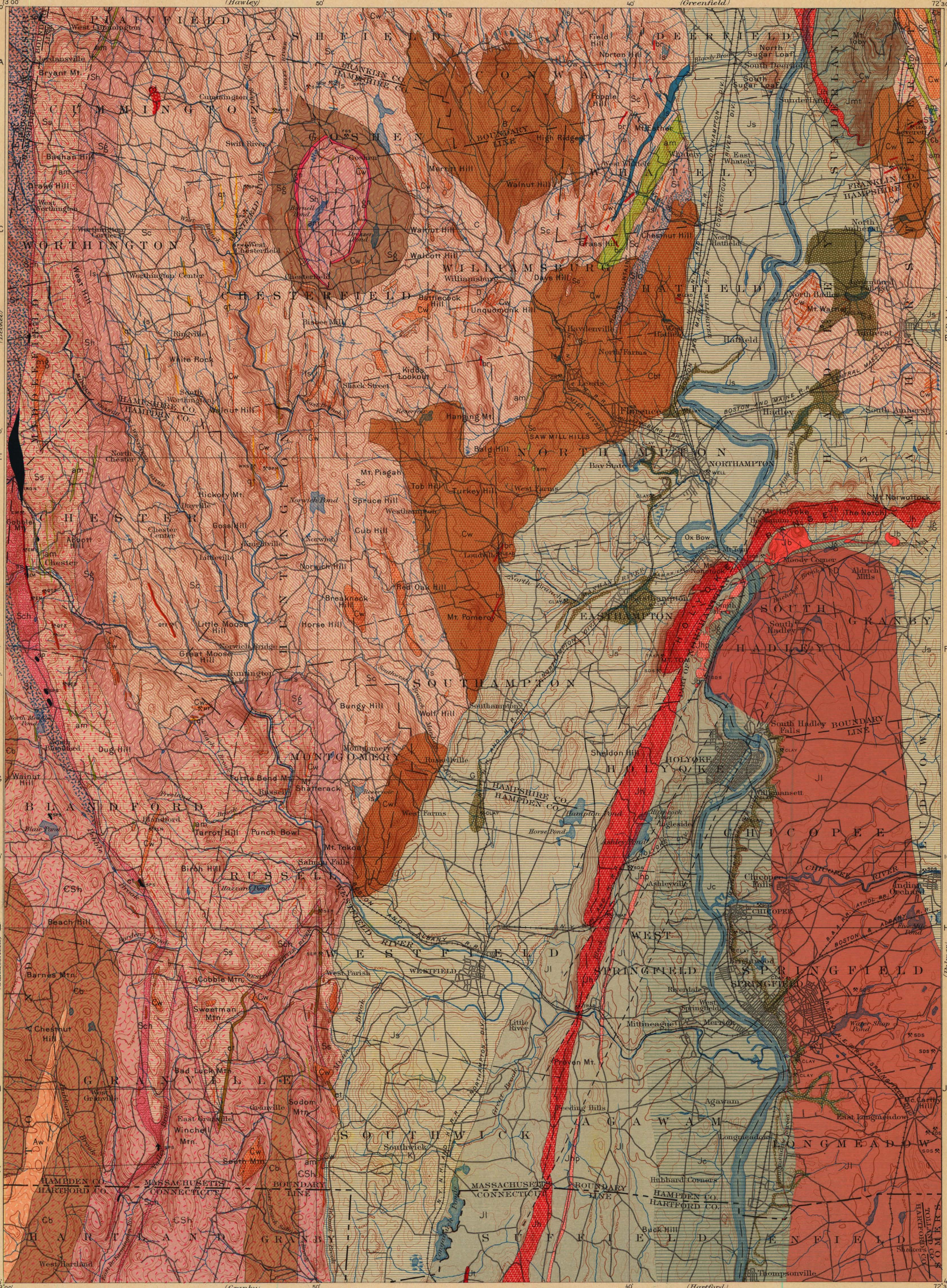
Road ballast *(diabase or trap-rock)*

Brick-clay *(clays of the Glacial epoch)*

br — Barite-galena veins *(lead)*

qtz — Quartz veins *(silica)*

rd — Rhodonite *(large bowlders in the surficial deposits, used for inlaid work)*



Henry Gannett, Chief Topographer.
Marcus Baker, Geographer in charge.
Triangulation by U.S. Coast and Geodetic Survey.
Topography by C. Arrick, C.C. Bassett, L.F. Cutter, A. Karl, and H.L. Smyth.
Surveyed in 1884-87.

Scale $\frac{1}{125000}$

1 ½ 0 1 2 3 4 5 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Contour Interval 40 feet.

Datum is mean Sea level.

Edition of July 1898.

Geology by B.K. Emerson.
Surveyed 1875—1896.

U.S.GEOLOGICAL SURVEY
CHARLES D.WALCOTT, DIRECTOR

STRUCTURE-SECTION SHEET

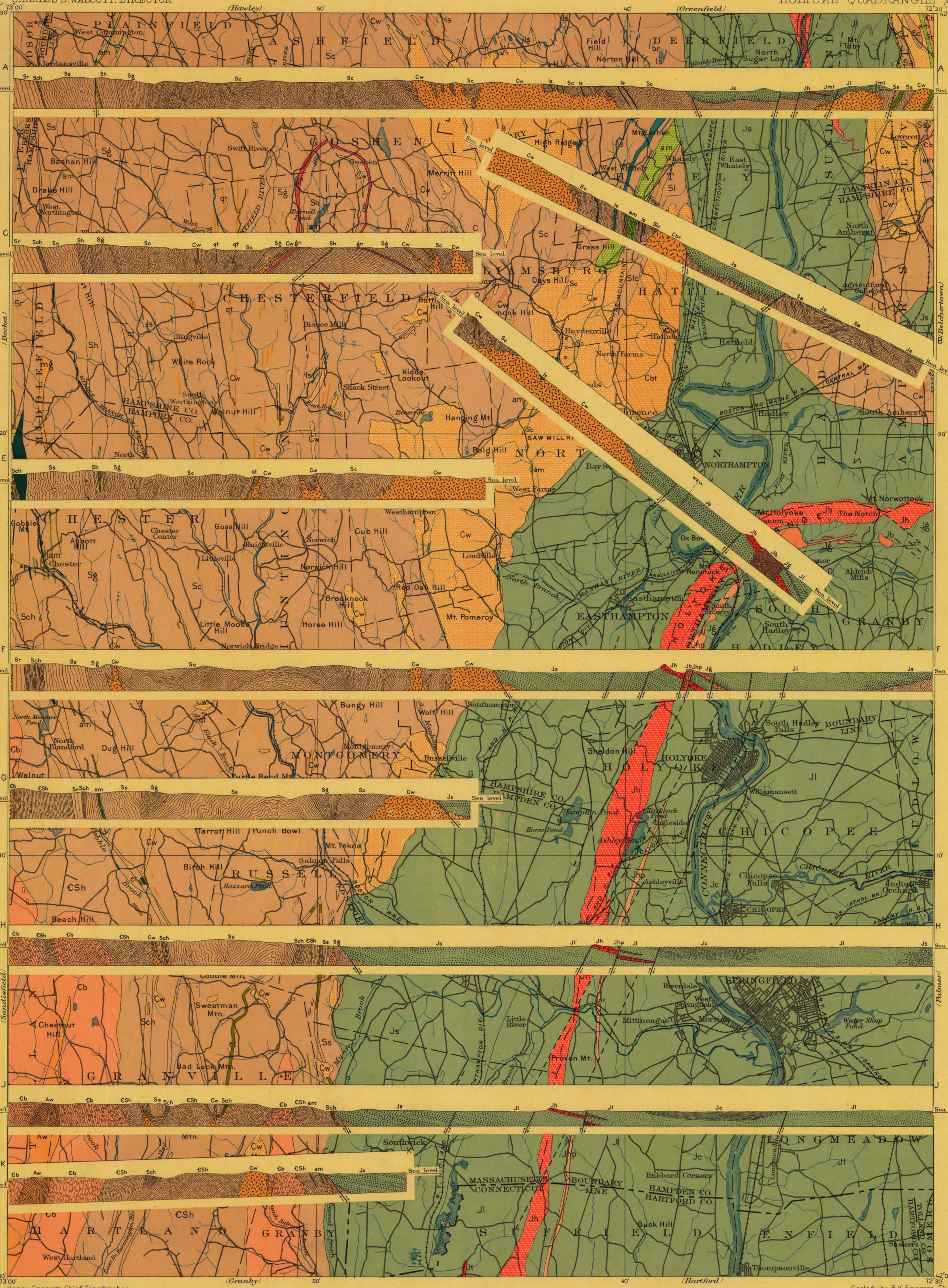
MASS.-CONN.
HOLYOKE QUADRANGLE

LEGEND
(continued)

IGNEOUS ROCKS

SHEET SYMBOL	SECTION SYMBOL			
Jb	Jb	Blackrock diabase	*(intrusive)*	JURATRIAS
Jh	Jh	Holyoke diabase	*(main sheet of Percival, interbedded)*	JURATRIAS
Jt		Talcott diabase	*(anterior sheet of Percival, interbedded)*	JURATRIAS
Jhp	Jhp	Hampden diabase	*(posterior sheet of Percival, interbedded)*	JURATRIAS
Cw	Cw	Williamsburg granite	*(coarse muscovite-biotite-granite, with pegmatite and albitic granite veins)*	CARBONIFEROUS
Cbt	Cbt	Belchertown tonalite	*(granitoid quartz-plagioclase-hornblende-rock)*	CARBONIFEROUS
mg		Middlefield granitite	*(porphyritic biotite granite)*	

Probable faults



Henry Gannett, Chief Topographer.
Marcus Baker, Geographer in charge.
Triangulation by U.S.Coast and Geodetic Survey.
Topography by C.Arrick, C.C.Bassett, L.F.Cutter, A.Karl, and H.L.Smyth.
Surveyed in 1884-87.

Scale $\frac{1}{125000}$

1 ½ 0 1 2 3 4 5 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Edition of July 1898.

Geology by B.K.Emerson.
Surveyed 1875—1896.

LEGEND

SEDIMENTARY ROCKS

SHEET SYMBOL	SECTION SYMBOL			
Jc	Jc	Chicopee shale	*(black and red sandy shale)*	JURATRIAS
Jl	Jl	Longmeadow sandstone	*(reddish-brown sandstone with shore and shallow water markings)*	JURATRIAS
Jg	Jg	Granby tuff	*(coarse agglomerate of fragments of diabase, graduating into tufaceous sandstone)*	JURATRIAS
Js	Js	Sugarloaf arkose	*(coarse felspathic sandstone, composed of the angular debris of granite)*	JURATRIAS
Jmt	Jmt	Mt. Toby conglomerate	*(very coarse conglomerate composed largely of slate fragments)*	JURATRIAS
Sl	Sl	Leyden argillite	*(dark, coarse slate or fine-grained mica-schist)*	SILURIAN
Slc	Slc	Leyden argillite	*(chiastolitic contact zone)*	SILURIAN
Sc	Sc	Conway schist	*(dark, graphitic mica-schist with biotite, garnet, staurolite, and zoisite, and many beds of dark impure limestone and sandy quartzite)*	SILURIAN
Sa	Sa	Amherst schist	*(coarse, fibrolitic and feldspathic schist, probably the equivalent of Conway schist)*	SILURIAN
Sg	Sg	Goshen schist	*(dark, graphitic, flaggy mica-schist, with biotite and garnet)*	SILURIAN
Sh	Sh	Hawley schist	*(sericite- and chlorite-schists with many beds of hornblende-schist)*	SILURIAN
Ss	Ss	Savoy schist	*(sericite-schist with garnet and chlorite locally developed)*	SILURIAN
Sch	Sch	Chester amphibolite	*(dark, flaggy hornblende-schist, in places changed to serpentine, and emery)*	SILURIAN
Sr	Sr	Rowe schist	*(quartzose sericite-schist)*	SILURIAN
ЄSh	ЄSh	Hoosac schist	*(albitic sericite-schist)*	CAMBRIAN
Єb	Єb	Becket gneiss	*(light-gray biotite-gneiss, at times a conglomerate; contains intrusive masses of saxonite altered to serpentine and asbestos)*	CAMBRIAN
Aw	Aw	Washington gneiss	*(dark, compact gneiss slightly fibrolitic)*	ALGONKIAN

ROCK MASSES
(in various formations)

SHEET SYMBOL	SECTION SYMBOL		
ls	ls	Limestone	*(in Conway and Goshen schists)*
qt	qt	Quartzite	*(in Conway and Goshen schists)*
gn	gn	Gneiss	*(fine-grained biotite-gneiss in Goshen schist, possibly bedded granite)*
am	am	Amphibolite	*(in Conway, Hawley, Savoy, and Hoosac schists)*
et	et	Enstatite rock, pyroxene rock, and dolomite	*(in Chester amphibolite)*

Legend is continued on the left margin.