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GEOLOGY
OF THE
QUICKSILVER DEPOSITS
OF THE
PACIFIC SLOPE

WITH AN ATLAS

BY
GEORGE F. BECKER



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CHAPTER XI.

DESCRIPTIVE GEOLOGY OF THE STEAMBOAT SPRINGS DISTRICT.

[Atlas Sheet XIV.]

Character of the district.—Steamboat Springs lies between the Sierra Nevada and the Virginia Range, at the western edge of the Great Basin. The forests and snows of the great Sierra are in sight a few miles away, but in the neighborhood of the springs only sage brush grows without irrigation. The soil in the lowlands, however, is fertile, and sufficient water is available to bring a considerable surface under cultivation. The hills are for the most part bare rock, as geologists love to see them. Many of the exposures are whitened or reddened by solfataric action, and on cool days tall columns of steam rise from the numerous hot springs, giving the locality a weird appearance. Steamboat Springs is only six miles from the Comstock lode and lies at the northwest base of Mt. Davidson, on the eastern flank of which is the great silver vein. The intervening space is for the most part covered with lavas, one of the sheets of which seems to be continuous for the entire distance. All the rocks which occur at Steamboat are also found in the immediate neighborhood of the Comstock, and the fissures of the two localities are approximately parallel cracks, with many points of resemblance. Steamboat affords fine opportunities for the investigation of massive rocks, and the occurrences here serve to throw much additional light on the rocks of the Washoe district, described by me in Vol. III of this series. The proximity of the areas permitted me to make direct comparisons during the present investigation. The spring

deposits also have long been known to be of extraordinary interest, because they contain metallic compounds, including cinnabar and gold. So much cinnabar is found here in areas still emitting steam and sulphur gases that mining operations were undertaken some years since and a furnace was run for a time on the ore. That quicksilver was produced is certain, though I was unable to ascertain how many flasks. A considerable amount of ore is in sight, and there is no apparent reason to doubt that were the price of the metal to rise to a dollar a pound the deposit might be worked at some profit.

Here, if anywhere, the question of the mode of genesis of cinnabar deposits can be settled, and the study of the locality was undertaken on that account. The results of this study and of laboratory experiments suggested by it appear in this and succeeding chapters.

Granite.—The lithological character of the massive rocks of Steamboat has been described in Chapter IV, and the details do not require repetition here excepting in reference to the distribution of the rocks and their relations to field habit. The granite, which is exposed to a large extent, manifestly underlies the whole region. In external appearance it is thoroughly typical, and no geologist would doubt for a moment how to classify it. It is unstratified, much fissured, weathers irregularly, and sometimes crumbles to a coarse gravel, as granites often do. Some of it is coarse, and it displays considerable irregularities in texture and mineralogical composition, as if it had never been thoroughly fluid. Plagioclase is occasionally visible with the naked eye, but the predominant feldspar seems to be orthoclase. Under the microscope this granite appears less typical, inasmuch as the quantity of triclinic feldspar seems in the slides unusually large, and one might well doubt whether to class some of the rock as orthoclastic or plagioclastic. This is one of the cases in which the appearance is less truthful under the microscope than to the unaided vision, and this is doubtless due to the fact that the plagioclase is recognized by positive characters between crossed nicols, while the presence of orthoclase is evinced chiefly by the absence of polysynthetic structure. Separation by specific gravity shows that the more plagioclastic specimens of the rock contain about as much orthoclase as plagioclase. The granite of Steamboat Springs is substan-

tially similar to that which appears near the southern end of the Comstock Lode. The superficial exposure there is very small, but the rock extends into the workings of the mines at American Flat. Similar granite is found near Washoe Lake, some miles south of Steamboat, and large exposures of it exist between these points and Lake Tahoe, in the Sierra.

The granite is intersected by distinct dikes of granite porphyry. So far as observed these dikes do not penetrate the sedimentary rocks and are probably older than the beds.

The metamorphic series.—Upon the granite lies a considerable area of sediments, which are in part very highly metamorphosed and in part but little altered. These beds are usually nearly vertical and strike with the trend of the Sierra. Attempts to make two series of them failed and only resulted in showing that the metamorphism was partial and irregular. The highly altered portions considerably resemble Archæan schists, but the partial character of the metamorphism seems to forbid their reference to a Pre-Cambrian age. They are certainly Pre-Tertiary, for there are Tertiary strata within a few miles both to the north and to the south which are far less disturbed and not at all metamorphosed. The only other sedimentary rocks known to exist near the eastern edge of the Great Basin in this latitude are those determined to be Jura-Trias by the paleontologists who discussed the fossils collected by the geologists of the Geological Exploration of the Fortieth Parallel. Dr. White, on reviewing the evidence on which the assignment was made, thinks it insufficient to justify any conclusion more definite than that the beds in question are Mesozoic. The descriptions of these Mesozoic rocks accord very well with the strata found at Steamboat. Their metamorphism is perhaps an evidence that they are not younger than the Neocomian, for no more recent alteration of any such intensity is known to have taken place later than the Post-Neocomian upheaval so often referred to in this volume. The upheaval is the same as that called the Post-Jurassic by Professor Whitney, and its existence was no doubt given due weight by the geologists of the fortieth parallel when they referred the Mesozoic beds of Nevada to the Jura-Trias. As this region is separated from the gold belt by a great range of mountains, however, it is not impossible that its metamorphism may have been subsequent to and independent

of that of California, though no known fact lends this supposition probability. A prolonged, but wholly unsuccessful search was made for fossils, which are also very rare in the other Mesozoic rocks of Nevada.

A portion of these rocks are conglomerates. Among the pebbles of these conglomerates are some of diabase, identical with the porphyritic diabase which forms the hanging wall of the Comstock lode. There can be little doubt that these pebbles formed a portion of masses which were erupted simultaneously with that at Virginia, and it is possible that they came from that very mass, though this is not certain. I did not succeed in finding pebbles of the still older diorite of Mt. Davidson, which may perhaps have been buried under the diabase at the time when the conglomerates were laid down. The bearings of the occurrence of diabase pebbles at Steamboat on the geology of Washoe I have enlarged upon in another publication.¹

Earlier hornblende-andesite.—The oldest of the lavas of the district is hornblende-andesite. It overlies the metamorphic beds in part and is distinctly more recent than the date of their upheaval. All this lava is very compact and of a bluish tint, but it is divisible into three varieties: one extremely fine-grained and often of a slaty texture; one a comparatively coarse-grained, porphyritic rock; the last glassy. Of these the first is most common. It is also found near the Ophir grade at Virginia, and the two occurrences are indistinguishably similar. The coarse-grained, somewhat grayish porphyry is best represented at Steamboat, near the eastern edge of the map. At Virginia this modification is perhaps the commonest. The glassy variety, associated with the others, is found at the western edge of the map of Steamboat Springs. In this area there also occurs a very small amount of a pyroxenic andesite which, after careful study, seems to me to represent a strictly local variation in mineralogical composition and to pass over into the hornblende rock by transitions. The fact that this andesite overlies the metamorphics seems to indicate that it is later than the early Cretaceous. The existence of glassy modifications forming a portion of the areas is evidence that it is much later than the Cretaceous. Indeed it is hard to understand how the glass can have failed to be removed if this andesite is older than the Pliocene.

¹ The Washoe rocks: Bull. California Acad. Sci. No. 6, vol. 2, 1887, p. 93.

Later andesites.—More recent than the hornblende-andesites described above are other andesitic rocks. These are divisible mineralogically into three varieties, and are so laid down upon the map. They appear, however, to have been ejected almost simultaneously. They are all so recent that extremely little erosion has taken place and only a few depressions are marked by water-courses. The difference in this respect between the areas of later andesites and the metamorphic areas is readily seen from the map where the amount of sculpturing corresponds to the geological colors.

All the later andesites are rough, soft rocks, in which the feldspars are much cracked. Some of them are laminated, the beds averaging perhaps an inch and a half in thickness, and this modification is physically indistinguishable from similar occurrences at Clear Lake. One variety of these rocks is highly pyroxenic; a second is hornblendic, though not free from pyroxene, and sometimes contains mica, while often lacking this constituent. Between the pyroxenic and hornblendic rocks are transitions of the most unmistakable kind, which I have designated by a separate color and have entitled for the purposes of this one map "transition andesite." In these areas the composition of the rock is curiously variable. Thus, in a little triangular patch nearly south of the mines and embracing considerably less than two acres, specimens can be collected which in the office might well be supposed to represent three distinct species: one a pyroxene-andesite, one a simple hornblende-andesite without mica, and the third a micaceous hornblende-andesite. But the whole area is thoroughly exposed and certainly represents only a simple eruption. The different varieties of rock were found here and elsewhere within a few inches of one another on the same blocks of lava. Such occurrences show how hopeless is the attempt to reconstruct the geology of an eruptive district from collections alone.

The area colored as later hornblende-andesite is covered with rock almost indistinguishable from the later hornblende-andesite near the Comstock; indeed, a very large proportion of the region intervening between the two districts is occupied by this rock and the lava field seems to be continuous from the northern end of the Comstock area to the eastern edge of the Steamboat Springs map. In both neighborhoods the quantity of mica is variable, but near Steamboat it is exceedingly capricious. Mica is

sometimes present in most unusual quantities, forming a large percentage of the entire mass, and such flows appear to have been the latest of all. Elsewhere the rock is scantily supplied with mica and over considerable areas the most diligent search failed to reveal a single flake.

The non-micaceous portions of the later hornblende-andesites are distinguishable from the pyroxene-andesite only by the relative abundance of the bisilicates, texture and habitus being identical and both of them trachytic. The hornblendic and the pyroxenic modifications of this rock are in contact at the eastern portion of the map. Neither is eroded to any considerable extent, though both areas are more or less covered with loose fragments. I was unable to make sure whether the eruptions had been actually simultaneous or not. On the whole, the pyroxenic rock seemed a little earlier than the hornblendic lava. On comparing the occurrences here with those at Virginia I found that transitions occurred at the latter locality also, which I had overlooked when I mapped the geology of that region. The transition rocks in the Washoe district occur along the ridge of which Mt. Kate forms a part and near that peak, and are present in small quantities only.¹ At Virginia the pyroxenic portion of the later andesites is older than that which carries mica. On the other hand, Mr. Lindgren found near Mono Lake flows of pyroxenic andesites, entirely similar to that of Steamboat, overlying micaceous, hornblendic andesites. The order of succession is thus not a fixed one. At Steamboat the two are very nearly and perhaps absolutely contemporaneous. Both of them are later than the earlier dense hornblende-andesite and have overflowed it. The area of the older andesites at the east of the map is also intersected by dikes of the later rocks. These dikes are in part micaceous and in part free from mica. Those portions of them which carry no mica are sometimes highly charged with hornblende and sometimes carry comparatively large quantities of pyroxene.

¹ The occurrence of these transitions shows that the pyroxene-andesite of the Mt. Kate Range immediately preceded the later hornblende-andesite adjoining it. The pyroxene-andesite of the Washoe district (laid down on the map as augite-andesite) is divisible into two eruptions, one much older than the other, though without any intervening outburst. The Washoe district contains three pyroxenic rocks of different ages: diabase, which was followed by a hornblende-andesite, and two successive outflows of pyroxene-andesite, both later than this earlier hornblende-andesite. The pyroxene-andesites were again followed by later hornblende-andesite. Dr. Whitman Cross pointed out the prevalence of hypersthene in andesite after my discussion of the lithology of Washoe was completed. Compare my paper, "Washoe rocks," cited above.

They are all of the trachytic type. Similar rocks occur abundantly in the surrounding region. Special mention may be made of the Hufaker Butte, which is an isolated volcanic mass about four miles north of Steamboat, in the valley. This seems clearly to represent a single eruption or a series of eruptions embraced within a short interval of time. The rock is all trachytic, in part highly micaceous and in part free from mica.

While it is quite possible to distinguish varieties among these later andesites, they pass over into one another in such a manner as to indicate that they form a natural group. The distinctions are, at least near Steamboat Springs, of little geological importance. As is pointed out in Chapter IV, similar rocks occur at Mt. Shasta and from Clear Lake to the Bay of San Francisco, but those of the latter area are remarkable because they usually contain mica and pyroxene, but no hornblende. All these andesites seem to be more recent than the close of the Pliocene and all have a similar physical character. Some contain pyroxene with a very little hornblende; some, pyroxene and mica, but no hornblende; some, hornblende with a little pyroxene and no mica; some, much mica, a little hornblende, and a trace of pyroxene. Every possible combination of these ferromagnesian silicates excepting those altogether excluding pyroxene is represented; there is no known difference in mode of occurrence and the order of succession is variable. This group of rocks is the same which, before the reference of lavas to the microscope became habitual, were regarded as trachytes. The name is indefensible, for the rocks are plagioclastic; but the thing to which it was given is a geological entity. I have therefore proposed for this natural group of rocks the name *asperites*, which is etymologically an equivalent of trachyte, but of Latin origin.

Basalt.—The basalt of Steamboat is in no respect remarkable. Though it covers a considerable area, the amount of the rock is by no means great, for it is evident from some exposures that the sheet is only a few yards in thickness. Doubtless, however, the depth of the lava is variable. Basaltic breccias form a portion of the mass. The basalt eruption antedates the deposition of ore, at least in part; for where it adjoins the mine it is solfatarically decomposed and cinnabar has been deposited in crevices in the lava. The spring deposits, including the cinnabar, have formed close to

the edge of the basalt, and I can see no reason to doubt that they result from the volcanic action of which the lava eruption was one manifestation.

The springs.—The present vents of the springs lie along a series of fissures about a mile in length, shown on the map nearly parallel to the railroad. These cracks have formed in a mass of sinter deposited from earlier vents and are in part choked up by detritus, in part covered by recent deposits, but they are nevertheless traceable for long distances. The vents in many cases retain their fissure character and the water may be seen and heard boiling in openings, evidently of great depth, from an inch to two feet in width and many yards in length. At other points the cracks are closed, with the exception of pipe-like openings, through which the water reaches the surface. At vents of the latter class there often form smooth mounds of sinter, from the summit of which the water escapes continuously or fitfully. Some of the springs have a true geyser character, though on a very small scale, alternately disappearing from their basins and returning to them with noise and agitation at short intervals of time. It is said by the inhabitants that in some seasons the water returns to certain of the basins with sufficient violence to be thrown several feet into the air, but during my visits the maximum action did not exceed a plentiful overflow.

It is very clear that these springs are short-lived. In the most active area they are to be found in every approach to extinction. Some have completely covered their own vents with sinter, though when the crust is broken hot water is still found below, while other mounds and cracks are completely cold. Some very active vents are also manifestly extremely recent and have only lately begun to form new deposits. The extinction and subsequent formation of springs has certainly been in progress for a long time and the accumulation of sinter is large. The upper line of vents is about one hundred feet above the railroad, which runs along the base of the mass of sinter. The ground beneath the sinter, however, evidently slopes outward from the hills, and the maximum thickness of the deposits is probably about fifty feet. Active springs formerly existed at many other points. The map extends eastward to the foot of the Virginia Range. The rocks of this range a little farther eastward are greatly decomposed, apparently by solfataric action. There is also on the map east of the railroad one

small area of sinter in which there is now no evidence of activity. Much of the main area of sinter is likewise cold and dry, but some three thousand feet due west of the active group of fissures is a second group, now nearly extinct, of which only one is shown on the map. From this small quantities of steam and other gases still escape at a few points. At the mine only small quantities of sinter exist and the fissures are not superficially defined as in the areas just mentioned, though it is clear that the lines of vent extended in a direction nearly north and south. In some of the excavations the ground is moist and still hot enough to be painful to the touch. Gases, too, still escape, but no water flows. The entire area of sinter and decomposed granite north and west of the basalt area is continuous and manifestly has a common origin. There can of course be no question that the thermal action of this locality is volcanic. The area of thermal activity is at the foot of a stream of comparatively recent basalt, which was the last rock ejected. The relations thus point very clearly to an immediate connection between the basalt eruption and hot springs.

In discussing the solfatarism of the Washoe district I inferred that it was probably of later date than the eruption of later hornblende-andesite, while of its time-relations to the basalt eruption there was no means of judging.¹ I was not then aware of the evidence that the activity at Steamboat was directly referable to the eruption of basalt. The thermal action on the Comstock has advanced somewhat further towards extinction than that at Steamboat; for, while the water on the 3,000-foot level of the Comstock is charged with carbonic and sulphydric acids and has a temperature of 76.7° C., most of the vents at the surface at Steamboat show still higher temperatures and the water at a distance of half a mile below must be greatly superheated. Nevertheless the thermal action in each of the districts must be of approximately the same age, as are also the basalt eruptions of the two areas; and the fact that the origin of the spring in the one case is directly traceable to the eruption of basalt makes it extremely probable that in the other also the basalt eruption gave rise to the thermal activity. The relations of the lava to the springs at Steamboat are strikingly

¹ Geology of the Comstock Lode, p. 207.

similar to those studied by Dr. Hector near Lake Omapere, in New Zealand, where, too, the sinter contains cinnabar. (See page 50.)

Diversities.—The effects produced by the action of the heated waters and of the gases accompanying them in the various portions of the affected area differ very materially and in an interesting manner. The heavy masses of sinter near the railroad are to a considerable extent composed of carbonates and all effervesce with acids. Much of the mass is silica, however, in part crystalline and in part amorphous. The material is deposited in layers or bands, partly lining crevices and partly covering the adjacent country in more or less nearly horizontal sheets. The linings of the crevices have a ribbon structure precisely such as is found in veins and composed of substantially the materials most common in veins, excepting indeed the hydrated silica. In the northwestern part of the area carbonates occur only in small quantities. The deposits here are for the most part chalcedony, which also exhibits ribbon structure. In the neighborhood of the mine workings only small quantities of silica and carbonates have been deposited. Here, indeed, the quantity of material removed by the spring waters is greatly in excess of the deposits which they have formed. In the southern part of the ground, where mining has been carried on, an actual basin has been formed, with a low rim to the north, which, however, is not sufficiently high to be exhibited by the 20-foot contour lines. This basin, from which there is no drainage, is not artificial, and appears beyond question to have formed in consequence of the collapse of the decomposed granite, yet it contains not only cinnabar, but a thin layer of sinter composed of carbonates and silica

There is no reason to suppose that the general character of the fluids and gases which have been active in the various portions of this area differed qualitatively; on the contrary, the entire character of the deposits and the distribution of decomposed granite indicate that the qualitative composition was the same. Variations in the quantitative composition of the waters thus seems to have been sufficient to bring about either the deposition of large masses of material or an actual subsidence of the surface. This important inference may seem doubtful when drawn from this locality alone; for, though there is no indication of a qualitative difference in the

waters, the proof that the water which undermined the basin south of the furnaces was similar to that now issuing near the railway is negative. At Sulphur Bank, however, we have springs of similar qualitative composition which are not depositing sinter to any extent and which are actually removing material by their solvent action. The difference at the two localities appears to depend largely upon the quantity of sulphuric acid generated. At Steamboat, also, the depressed basin contains sulphates, which have been formed by the action of sulphuric acid on the rocks, and I can see no reason to doubt that the quantity of sulphuric acid generated has determined deposition of sinter or removal of constituents of the rocks.

The silica of the sinters.—As has been stated, one portion of the sinter area consists almost solely of a flinty or chalcedonic mass. This is by no means ancient, for scalding steam still issues at one point, nor does it show any signs of erosion. Under the microscope the sinter is found to be composed of ordinary quartz crystals and fibrous, crystalline silica. No opal was detected with certainty by the microscope. This rock is almost absolutely identical with some of the chalcedonic specimens from Knoxville, which contain, in addition, cinnabar. The sinters from the springs now most active are finer grained than that just described. They are composed of silica and carbonates. The silica is certainly in part crystalline and does not remain dark between crossed nicols.

To obtain further information about the existence of opal, water determinations were made of three specimens, care being taken to separate the water from other volatile constituents. One of the specimens was a milky-white, compact rock with dull luster; a second was a very dark slate-colored rock with a resinous luster; and the third, a pure-white sinter, earthy and friable in part. The water absorbed in a calcium chloride tube was in the order of the descriptions 0.72, 3.77, and 0.67 per cent. These experiments show that hydrous silica was present in three specimens and that they were true chalcedonies, if by that term is understood a mixture of crystalline and amorphous silica.¹ It is evident from these observations

¹ Some remarks will be made in Chapter XIV on another use of the word chalcedony.

that crystalline silica, both fibrous and granular, forms from thermal springs at the earth's surface.

Gases.—Besides steam, hydrogen sulphide, carbonic anhydride, and sulphurous anhydride escape from the springs and fissures. The quantitative composition of the gas manifestly varies from point to point, and therefore quantitative analyses were not made. In the qualitative analyses free hydrogen and hydrocarbons were looked for, but none was detected. Neither were oily hydrocarbons found here as they are at most quicksilver deposits, though low forms of vegetation flourish in the waters of the hot springs even at very high temperatures. The absence of hydrocarbons from the gases and deposits is a very important fact. The sinter rests upon granite, and through this rock the springs reach the surface. If the hydrogen sulphide were a result of the reduction of soluble sulphates by organic matter, hydrocarbons would almost certainly be present, as was pointed out by Bunsen in his great memoir on the geysers of Iceland. The composition of these gases, therefore, points to generation from inorganic material at the seat of volcanic activity far below the surface. Whether, under the unknown conditions there prevailing, hydrogen sulphide can be derived from sulphates without the intervention of organic matter by some reaction not yet discovered, or whether the sulphur comes from regions which have never been oxidized, is uncertain. The same gases are perceptible at the mine as at the more active springs; it is possible, however, that a portion of the sulphurous anhydride at the mine is due to the decomposition of hyposulphites.

The metalliferous deposits.—The springs now flowing emit no great quantity of water and many of the vents did not overflow at all during my visit; neither does the water seem to be impelled toward the surface with any violence and in most cases it is perfectly clear. The mass of sinter through which the water attains the surface is also many yards in thickness. The deposits formed in the vents, particularly when they are narrow cracks, consequently consist of substances which have been held in solution by the waters and which have been precipitated by cooling, evaporation, and, to some extent, by acidification. Large quantities of these deposits were col-

lected at different points and were analyzed with the utmost care. In the waters themselves one could expect to find only those substances which were most abundant in the natural precipitates, because they represent the concentration of much larger quantities of water than it would be practicable to evaporate for analysis. The spring deposits were found to contain the following metallic substances arranged as nearly as may be in the order of their quantity: Sulphides of antimony and arsenic, ferric hydrate, lead sulphide, copper sulphide, mercuric sulphide, gold, and silver, together with traces of zinc, manganese, cobalt, and nickel. In the spring water itself only antimony, arsenic, and traces of mercury were detected. In considering the analyses, it must be remembered that the greater part of the metallic deposits are not at the vents of the living springs, but to the west at the mine, where no springs now exist, though steam and solfataric gases in small quantities still escape.

Metalliferous spring deposits.—Specimens I and II were from an old crevice in the plateau of sinter near the railroad. The crevice was sealed with sinter and the ground was entirely cold. When it was opened no water was found. The deposit was a true, simple fissure vein between walls composed of earlier sinters. It was brick-red in color, like almost all of the metalliferous deposits of the plateau, the tint being due to red, precipitated sulphide of antimony, a mineral which I believe has received no name.¹ The color of some of these deposits is such as to suggest impure cinnabar, but in none of those near the railway did we find enough mercuric sulphide to account for the tint. Qualitative analysis showed the presence of mercury, gold, silver, copper, lead, arsenic, antimony, iron, aluminium, manganese, zinc in minute quantity, traces of cobalt and nickel, lime, magnesia, lithium, sodium and potassium, silica and sulphur. A minute quantity of sulphates appeared to be present. Quantitative separations were made with very large samples. The object was to obtain weighable amounts of the metals, in order that an idea might be obtained of their relative abundance. The precise estimation, however, has only a general value, because the deposit

¹ Dr. J. Sterry Hunt desiring to mention this mineral in his classification, I suggested *metastibnite* (Proc. Am. Philos. Soc., vol. 25, 1888, p. 168).

is manifestly of variable composition. The following figures give the results:

	I.	II.
	<i>Grams.</i>	<i>Grams.</i>
Weight of sample	1,021.0000	3,403.0000
Gold	0.0009	0.0034
Silver	0.0003	0.0012
Mercuric sulphide	0.0014	0.0070
Lead sulphide	0.0899	0.0720
Cupric sulphide	0.0064	0.0424
Antimonious and arsenious sulphides		78.0308
Ferric oxide		3.5924

Specimen III was taken from a crevice at some points of which hot water and gas still escape, but from a portion of the fissure no longer active. Qualitative examination showed the presence of mercury, gold, lead, copper, antimony, arsenic, iron, aluminium, manganese, traces of nickel, lime, traces of strontium, magnesium, sodium, potassium, lithium, caesium, rubidium, free silica, and free sulphur. The bases were combined as silicates, carbonates, sulphates, sulphides, chlorides, borates, and phosphates, the last in small quantities. The color of the material showed that the greater part of the arsenic and antimony was in the form of sulphide. Special determinations of the mercury were made with portions of this deposit. After drying and pulverizing, the carbonates were extracted with dilute chlorhydric acid and the heavy metals were dissolved in aqua regia. The precipitate given by sulphureted hydrogen was leached with cold, yellow ammonium sulphide and the residual sulphides were weighed. A portion of this residue, heated in a closed tube with sodium carbonate and pure iron powder, gave a sublimate of metallic mercury. This sublimate was tested by uniting the globules to larger ones, by amalgamating gold, and by conversion into mercuric iodide in a closed tube. From another portion mercurous chloride and gold were precipitated by phosphorous acid. The gold produced the characteristic tint and a button of metallic gold in a pure state was finally extracted. Another portion of specimen III, examined quantitatively, gave the following result:

	<i>Grams.</i>
Weight taken	2,835.0000
Mercuric sulphide found	0.0024
Sulphides of arsenic and antimony	4.2725

Another sample (IV) from the same crevices which contained III, but from a point at which steam and sulphureted hydrogen bubbled through the hot water, showed an entirely similar composition; it contained mercury, lead, copper, arsenic, antimony, iron, aluminium, calcium, magnesium, sodium, potassium and lithium, free silica, and free sulphur. The bases were combined as silicates, sulphides, sulphates, carbonates, chlorides, borates, and to a small extent as phosphates.

Specimen V was from one of the springs which had formed a basin, through which occasional bubbles rise to the surface. The sediment consisted of layers of gray and yellow material, the latter being tinted by sulphide of arsenic. It contained mercury more abundantly than those previously mentioned, and also lead, copper, arsenic, antimony, iron, and aluminium, a trace of cobalt, magnesium, sodium, potassium, caesium, lithium, free silica, and sulphur. The bases were combined as silicates, carbonates, sulphides, sulphates, chlorides, and phosphates.

At one point on the plateau a mud deposit is formed by deposition from streams issuing from two of the more active springs. Here mica scales exist, showing that in this case some material is brought up in suspension from the underlying granite, which must consequently be undergoing decomposition; for the feeble streams of water which rise through it are certainly incapable of wearing granite away at such a rate that the abraded portions would be visible to the naked eye. This mud must therefore contain products of decomposition of granite, as well as any substances which may have passed through the granite in solution. Qualitative analysis showed that it had nearly the same composition as the other deposits. The portion soluble in acid contained mercury, gold, silver, lead, copper, arsenic, antimony, much iron, aluminium, a trace of cobalt, magnesium, calcium, and of course alkalis. The bases were combined as silicates, carbonates, sulphides, and to a small extent as phosphates.

A warm spring, which is known as the Chicken Soup Spring, issues at the base of the plateau close to the railway, the water of which is drunk by visitors to the locality. No mercury could be detected in the sediment; but sulphides of arsenic and antimony and free sulphur, as well as low vegetable forms, abound in it.

Free sulphur occurs at many of the springs and also at the mine. It is of course produced by the partial oxidation of hydrogen sulphides, either by atmospheric air or by sulphurous anhydride. The quantity is nowhere large, and I doubt whether more than a pound or two could be collected at any one spot. In this respect there is a great difference between this locality and Sulphur Bank, where a great quantity of sulphur was exploited. The sulphur is found chiefly at points to which the access of air is limited, as should be the case according to the thermochemical relations stated on page 255.

The water.—The water analyzed was taken from a spring at the eastern edge of the sinter plateau, which had formed a basin. The water in the basin seemed perfectly limpid and the overflow was gentle and nearly constant. The temperature of the spring was found to vary considerably, the extreme limits noted being 75° and 84.5° C. In order that the water might be free from solid impurities it was siphoned off from the basin into a covered funnel and was filtered directly into the demijohns used to transport it. In passing through the siphon the water was inevitably cooled, and it was found that the water on the filter paper had a temperature of from 30.5° to 33° C. In collecting the water in this manner a very interesting fact was observed. Near the lower end of the glass siphon a red precipitate formed. Since neither air nor any other foreign substance had access to the water at this point, the precipitation could hardly be attributed to any other cause than cooling. The precipitate consisted of sulphides of antimony and arsenic and silica, the last being deposited chiefly on the upper part of the coated portion of the tube. Here, then, ores and one of the most important of gangue minerals were deposited in an opening by natural means, and I had the pleasure of watching the actual progress of the formation of an ore deposit. On the filter paper also a similar precipitate formed, but here the organic matter of the paper and atmospheric influences were at work, and floating dust came in contact with the fluid. Even the water in the spring basin must have contained organic germs, for at all the springs, so soon as the water has somewhat cooled, low forms of vegetable life flourish and form red and green, pulpy sheets of slimy matter. The germs of these organisms are no doubt abundant in the atmosphere and fall

into all the spring basins. On the inner walls of the siphon tube diatom-like structures were visible with the microscope. The cooling of the water was unquestionably necessary to the development of these organisms, and in the absence of air it seems impossible to suppose that they can have grown sufficiently to have influenced the precipitation of the sulphides.

An attempt was made to collect a considerable quantity of precipitate by simply cooling the water of this spring as described above, and for this purpose a number of long siphons were set in operation. But, though the precipitates in the tubes were very striking in appearance, the quantity of precipitate obtained in filtering 118 liters was only about nine milligrams. It was almost completely soluble in yellow ammonium sulphide, and, to my disappointment, not a trace of mercury could be detected. Perhaps this was to be expected in view of the proportion which cinnabar bears to the sulphides of antimony and arsenic in the other deposits.

The following results were obtained from analysis of the water:

Analysis of Steamboat Springs water.

• [Contents of 10 liters in grams.]

Silica, SiO_2	3.1065
Carbon dioxide, CO_2	1.7759
Boric anhydride, B_2O_3	2.1741
Sulphuric anhydride, SO_3	1.0339
Hyposulphurous anhydride, S^2O_3	0.0307
Sulphur combined, S as RHS	0.0327
Hydrogen sulphide, H_2S	0.0055
Or sulphur, S	0.0052
Chlorine, Cl	9.5243
Antimonious anhydride, Sb_2O_3	0.0051
Arsenious anhydride, As_2O_3	0.0357
Phosphoric anhydride, P_2O_6	0.0063
Mercuric sulphide, HgS	Trace
Alumina, Al_2O_3	0.0025
Ferrous oxide, FeO	0.0018
Lime, CaO	0.0958
Magnesia, MgO	0.0047
Soda, Na_2O	9.1929
Lithia, Li_2O	0.1541
Potassa, K_2O	1.2460
Cæsium and rubidium oxides, Cs_2O , Rb_2O	Trace

The cæsium and rubidium in this analysis were detected by the spectroscope, but the quantity present was too small for determination. The

mercury was precipitated by phosphorous acid under conditions precluding the precipitation of any other metal. A faint cloudiness indicated its presence, but no weighable quantity came down.

The basin from which this water was taken was small and contained perhaps no more than a cubic foot of water; but the overflow was also small, and a part of the water in it must have been exposed to the air at a high temperature for a considerable time. Some decomposition was therefore to be expected. If solutions of alkaline sulphides be allowed to oxidize, hyposulphites are well known to form. The analysis shows hyposulphurous acid, and this, I think, must be attributed to decomposition, for its formation at great depths appears hard to explain, nor am I aware that hyposulphites have ever been detected under conditions which suggest their existence in nature at points removed from oxidizing influences of the air. The hyposulphurous acid is undoubtedly combined with sodium, and probably represents a certain amount of oxidized sodium sulphhydrate. The decomposition of sodium sulphhydrate is well known to be attended by the formation of sodic hydrate. The antimony and arsenic were certainly in solution, and it is altogether probable that they were originally in the form of sulpharsenides and sulphantimonides of sodium. But in the presence of caustic soda these sulphides are partially decomposed with the formation of arsenites and antimonites. The sum of the quantities of sulphur found in combination with metals and in the free state or in combination with hydrogen is just sufficient to form sulphantimonides and sulpharsenide of sodium, and the presence of hydrogen sulphide is explained if one supposes the sulphosalts partially decomposed, as suggested above. In the table given below I have supposed the arsenic and antimony to be entirely in the condition of sulphosalts and that the hyposulphite is represented by sodium sulphhydrate. As has been mentioned, silica is precipitated when this water is cooled; but when the fluid reaches the surface there can be little doubt that it all exists in combination with the alkalis as an acid silicate. It is not improbable that this compound is the quadrisilicate of sodium. It is computed as such.

Acid sodium carbonate is well known to be partially decomposed at high temperatures, and it is therefore by no means unreasonable to suppose

that a part of the sodium salt was neutral. This supposition also accords with that made with reference to the silica. The alumina was probably present as an alkaline aluminate, but the quantity found was so small that it did not appear worth while to compute its hypothetical compounds. In Chapter XV it will be shown that the trace of mercury in this water is combined as a double sulphide with sodium, which is of the form HgS , $n\text{Na}^2\text{S}$. The value of n in this case is probably four. No comments seem needful on the state of combination of the other constituents of this water. The suppositions made lead to the following scheme of composition as the most probable prior to the action of the atmosphere upon the fluid:

Probable composition of the water prior to oxidation.

	Grams.
Ferrous carbonate, FeCO_3	0.0029
Magnesium carbonate, MgCO_3	0.0099
Calcic carbonate, CaCO_3	0.1577
Calcic phosphate, $\text{Ca}^3\text{P}^2\text{O}_8$	0.0137
Potassic chloride, KCl	1.9735
Lithic sulphate, Li^2SO_4	0.5650
Sodic chloride, NaCl	14.1475
Sodic sulphhydrate, NaHS	0.0358
Sodic sulphate, Na^2SO_4	1.1147
Sodic bicarbonate, NaHCO_3	2.9023
Sodic monocarbonate, Na^2CO_3	0.4314
Sodic baborate, $\text{Na}^2\text{B}^4\text{O}_7$	3.1368
Sodic quadrisilicate, $\text{Na}^2\text{Si}^4\text{O}^9$	3.9090
Sodic sulphantimonide, Na^2SbS^3	0.0100
Sodic sulpharsenide, Na^2AsS^3	0.0866
Alumina, Al^2O^3	0.0025
Sodium-mercury sulphide, HgS , $n\text{Na}^2\text{S}$	Trace

Origin of the water.—Old residents informed me that the quantity of water flowing from the springs varies from year to year, being greater in years of heavy rain-fall than in dry seasons and greater in spring than in autumn. If these statements be accurate, the supply must come from the surface and no very long time can intervene between precipitation and return to the surface. It is natural to suppose the great snowy range to be the source of supply. The fissures underlying the range may afford a downward passage for the waters to the heated mass from which the basalt came, while the fissures associated with the channel through which the basalt was ex-

truded furnish a shorter road back to the surface.¹ The water must be well filtered on its course, since there is no evidence that organic matter is carried to the source of heat.

The cinnabar deposit.—The quantity of mercuric sulphide in the deposits from the active springs is very minute, and there is in this district nothing which could be called quicksilver ore in a commercial sense, excepting near the mine workings and furnace on the northern central portion of the area mapped. Cinnabar is deposited in considerable abundance only in the decomposed granite, though a few veins and seams have penetrated into the basalt at the southern end of the basin-like depression. By no means all of the decomposed granite, however, even in this area, shows any ore, the cinnabar occurring only as impregnations in the decomposed area, apparently along the courses of half-obliterated fissures in the soft material. The underground workings are now almost wholly inaccessible, and some prospecting would be necessary to ascertain anything definite with regard to the amount of ore available. The mode of occurrence of cinnabar indicates that the deposition did not proceed *pari passu* with the decomposition of the granite, but followed it. Had it been otherwise, cinnabar would be found generally over the decomposed area and the impregnated granite would be tolerably firm, instead of forming a gravel-like, incoherent mass. It is very probable that at depths of a hundred feet, more or less, the character of the deposit would be found to differ markedly from that at the surface, for the phenomena here, as at Sulphur Bank, are complicated by the action of sulphuric acid due to the oxidation of sulphureted hydrogen.

Metals in the granite.—The present springs are certainly decomposing granite to some extent, and decomposition of this rock on a large scale has occurred within no long period. It seemed probable that at least a portion of the heavy metals found in the deposits were derived from the granite and possible that all of them had this origin. Rock from the area east of the railroad was selected because it was fresh and well removed from springs, active or extinct. Large quantities of granite, in one case 15.5 pounds, were finely pulverized and decomposed either by aqua regia, which does not

¹ Compare my suggestion as to the source of the water entering the mines on the Comstock (Geology of the Comstock Lode, p. 243).

decompose the mica, or by hydrofluoric and sulphuric acids. Both the resulting solutions were examined for heavy metals; and arsenic, antimony, lead, and copper were found in those prepared by each of the above methods, but neither mercury nor gold could be detected in either. Experiments made with 50 grams of hornblende and mica separated from the rock also failed to detect mercury or gold. Lead almost if not quite always contains silver, so that the presence of lead in the granite points to the existence of silver in that rock, although the tests available were not sufficiently delicate to reveal it. Professor Sandberger has actually found silver in the micas of German granites, as well as arsenic, lead, copper, and other metals. He has also detected zinc in the mica of gneiss.¹ Silver is rarely if ever found in nature unaccompanied by gold, and it is altogether probable that micas in which Professor Sandberger found silver also contained the sister metal. According to Mr. A. Simundi some of the Idaho granites, collected at long distances from any veins, carry determinable quantities of gold.²

The granite of Steamboat Springs exhibits considerable variations in texture and mineral composition, as do most other granites. This and other phenomena indicate, as Scheerer and others have pointed out, that granite has never been thoroughly fluid and is not uniform in composition. It is therefore far from impossible that specimens of this rock from other points in the region of Steamboat Springs might have shown gold, silver, and zinc.

Considering that the granite is certainly undergoing decomposition and partial solution by action of the springs and that the metals most abundant in the spring deposits are also found in the granite, it seems to me only reasonable to conclude that from the granite the springs derive the arsenic, antimony, lead, and copper which they bring to the surface. The other metals are found in the deposits in far smaller quantities than those just enumerated. Though not detected in the granite here, all of them excepting quicksilver are known to occur elsewhere in granite or gneiss. It is also worth noting that silver, gold, and zinc are very frequently associated in nature with arsenic, antimony, lead, and copper. The prevalence of this

¹ Untersuchungen über Erzgänge, p. 25.

² Emmons and Becker, Statistics and Technology of the Precious Metals, p. 54.

association seems to point to the supposition that these metals are often derived from the same source. It is therefore much more probable that the silver, gold, and zinc also were derived from the granite at Steamboat than that they came from the unknown regions beneath it or from some mass of lava crossing it. As for the quicksilver, I am not aware that it has ever been detected as a constituent of a massive rock; but it is found at very many points the world over in association with gold, copper, arsenic, and antimony, or some of them. All the circumstances at Steamboat seem to point to the granite as its probable source, and, so far as I know, nothing suggests a different origin.

Conclusions—As Messrs. J. A. Phillips¹ and Laur² have pointed out, Steamboat affords instances of the formation of true fissure veins by hot springs at the present day. While it is quite probable that some veins are formed in a different manner, it is substantially certain that many deposits have been generated in this way. The composition of the waters, with special experiments devised for the purpose, also leads to definite conclusions concerning the soluble compounds of the metals contained in the waters, as will be shown in Chapter XV. Steamboat Springs, too, affords a striking illustration of lateral secretion. This term is sometimes limited to segregations affected by cold solutions, but quite improperly, for the extraction and deposition of ore from the rocks adjoining fissures by hot solutions are just as much lateral secretion as if the prevailing temperature were low. The term is used by von Cotta without any limitation as to temperature. As it has been employed by Mr. S. F. Emmons and myself also, a limitation as to temperature has never been implied.

Comparison with the Comstock.—There are noteworthy similarities and differences between the deposits of Steamboat and of the Comstock lode. At Steamboat gold is present in much larger quantities than silver, as it is in all the deposits of the gold belt of California. At the Comstock the proportion of gold to silver by weight is only about 1 to 20. At Steamboat arsenic and antimony, lead, copper, and mercury are the most abundant metals, while on the Comstock mercury is not found at all and the prevailing ore is auriferous argentite. As I showed in my memoir on the Com-

¹ Ore Deposits, 1884.

² Annales des mines, vol. 3, 1863, p. 423.

stock, it is probable that the ore was there leached from the diabase hanging wall by the action of ascending waters of very high temperatures, charged with alkaline solvents, and was not deposited by sublimation or distillation, as Baron von Richthofen surmised. The difference in origin of the two ore deposits sufficiently explains their difference in character. It is of course possible that a part of the ore of the Comstock may have been derived from granite, and it is noteworthy that the ore of the Justice mine, which is near the granite area, was much baser than and quite different from that of the mines of Gold Hill and Virginia. I shall be obliged to return to this subject in Chapter XVI.