SULPHUR ON UNALASKA AND AKUN ISLANDS AND NEAR STEPOVAK BAY, ALASKA.

By A. G. MADDREN.

INTRODUCTION.

Sulphur claims have been recorded at three localities in southwestern Alaska—in the crater of Makushin Volcano on Unalaska Island, on Akun Island, and near Stepovak Bay on the Alaska Peninsula. (See Pl. VII.) The deposits covered by these claims have not yet been mined, but during the last year they have received considerable attention with a view to production.

These sulphur-bearing deposits are of the volcanic type termed solfataras—that is, they are surface deposits formed by sublimation from hot sulphurous volcanic vapors. They are situated in the belt of active and quiescent volcanoes that extends throughout the Alaska Peninsula, the Aleutian Islands, and Japan. Similar deposits undoubtedly occur at other localities in this belt.

Unalaska and Akun islands are near the east end of the Aleutian Islands, in latitude 54° N. and longitude 166° W. They lie west of Unimak Pass, the chief thoroughfare for vessels to Bering Sea. Stepovak Bay is on the south coast of the Alaska Peninsula, about 200 miles northeast of Unimak Pass, in latitude 55° 50′ N. and longitude 159° 40′ W., about 1,600 miles from Puget Sound.

The only regular access to southwestern Alaska is by a small mail steamer that sails from Seward once a month. Unalaska is about 1,150 miles from Seward and about 1,750 miles from Seattle in an air line or 3,000 miles by way of Seward. During the summer steamers from Seattle to Nome and St. Michael enter Bering Sea through Unimak Pass but seldom call at Unalaska or near-by ports because of lack of trade. However, they would be available for shipment of freight to Puget Sound. Fishing vessels and Government patrol and supply steamers make irregular cruises along the coast during the summer and occasionally replenish their coal bunkers at Unalaska. A Navy wireless station at Unalaska is available for transmitting commercial messages.

The following descriptions of the sulphur-bearing deposits are based upon examinations made by the writer during August and September, 1917.

MAKUSHIN VOLCANO.

TOPOGRAPHY.

Makushin Volcano, about 6,000 feet in altitude, is in the northern part of Unalaska Island, about 12 miles west of Dutch Harbor. (See figs. 7, 8.) It is 5 to 6 miles from the northwest coast and about the same distance north of Makushin Bay.

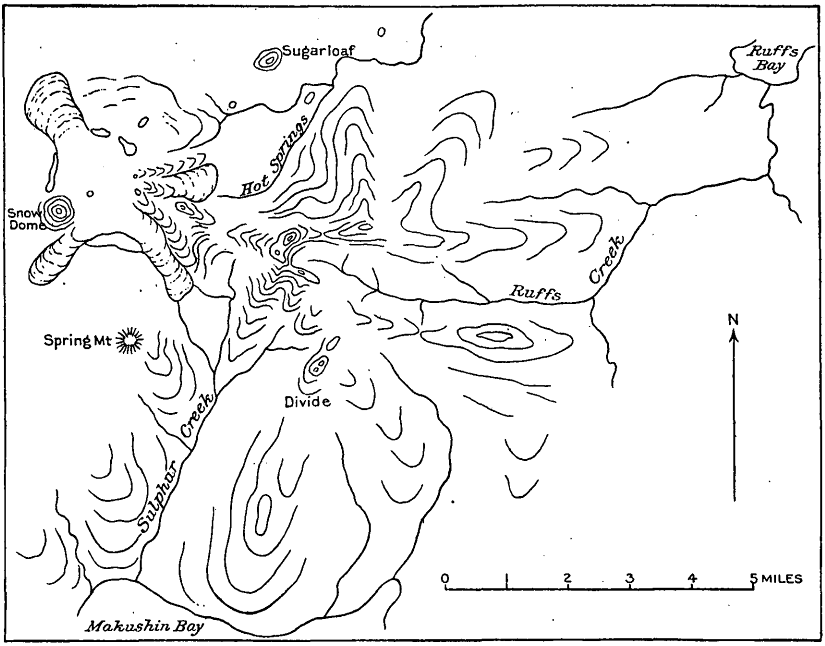
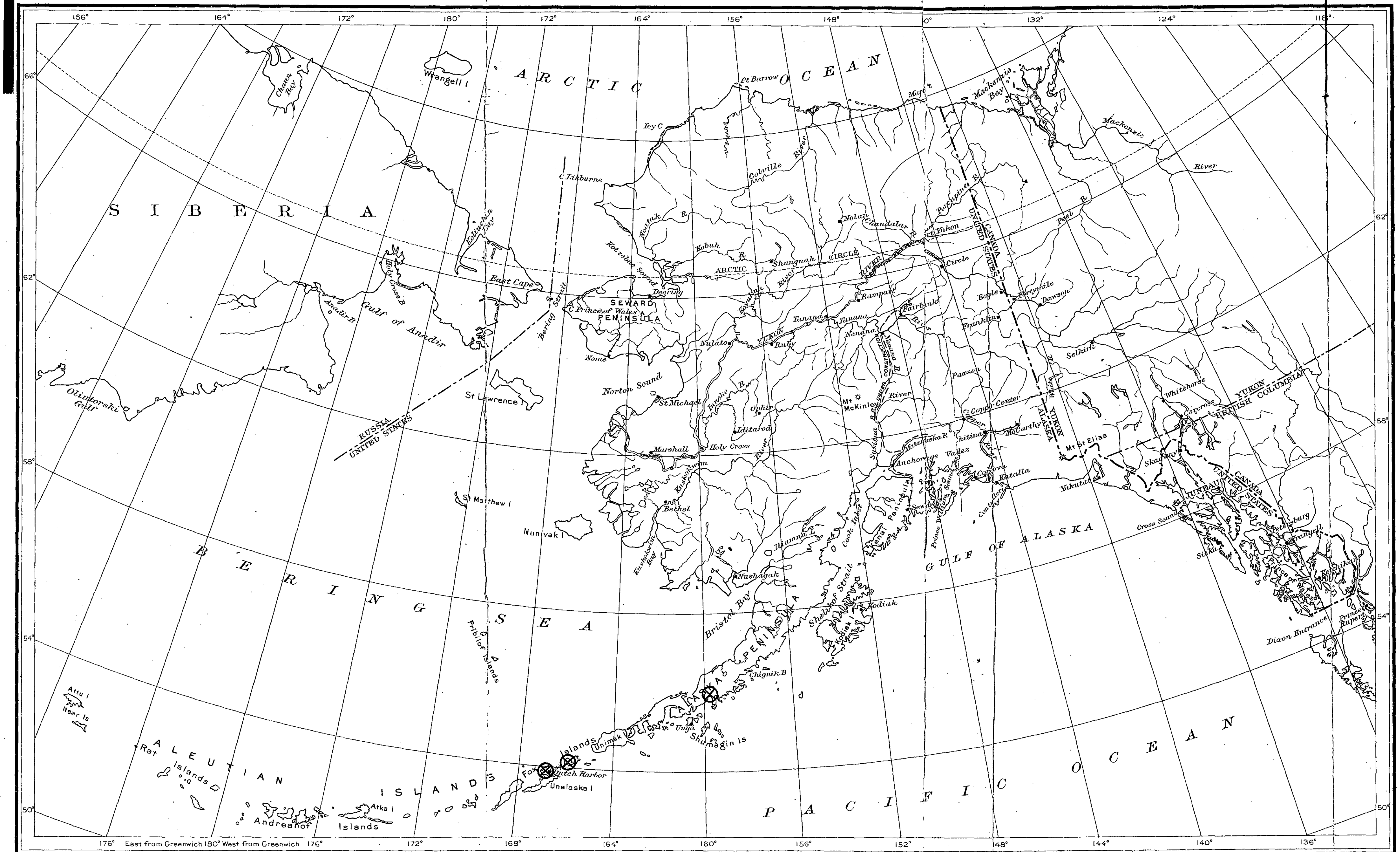


FIGURE 7.—Sketch map of Makushin Volcano and vicinity.

Makushin Volcano is a composite volcanic pile built up of alternating accumulations of basaltic lava, scoria, lapilli, and dust. In shape it is a broad dome, which forms a prominent feature of the landscape on account of its snow and ice capped summit and flanks. Glaciers descend its slopes to points about 2,500 feet above sea level, and rugged radiating ridges lie between the glaciers. A ring of ragged peaks surrounds a broad depression which marks the crater of a large extinct volcano. The mountain topographically dominates the part of the island it occupies over a radius of 5 or 6 miles.

The crater of Makushin Volcano, as defined by its rim ridges, is broadly oval or horseshoe-shaped in plan and is nearly 2 by 1½ miles in dimensions. Nearly continuous ridges form the crater rim except



MAP OF ALASKA SHOWING LOCATION OF SULPHUR DEPOSITS

100 0 100 200 300 400 500 Miles

100 0 100 200 300 400 500 Kilometers

ENGRAVED AND PRINTED BY THE U.S. GEOLOGICAL SURVEY

on the northwest side, at Big Gap, and at lesser gaps in the south and southeast sides.

The floor of the crater is 300 to 500 feet below the higher crags of the rim, but the floor of the basin is exposed only in an area of 20 to 30 acres, where the sulphur deposits occur. Except in this bare area, the basin is occupied by glacial ice and snow that probably is several hundred feet thick in the central part of the basin. This ice and snow sags away from the walls of the crater and presents a concave surface that slopes northwestward to the Big Gap. This gap is the chief outlet of the crater, and the flow of ice toward it is indicated by the crevasses.

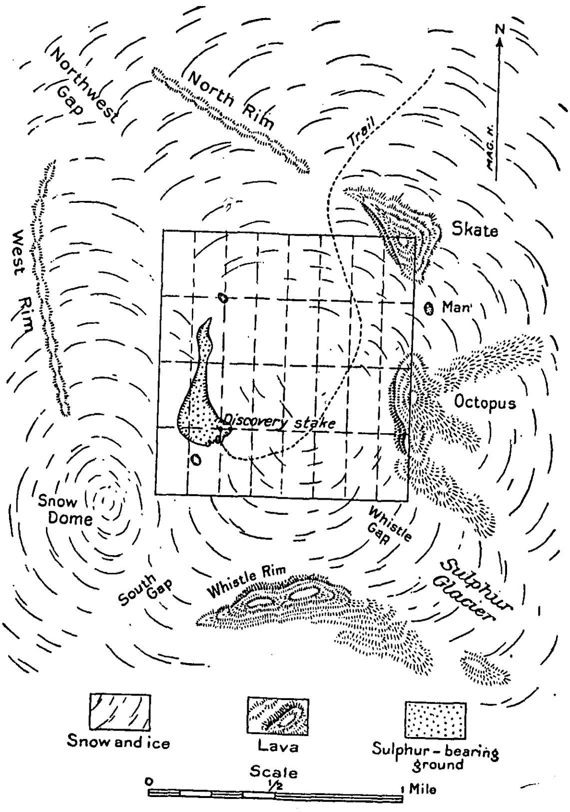


FIGURE 8.—Sketch map of part of Makushin Volcano showing location of sulphur claims.

THE SOLFATARA.

POSITION AND CHARACTER.

The sulphur deposit of Makushin Volcano is situated a short distance southwest of the center of the crater and is the only part of the crater that appears to be permanently free from snow and ice. The bare area comprises a main southern portion about 1,200 feet long and 700 feet wide and a narrow tongue-like strip that extends north from the main area for about 1,500 feet and has an average width of 200 feet. (See fig. 9.) The area of these tracts is estimated to be 20 and 10 acres respectively. Some minor marginal patches extend beneath the overhanging edges of the ice. These marginal areas are, however, a variable quantity and are inaccessible, because they comprise the floors of grottoes or caverns and tunnels melted from the under surface of the snow and their roofs collapse from time to time.

The southern part of the solfatara is a hummocky hill or ridge which rises about 100 feet above the comparatively smooth surface of the surrounding snow and ice. On the southwest flanks of this ridge are several grottoes or tunnel-like caverns. These grottoes appear to lead toward a large chimney-like hole in the ice, about 150 feet in diameter, from which hot vapor discharges. This hole evidently marks a cleft in the rock from which hot vapor has melted the ice, and the grottoes are irregular passages that were melted in the ice by the circulation of hot vapor. The sulphurous character of the vapor is indicated by the sulphur that is deposited about the mouth of the hole, which stains the snow slightly yellow.

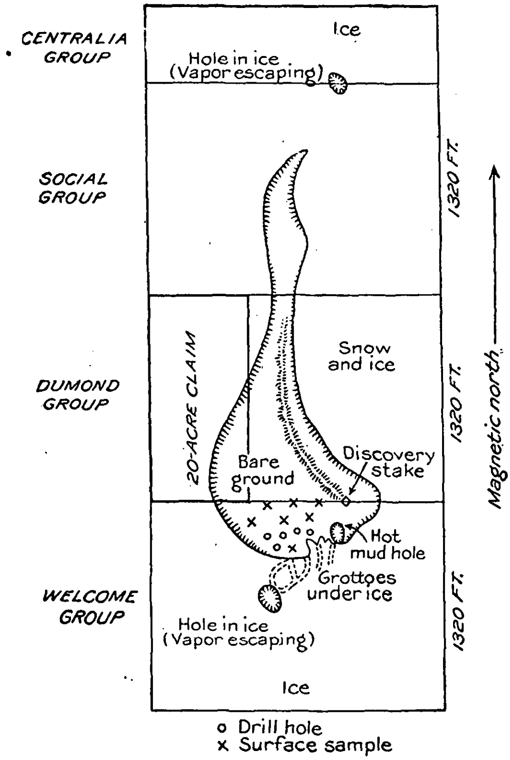


FIGURE 9.—Sketch map of sulphur area on Makushin Volcano.

It is evident that the main solfataric area is kept bare by subterranean heat. The heavy persistent clouds of condensed vapor indicate that the radiation of heat is active and fairly constant. In calm weather the condensed vapor rises many hundred feet and resembles smoke from a great chimney or a forest fire, but as violent winds are common the heavy clouds of vapor are usually swirled and eddied along the surface of the ice in different directions. If the wind blows from one direction for some time there often is a perceptible yellowing of the snow with sulphur. At such times the solfatara is approachable only from the direction of the wind, as the sulphur fumes are strong and the thick vapor obscures the way over the crevassed surface. Probably the smokelike grayness of the vapor is due to finely divided particles of sulphur, and the precipitation of these particles causes the yellow film on the ice.

LITHOLOGY.

As a whole the sulphur-bearing deposit is earthy and appears to be composed chiefly of siliceous residual products of rock decomposition that have resulted from the highly corrosive chemical actions of the hot solfataric vapors on the basalt. No outcrops of the basalt rock that are certainly in place could be closely examined, because the only exposures are in the walls of the deeper fissures and down the throats of fumaroles from which vapors issue at temperatures too high to allow near approach. The firm, massive character of the walls of such openings probably confines the escaping vapor, so that it issues with a loud, roaring sound. The country rock is seen only in blocks, slabby fragments, and kernel-like pebbles and scaly flakes, in various stages of decomposition, that are scattered about on the surface and disseminated throughout finely divided residual material. The larger and least-altered blocks of basalt, from 1 to 2 feet in dimensions, have somewhat pitted light-gray surfaces but within are dark and of compact crystalline texture, similar to the nonvesicular portions of the lava flows on the flanks of the mountain. The underlying rock of the solfatara area is thus chiefly compact crystalline basaltic lava, but it probably includes also some porous vesicular lava and possibly some fragmental volcanic material such as lapilli and dust, which are present in the old crater rim.

The olivine is considerably decomposed throughout the compact crystalline lava, but the other minerals are not extremely altered except near the surface. The leached surface layers of these blocks show the faded texture of the original lava and have a tendency to exfoliate or spawl off as concentric shells, especially when struck with a hammer. Some of the blocks have the form of roughly rounded boulders and cobbles and thus resemble volcanic bombs, and the residual earth suggests, at first sight, a light-colored volcanic ash. However, none of the boulders show the vesicular texture that usually characterizes bombs, and the earthy deposit appears to be mainly residual in origin.

The residual earth that constitutes the bulk of the surface mantle of the solfataric area is light gray to creamy white. As explained above, most of it was formed in place, although naturally some has been shifted locally by winds and rains, both of which are violent and frequent, and no doubt much of the finer clayey material has been washed away. Test holes drilled into the deposit show that the earthy mantle in places is fully 16 feet thick and that it changes little in character to that depth, although some thin layers are dark brownish red. The deposits were not bored to a greater depth than 16 feet, but below that depth they are believed to grade into less decomposed phases of the country rock. For the most part the deposit has a coarse mealy texture, but some of it resembles loosely compacted sandy clay. In general the material is quite porous and comparatively light weight when dry. It resembles kaolin, although its aluminous content is low.

Although the earth is highly siliceous no sinter deposits were observed. Slight cementation occurs, but the somewhat crusty character of the surface zone seems to be due in part to the drying out induced by the warmth of the ground and also to the deposition of sulphur in the upper 1 or 2 feet of porous ground, especially on the immediate surface of the tracts that are more or less constantly bathed by sulphurous vapors.

SOLFATARIC ACTION.

The most striking feature is the rather vigorous solfataric activity of the greater part of the bare ground. This activity may be divided into two phases that are somewhat distinct but nevertheless closely related. The most manifest activity is the discharge of hot sulphurous vapor that deposits sulphur in the cooler part of the deposit. The other phase of solfataric activity is the corrosive chemical action upon the rock in the zone of oxidation, which has caused the formation of a highly decomposed earthy residue that includes the bulk of the sulphur-bearing deposit and that rests upon the volcanic rocks from which the hot vapor emanates. Sulphurous and sulphuric acids probably are formed in small quantities in this surface zone.

The most active escape of hot vapor seems to be in the southern part of the area of bare ground near the highest part of the ridge. At this place vapor at relatively high temperature issues with a roaring sound from several openings. The largest vent is at the southeast end of the ridge in the lower wall of a pit, about 75 feet in diameter and 40 feet deep, the bottom of which is filled with steaming gray mud. The sound from this fumarole can be distinctly heard for a distance of half a mile. The temperature of this fumarole was not measured, but that of a smaller one on top of the ridge was 310° F. at a point 2 feet down its throat. Temperatures of 170° and 180° were observed in crevices from which the escape of vapor was much less active, and fragments of ice were boiled in about 10 minutes in a kettle placed over one of the openings after the crust of sulphur that partly sealed it was broken away.

The temperature of 310° F. indicates that the vapor is far hotter than the melting point of sulphur, which liquefies at about 240°. It was noted that no sulphur was being deposited where the temperature was 310°, although near the cooler border of the opening was a thin incrustation of sulphur.

Several test holes that were drilled into cooler parts of the deposit tapped hot sulphurous vapor at depths of 4 to 8 feet, indicating that the porous earthy mantle is more or less charged with hot vapor. Thus it appears that except for a comparatively thin superficial zone the solfataric deposit as a whole is probably too hot at a short distance below the surface to permit the deposition of sulphur, or conversely that the heat of the deposit below the surface is sufficient to keep most of the sulphur that may be present in a molten or vaporized state until it reaches the surface. In this connection it may be noted that sulphur may be extracted from ores of this character by melting it with steam under a pressure of about 60 pounds to the square inch. Steam under this pressure has a temperature of about 292° F. No field evidence was noted, however, of any of the sulphur having been melted after its deposition by sublimation.

The commercial bodies of sulphur in this deposit are clearly superficial. The percentage of sulphur at the surface does not indicate that rich deposits exists at depth, as is usually believed by the optimistic prospector.

THE SULPHUR DEPOSITS.

OCCURRENCE.

The richer deposits of sulphur occur within 2 feet of the surface, but there is also more or less finely divided sulphur disseminated to a depth of at least 16 feet, the greatest depth from which samples were obtained. Some of the finely divided sulphur may be redeposited, especially in the earthy accumulations along the lower flanks of the ridge, but most of it was undoubtedly sublimed from the vapor where it is now found.

The most conspicuous deposits of sulphur occur along crevices or large clefts that intersect the surface of the ground in many directions and around the holes from which large volumes of hot vapor issue continuously. Some of the larger holes are true fumaroles. The cracks in the surface might be attributed to shrinkage of the earthy mantle, but as they have no geometrical arrangement it is more probable that they lie just above open fissures in the underlying rock.

The largest masses of sulphur occur as irregular pieces, some of which are 8 to 10 inches in diameter. These pieces have more or less completely sealed the vents. Incrustations of sulphur an inch or more thick are being deposited on the lips of crevices and about the open vents. Hot sulphurous vapors issue from these openings in considerable volume, but only small amounts of vapor escape from sealed crevices. There may be a circulation of the sulphurous vapors from one set of crevices to another or from one part of a crevice to another part as the sealing progresses, the vapors seeking an outlet along passages of least resistance. In this way the sulphur may become distributed over the solfataric area.

At present the most abundant deposition of sulphur appears to be in the crevices and vents which have temperatures of about 170° to

180°. Comparatively little sulphur is being deposited about the hot fumaroles, such as one whose temperature is approximately 310°.

In addition to the sulphur that may be brought from primary sources in the hot vapors and deposited directly at the surface, it is probable that sulphur is revolatilized from the hot lower zones of the deposit and recondensed in the cooler surface zone. Thus there may be a migration of the sulphur from deeper parts of the deposit to its surface. It also seems possible that some of the sulphur reaches the surface dissolved in superheated water vapor and is directly sublimed upon condensation of the water vapor in the cool atmosphere.

Some of the sulphur may be precipitated from mixtures of hydrogen sulphide (H_2S) and sulphur dioxide (SO_2), two compounds which presumably can not exist together and which when commingled set sulphur free. To judge by the odor, small quantities of both these compounds seem to emanate from the solfatara, but they undoubtedly constitute a very small percentage of the total vapor. The odor of hydrogen sulphide was evident but not very marked. As one ten-thousandth part of sulphur dioxide in air is intolerable to human beings there probably is not much sulphur dioxide in the vapor, for no particularly suffocating effects were experienced upon breathing the vapor, even near the hot fumaroles. Water vapor is by far the most abundant emanation. It contains some dissolved sulphur which it deposits when it is condensed on the ice.

AMOUNT.

The sulphur deposit has not been sampled comprehensively, and it is very doubtful whether ordinary methods of sampling will give sufficiently accurate results to serve as a reliable basis for estimating the content of sulphur.

The deposit may be divided roughly into two zones on the basis of percentage of sulphur—a richer zone that forms a surface layer from 1 to 2 feet thick that seems to owe its crusty character chiefly to the sulphur deposited in it, and a poorer subsoil zone that consists in greater part of moist, hot, porous, decomposed material in which a small percentage of sulphur is disseminated as grains and blebs to a depth of at least 15 to 20 feet at some points.

The surface crust of the solfatara is rather irregular in general contour and quite uneven and hummocky in relief. Its minor ridges, hollows, and hummocks seem to owe their form partly to uneven deposition of sulphur along the intricate mesh of crevices and vents and partly to subsequent erosion by wind and rain. The higher tracts along the main ridge of the solfatara appear to owe their general prominence to the proximity to the surface of the lava, which probably underlies the whole solfataric area at no great depth, for all the blocks that are scattered about on or protrude from the surface of these tracts are of a uniform crystalline basalt and the walls of the fumaroles and larger openings appear to be similar solid rock to a level within a foot or so of the surface.

No definite data regarding the thickness of the lower layer or zone are at hand, and it can not be assumed that the earthy mantle has a uniform thickness throughout the solfataric area. It is assumed to be thickest along the lower flanks of the area, where it has been tested to a depth of at least 16 feet. Over some of the higher tracts it is generally thin and in places is entirely absent.

The sulphur is very irregularly distributed even in the crusty surface zone of the deposit. Although practically pure masses of sulphur occur as fillings in some of the dormant and semidormant crevices and vents and seal their outlets it does not extend down these openings very far. Some of these masses are estimated to contain several cubic feet of reasonably pure sulphur that could be mined by careful hand methods. The aggregate crevice and vent space thus occupied with sulphur is relatively small. Although a few of the crevices are 10 to 12 inches wide, most of them are not more than 2 or 3 inches wide, and the cracks and crevices in which sulphur has been deposited are about the same size. The sulphur-bearing crust between the crevices averages about 12 inches in thickness, although in some places it is as much as 2 feet. In many places the upper half of this crust is composed chiefly of sulphur, and the lower half contains a large percentage of earthy material. The amount of sulphur in the solfatara is not so striking as the area of gray earth, streaked and dotted here and there by the sulphur deposited along discontinuous cracks and about small vents that are irregularly distributed over the surface of the ground in more or less definite tracts.

Of the approximately 20 acres of bare ground that comprise the main area of the solfatara probably not more than 5 acres, in the southern part of the area, may be classed as containing a good grade of sulphur-bearing material, the remainder being of inferior grade, and only certain rather small tracts in the 5 acres of better ground contain high-grade material, even in the surface crust zone. Probably the average sulphur content of this surface crust is about 60 per cent of the material that would be handled in mining. If this estimate is correct it indicates about 260,000 cubic feet of sulphur, on a basis of 2 feet of depth, which is 12,500 tons at 125 pounds to the cubic foot.

The high-grade sulphur deposited at the open vents is about 98 or 99 per cent pure and is estimated to constitute about 5 per cent of the surface material as a whole. It is estimated that about 70 per cent of this surface material, to a depth of 1 or 2 feet, is composed of material of which four analyses show a sulphur content of 86.3

to 89.6 per cent and average about 88 per cent. According to these figures, the average sulphur content of the surface material to a depth of 1 or 2 feet is about 60 per cent. If the weight of the dried material is about 70 pounds to the cubic foot, as is indicated by the determination of the specific gravity of a sample that was assumed to be representative, the 5 acres of better ground should contain about 1,800 tons of sulphur to the acre within 2 feet of the surface.

It is difficult to make even a rough estimate, like that just given, for the sulphur content of the remainder of the deposit, especially of the earthy portion beneath the surface crust. In the first place this earth can not be assumed to be of uniform thickness, and secondly, in the absence of comprehensive sampling over the whole area, the quantity of sulphur that may be disseminated in it is a matter of conjecture. Five samples taken in the southwestern flanks of the deposit from depths of about 4, 8, 10, 12, and 16 feet contain, respectively, 47, 29.8, 14.7, 13.8, and 9.5 per cent of sulphur, averaging about 23 per cent. If this average holds the zone from 2 to 16 feet below the surface should contain from 716 tons of sulphur for each acre-foot at a depth of 4 feet to 145 tons for each acre-foot at a depth of 16 feet, or a total for the entire 14-foot zone of 4,900 tons to the acre.

PURITY.

The chief impurity of the sulphur is the earthy material in which it is deposited. In the small samples collected by the writer this impurity ranges from 1.5 or 2 per cent in selected pieces of solid sulphur to 75, 80, and even 90 per cent in the poorer earthy material. This finely divided earthy impurity is composed chiefly of silica and lime and is comparatively light in weight. The separation of the sulphur could be accomplished by heating the ore, for the sulphur would melt at a relatively low temperature and be drained off, making a commercial product of nearly pure sulphur.

AKUN ISLAND.

GEOGRAPHY.

Akun Island lies on the western side of Unimak Pass about 23 miles southwest of Unimak Island. (See fig. 10.) The settlement of Unalaska, on Unalaska Island, is about 45 miles southwest of the northern end of Akun Island.

Akun Island is about 12 miles long from north to south, has a very irregular coast line, and the northern part is nearly divided from the southern part by two large embayments that lie opposite each other—Akun Cove on the east coast and Lost Harbor on the west coast. The heads of these bays are separated by a strip of low land about 1 mile wide. Except this narrow strip of land, the island is comparatively high and has a general rolling relief that is marked by rugged ridges. Rugged topography is particularly characteristic of the northern

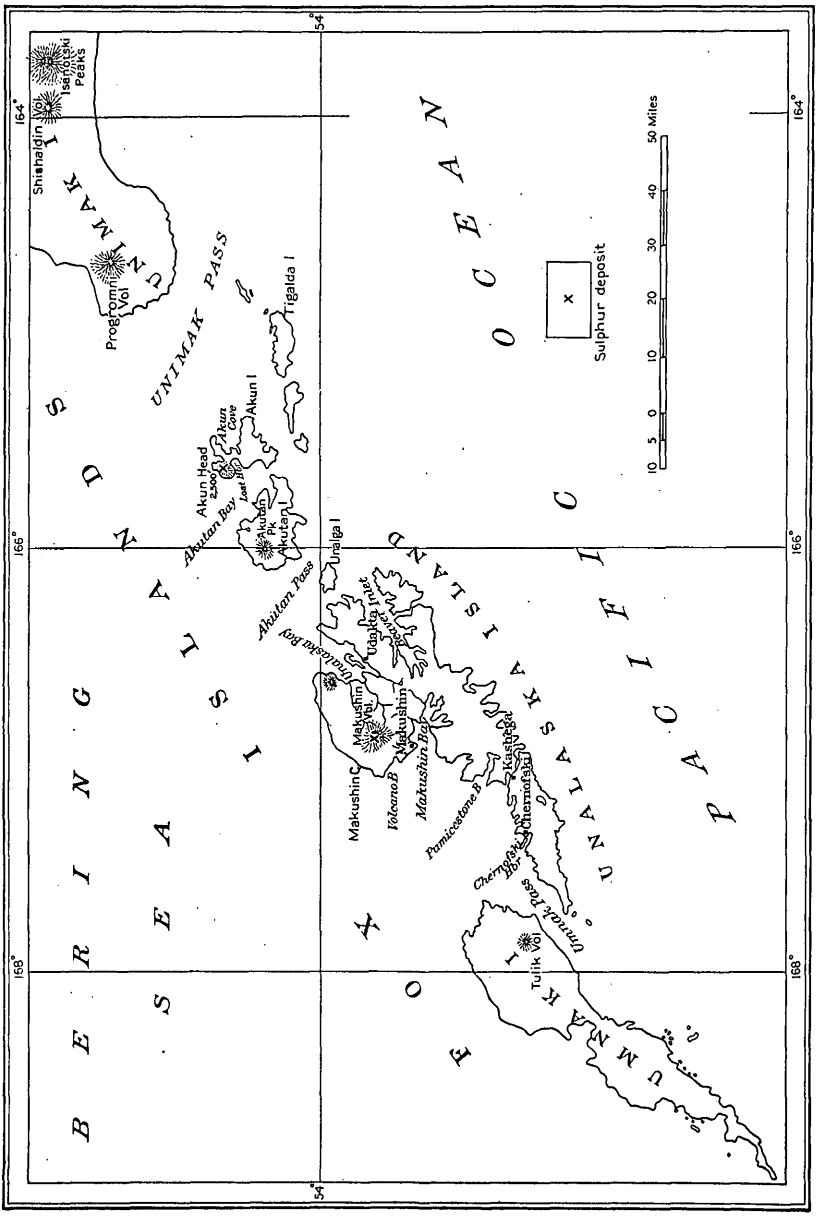


FIGURE 10.—Map of Unalaska and Akun islands showing location of sulphur deposits.

third of the island, the highest point of which is the summit of a roughly conical volcanic mountain 2,500 feet high. This volcanic mountain, locally called Akun Peak, stands near the northwest shore, and its westward and northward slopes terminate as abrupt sea cliffs 500 to 1,000 feet high.

GEOLOGY.

The hard rocks of Akun Island consist at the base of rudely stratified volcanic fragmental materials (agglomerates and tuffs) that are overlain by andesitic lava flows. Each of these formations is 1,000 feet thick where it attains its maximum development. Akun Peak is a typical volcanic cone and appears to have been one of the chief centers of outflow for the lava in the northern part of the island. Its conical form suggests that it is a comparatively recent volcano, and the lavas that flowed from it are little altered except by surface weathering. On the other hand, the basal deposits of agglomerates and tuffs, upon which the lavas rest, are considerably cemented and oxidized, and it is probable that they are considerably older than the lavas. At one exposure on the north side of Lost Harbor, where the contact between the lavas and the agglomerates and tuffs is well displayed, it is evident that the lavas flowed out and buried an old land surface that had been eroded in the agglomerates and tuffs.

THE SULPHUR DEPOSIT.

LOCATION AND AREA.

The sulphur-bearing area on Akun Island, upon which mining claims have been located (see fig. 11), is situated on the upper flanks of a rugged mountain ridge, 1,800 feet high, that lies about a mile northeast of Akun Peak. This ridge is a somewhat detached outlying spur

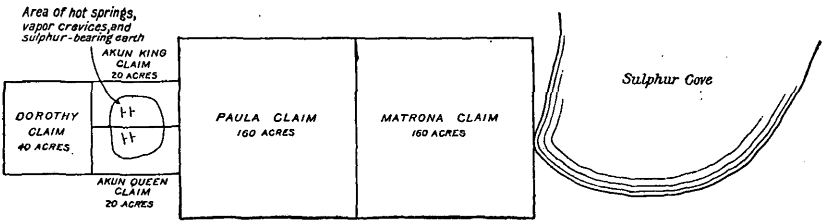


FIGURE 11.—Sketch of sulphur claims on Akun Peak.

of Akun Peak, and divides the northward and southward drainage of this part of the island. The solfatara lies in the broad headwater basin of a steep gulch that descends to a small cove immediately west of Akun Head on the north shore of the island and is about 1 mile from the cove. The southward drainage from this ridge flows to the north shore of Lost Harbor in a gulch about 2 miles long, and the easiest approach to the solfataric locality is by way of this valley. The best route is along its eastern slopes and thence through a small gap, at the head of a tributary gulch, that lies immediately south from the deposit at an altitude of 1,600 feet. The sulphur-bearing area is between 15 and 20 acres in extent and stands from 1,300 to 1,500 feet above sea level, but the part of the deposit that is characterized by mild solfataric activity comprises only about 5 acres.

VOLCANIC ACTIVITY.

The solfatara is in rather mild or semidormant activity. Within the smaller area of about 5 acres small volumes of steam and scalding water, accompanied by a small quantity of hydrogen sulphide gas (H_2S), issue from fissures at widely spaced intervals, and the remainder of the area shows no particular evidences of the escape of subterranean heat. The most striking evidence of solfatarism is of chemical decomposition of the rock.

GENERAL FEATURES.

The surface of the deposit consists of highly decomposed material, apparently of residual origin, that resembles the deposits of the solfatara in the crater of Makushin Volcano but is thinner. This earth is light gray to dull yellowish and forms a mantle from 1 to 4 feet thick. Much of it is essentially in place, but the steepness of the slope on which it rests has caused movement of some of the material and the hot waters that flow from crevices are transporting a small quantity to lower levels.

The earthy deposit is of uniform character throughout the area as is proved by the sections exposed in numerous open cuts that were dug in 1917. Many of these excavations are only 4 to 5 feet deep, but about six of them are from 12 to 15 feet deep and show the nature of the ground. All these cuts show a highly decomposed, leached, porous surface layer of light-gray earth from 1 to 4 feet thick that conforms to the slope of the ridge.

Beneath the surface layer is a zone of dark-gray semileached decomposed rock which in some places where it is saturated with water resembles massive clay. This zone ranges from 6 to 10 feet in thickness, and in its lower parts, where less decomposed, the joint planes and brecciated fragments may be seen. Along some of the seams in this subsurface zone a small quantity of alum salts is being deposited. This salt indicates that one of the changes which is taking place in the country rock is the decomposition of the feldspars.

In the bottoms of the deepest cuts, 12 to 15 feet below the surface, the highly decomposed rock of the subsurface zone grades downward into a less decomposed compact crystalline rock and although considerably altered shows the mineral constituents distinctly.

The highly decomposed rock and earth within the solfatara appears to be directly derived from the andesitic lava that composes the body of the mountain ridge, good outcrops of which may be observed on the crest of the ridge immediately above the solfatara. The area of the sulphur-bearing earth is clearly a locality where solfataric vapors have found an outlet and have intensely decayed the rock by highly corrosive chemical reactions.

The present solfataric activity at this locality is of a much milder stage than that of the solfatara on Makushin Volcano. In fact on Akun Island the activity seems to be entering into the hot spring stage. The evidence furnished in the open cuts as to the relatively shallow depths to which the solfataric decomposition extends indicates that this solfatara has never been extremely active. This conclusion is further indicated by the comparatively small amount of sulphur present.

THE SULPHUR.

MODE OF OCCURRENCE.

The sulphur in this deposit occurs chiefly in the form of crystalline incrustations one-sixteenth to one-eighth of an inch thick on the walls of narrow crevices and small cavities in the porous earthly surface zone. Most of the crevices are not more than one-eighth inch wide, and few of the larger ones are as much as one-fourth to one-half inch wide, and usually they are only partly filled with sulphur. Some sulphur is also disseminated through the decomposed material, but there are practically no solid bodies of sulphur, even of small size, in any part of the deposit. Apparently a small quantity of sulphur has also been deposited in the cooler parts of the subsurface zone, as is shown by incrustations observed along the walls of the deeper open cuts at points 10 to 12 feet below the surface, but this sulphur may have been deposited since the excavations were made by small jets of water vapor that now find an easier passage into the excavations. The sulphur-bearing vapor evidently rises through the material of the subsurface zone from a subterranean source by way of rather tight seams that mark joint fractures in the original lava. Where these crevices have been exposed in the excavations the vapor issues from them.

The temperature of the vapor is little above the boiling point (212° F.), and scalding water issues from some of the crevices, indicating that a considerable volume of the vapor condenses before reaching the surface.

AMOUNT.

Most of the sulphur in this deposit occurs in the porous earthy mantle within 1 to 4 feet of the surface. The average thickness of this mantle is believed to be about 2 feet. Two samples, one taken at the surface and the other at a depth of 4 feet, contained 55.5 and 22.8 per cent of sulphur, respectively. If the average thickness of the sulphur-bearing surface mantle is 2 feet, and if its average sulphur content is 40 per cent, it should contain 1,200 tons of sulphur per acre.

MINING AND SHIPMENT.

Although this deposit is of low grade and is not very extensive, it is fairly accessible. If the material should prove to be of sufficient value to justify mining it, there are no engineering difficulties to hinder development.

The sulphur-bearing material can easily be excavated and could then be transported to Lost Harbor by an aerial cable tramway that would be a little more than 2 miles long. The rise from Lost Harbor to the gap in the ridge about 1,000 feet south of the solfatara is 1,600 feet and the descent from this gap to the deposit is only 200 to 300 feet.

The sulphur doubtless could be extracted from its earthy gangue by melting in retorts with steam, but there is no fuel on the island. Oil, however, is now shipped from California to a whaling establishment on Akutan Harbor, 10 miles from Lost Harbor, for use in generating steam, and coal which might be developed for local use is reported to occur on Avatanak Island, about 5 miles southwest of Akun Island. It would probably be unprofitable to ship the sulphur-bearing earth in bulk to a distant point for treatment.

Lost Harbor does not afford good shelter for vessels, as it is open to the heavy southwest swell of Bering Sea and has a rocky bottom. Several vessels have been wrecked on its shores because their anchors failed to hold.

STEPOVAK BAY.

Stepovak Bay is on the south shore of Alaska Peninsula in latitude 56° N. and longitude 160° W. The only important sulphur deposit reported in the vicinity (see fig. 12) is about 7 miles northwest of the head of the bay, at an altitude of 3,000 feet, near the crest of the Aleutian Range, which is glaciated and contains numerous dormant or active volcanoes. This deposit was not visited because of the danger in crossing the crevassed glaciers covered with newly fallen snow that obstruct the only available route to it. As seen from a distance of about 2 miles, the supposed sulphur-bearing bed is a light-colored zone 100 feet thick and half a mile long in the wall of a cirque that may be the site of an extinct crater. A glacial moraine that extends from this cirque consists largely of sulphur-bearing rock that was probably derived from the light-colored band already noted.

The sulphur-bearing rock in the morainic deposits consists of porous volcanic breccia that contains compact crystalline sulphur in the interstices of the breccia and also in the vesicles of the constituent fragments. Some specimens probably contain 20 per cent sulphur (by bulk) in veins one-eighth to one-fourth inch thick and show masses up to 1 inch long at the intersections of the veins. In much of the rock the sulphur is finely disseminated and probably does not constitute more than 5 or 10 per cent of the rock. In regard to the sulphur content of the morainic material as a whole, it may be stated that parts of the moraine may contain 10 per cent

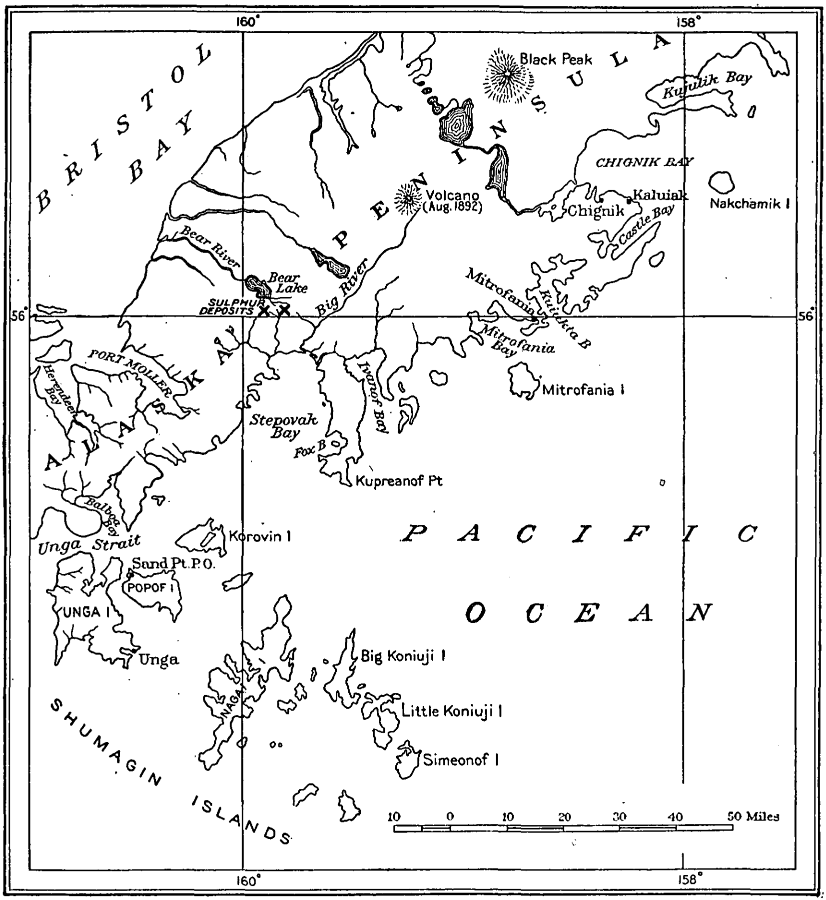


FIGURE 12.—Map of Stepovak Bay and vicinity showing location of sulphur deposits.

of sulphur, but larger parts are practically barren. The material in the moraine is probably poorer in sulphur than the bed from which it was derived and furthermore is a mixture of many different rocks rather than of those from the best parts of the sulphur deposit. Some of the sulphur-bearing boulders are 30 to 40 feet thick, thus indicating a minimum thickness for the bed from which they are derived. The abundance of the sulphur-bearing material in the moraine also indicates that the original source was of considerable extent.

THE BEACH PLACERS OF THE WEST COAST OF KODIAK ISLAND, ALASKA.

By A. G. Maddren.

INTRODUCTION.

This paper is based on about three weeks' field work in July, 1917. Previous to the writer's visit the west coast of Kodiak Island had not been examined by the Geological Survey since 1895, when Becker and Dall[1] landed there in the course of an extended cruise along the Pacific coast of Alaska. Becker[2] published a brief account of the beach placer mining in progress at the time of his visit.

It is not known in what year placer gold was discovered in the beach sands on the west coast of Kodiak Island, but mining has been carried on there for about 30 years, and the value of the annual production of gold is estimated to have been from $3,000 to $10,000 during that period. The total production of the west coast district is variously estimated to be from $50,000 to $150,000.

It is stated that as many as 100 men have mined along this coast in some years, especially during seasons when heavy storms have reworked and concentrated the sands, but generally the number of miners has averaged not more than 25. In 1917, when the writer visited the district, only about 12 men worked for part of the year. The most profitable operations have been conducted early in the spring and late in the autumn. During the winter the beach deposits are often frozen, and during the summer the patches of sand that contain the best concentrations are as a rule covered by an overburden of light sands that is unprofitable to remove.

GEOGRAPHY.

GENERAL RELATIONS.

Kodiak Island (see Pl. VIII) is situated between 57° and 58° north latitude and 152° and 155° west longitude. It is about 90 miles long from northeast to southwest and 50 miles wide from

[1] Dall, W. H., Report on coal and lignite of Alaska: U. S. Geol. Survey Seventeenth Ann. Rept., pt. 1, pp. 800, 843, 1896.

[2] Becker, G. F., Reconnaissance of the gold fields of southern Alaska: U. S. Geol. Survey Eighteenth Ann. Rept., pt. 3, p. 86, 1898.

northwest to southeast and is the largest of a group of islands that is separated from the mainland of the Alaska Peninsula, about 30 miles distant, by Shelikof Strait. Afognak Island, the only other large member of the group, lies northeast of Kodiak Island and is separated from it by a narrow channel. The remainder of the group comprises about 12 islands of comparatively small area, which are distributed along the shores of the two large islands. The group as a whole is about 150 by 50 miles in extent and trends southwesterly. In general it may be considered to be the submerged extension of the Kenai Peninsula, which lies to the northeast, just as Shelikof Strait may be considered the southwestward extension of Cook Inlet.

RELIEF AND SHORE LINE.

The surface of Kodiak Island and also its associated islands is dominantly rugged and mountainous. Altitudes of 1,500 to 2,500 feet are reached in many sections of the coast, and in the central interior several summits stand between 4,000 and 4,500 feet in elevation. The greater part of the shores is rock-bound and rugged, and the coast line, which is generally irregular, is indented by numerous deep narrow fiords and bays, some of which extend far inland. Many sections of the coast are bordered by outlying rocky islets and reefs, and most of the bays are more or less strewn with rocks.

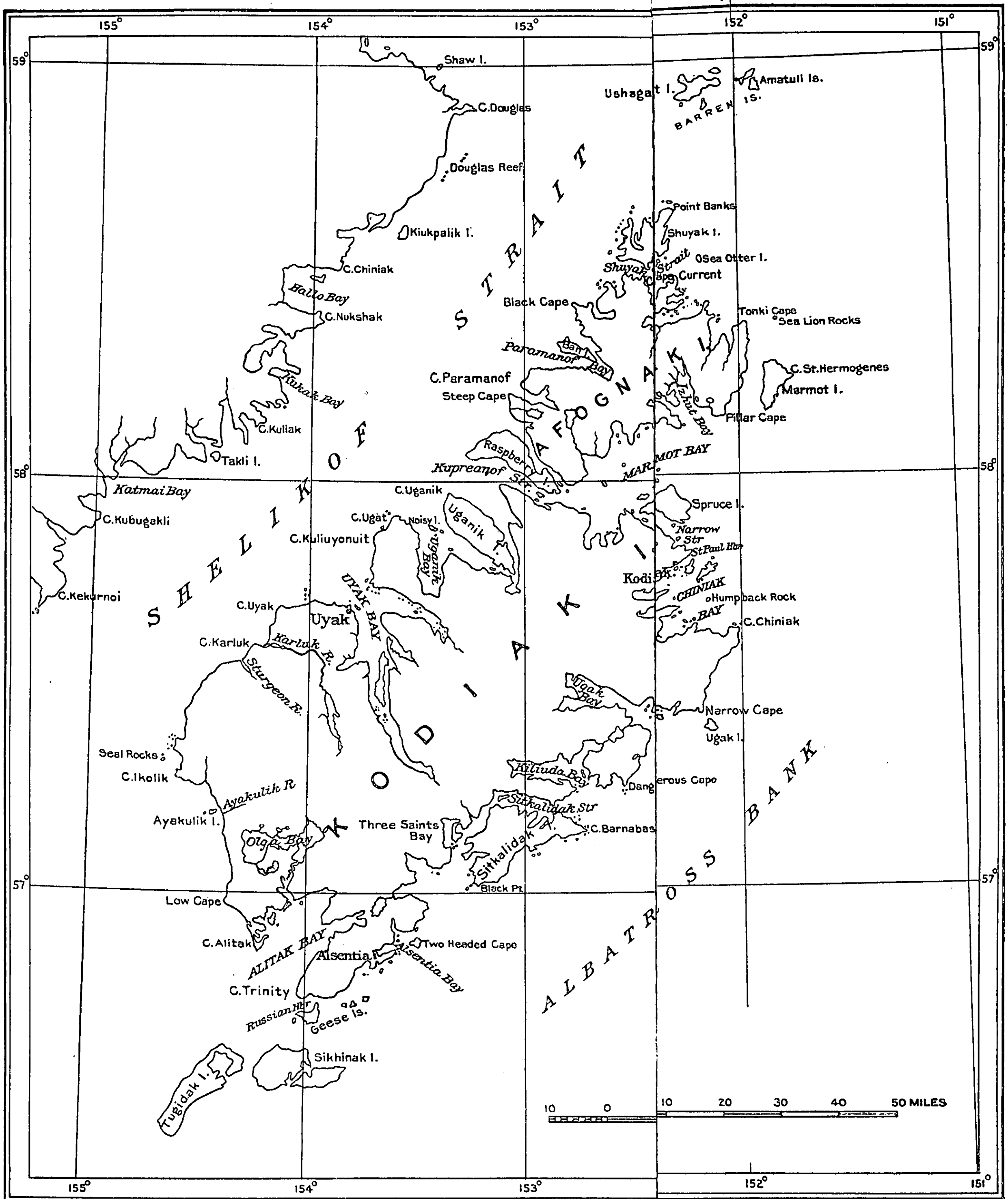
GEOLOGY.

Only the general features of the bedrock geology of Kodiak Island are known. These features have been briefly described by Martin,[1] but the observations of the writer in the western part of the island have increased the knowledge of that district. In this report the geology, as described by Martin, will be reviewed and will be supplemented by the notes of the writer concerning the western part of the island.

GENERAL FEATURES.

The rocks of Kodiak Island and the neighboring islands consist chiefly of slates and graywackes, which are cut by numerous but for the most part small intrusive masses, partly granitic. Schists that probably underlie the slates and graywackes are present along the northwestern part of the island, and small areas of poorly consolidated Tertiary sediments are reported to lie along the southeastern flanks of the island. Quaternary sediments that consist of ground moraine overlain by glacial outwash gravels and recessional moraines occupy the floors of all the larger valleys and form a considerable belt

[1] Martin, G. C., Mineral deposits of Kodiak and the neighboring islands: U. S. Geol. Survey Bull. 542, pp. 128–131, 1913.



MAP OF KODIAK ISLAND.

of coastal plain along the west coast. The sequence of the rocks may be expressed as follows:

Sequence of rocks of Kodiak Island, Alaska.

Quaternary:
- Present stream and beach deposits. Glacial outwash sediments, recessional moraines, and terrace gravels due to glacial ponding, ground moraine, or till.

Tertiary (?):
- Sandstones.
- Lignite-bearing beds.

Mesozoic (?):
- Granitic intrusive rocks.
- Graywacke and slate.
- Cherts and volcanic rocks of Triassic (?) age.

Paleozoic (?):
- Schist, greenstone, quartzite, and marble.

SCHISTOSE ROCKS.

Schistose rocks have been observed in only a small area on the northwest shore of Kodiak Island between Uyak and Sevenmile Beach, but from the reports of prospectors such rocks probably form a belt that extends southwestward from Uyak to the vicinity of Cape Ikolik and northeastward parallel to the northwest shore of the island, where they appear in outcrops on most or all of the promontories that overlook the coast of Shelikof Strait. Near Uyak these rocks comprise fine-grained quartzitic schist, crystalline limestone, and chloritic schist and constitute a group of diverse lithologic character but of uniform degree of metamorphism and structural complexity.

Associated with the schistose rocks are cherts and lavas, presumably of Triassic age, and slates and graywackes, but the relationship of these rocks to the schists has not been determined. However, it is presumed that the schists are older than the cherts and volcanic rocks, which are tentatively considered to be of Triassic age because they closely resemble similar rocks in Seldovia Bay, on Kenai Peninsula, that are definitely known to be of Triassic age. At Seldovia Bay highly metamorphosed rocks similar to the schists here considered are closely associated with the cherts and volcanic rocks.

On the west coast of Kodiak Island schistose rocks which correspond to those near Uyak were not observed in place, although pebbles and cobbles of this character were found in the beach deposits. These materials may be derived from the Cape Ikolik peninsula, where some schistose rocks are reported to occur. This area was not examined, except in its southern part, where observations were made along its south shore for a short distance west from the mouth of a stream that is locally known as Old Red River. At this locality the rocky sea cliffs consist of highly deformed and somewhat severely metamorphosed volcanic agglomerates, tuffs, and breccias whose massive bedding strikes east and dips 40°–50° N. These rocks are composed primarily of volcanic fragmental materials, but some of the tuffaceous parts contain rounded cobbles of dark-blue, finely crystalline, hard brittle limestone. The tuffaceous matrix in which these limestone cobbles are embedded is schistose and well foliated, especially around the limestone cobbles, to which it is firmly welded. Some members of this formation are highly silicified, and one massive member in particular is altered to a bright-red jasperoid rock, but it shows no bedding-like sedimentary cherts.

Possibly these volcanic clastic rocks of the Cape Ikolik area represent a lithologic phase of the cherts and volcanic rocks near Uyak, which are presumed to be of Triassic age. However, the degree of metamorphism of the Cape Ikolik rocks suggests that they may be more closely related in age to the schistose rocks of the island.

SLATE AND GRAYWACKE.

A series of interbedded slates and graywacke sandstones of considerable thickness forms most of the bedrock of Kodiak Island, to judge from the widespread outcrops of these rocks that have been observed along the northeast and northwest coasts, in the mountains of the southwestern part of the island, and along the shores of the long fiord inlets, such as Uyak and Alitak bays, that extend far into the interior. Apparently the only other rocks that may displace any considerable areas of these rocks in the interior of the island are massive bodies of granitic intrusive, one of which occupies a considerable area along the shores of Alitak Bay.

For the most part these semimetamorphosed sediments consist of approximately equal amounts of interbedded graywacke sandstone and slate in moderately thin beds, but in some outcrops the beds are more massive. Some conglomerate is present here and there; in one outcrop it is a hundred feet or more in thickness in the foothills north of upper Olga Bay.

The slates and to a less degree the graywackes have well-developed secondary cleavage, which has generally obliterated the bedding except where marked differences in composition preserve it. In general the dynamic metamorphism that has affected these rocks is expressed chiefly as thin cleavage in the slate members, which commonly show a tendency toward foliation, and as brecciation of the argillaceous graywacke members, which is generally marked by an intricate network of quartz veinlets deposited along the fractures. In some zones, however, the quartz-vein mineralization is chiefly of the tabular type, extending along bedding planes.

The stratigraphic thickness of these slates and graywackes and their structural details are not known, but a thickness of at least several thousand feet and probably a much greater thickness is indicated. Isoclinal structure appears to be dominant. The average strike of these rocks throughout the island is northeastward, parallel with the trend of the belt, which ranges from N. 20° E. to N. 60° E. (true), and the dip ranges from 20° to 80° NW.

INTRUSIVE ROCKS.

The slates and graywackes of Kodiak Island are intruded by small dikes and sills, among which quartz-mica diorite, porphyrite, and soda rhyolite have been recognized. Large massive intrusive bodies of quartz-mica diorite and mica granodiorite also occur at wider intervals, and several such bodies have been noted along the northeastern coast and in the southwestern part of the island. Becker[1] has described such a granite mass which forms Karluk Head, and the writer observed two large granitic areas in the vicinity of Alitak Bay, one of which forms the peninsula of Cape Alitak and the mountain mass named the Twins, immediately north of Lazy Bay, and the other a promontory locally known as Stockholm Point, on the south shore of lower Olga Bay.

In general the age of these intrusive masses is considered to correspond to that of the great bodies of similar rocks that are widely distributed throughout the coastal provinces of Alaska and which, where stratigraphic evidence is available, have been assigned with considerable assurance to late Mesozoic or early Tertiary time.

TERTIARY SEDIMENTS.

The Tertiary sediments so far reported to occur on Kodiak Island appear to be distributed almost wholly along the southeastern or Pacific seaboard of the island, although rocks of this age have been mentioned in Russian reports of doubtful accuracy as occurring in the northwestern part of the island.

The only locality examined by the writer from which Tertiary sediments have been reported is that mentioned by Dall[2] as situated in the bight of the west coast near Red River (locally known as Old Red River) about 2 miles north of Ayakulik Island. Upon careful examination the outcrops that presumably were referred to the Tertiary prove to be marine beach sediments interbedded with deposits of till, which are described under "Quaternary deposits." (See pp. 311–316.)

[1] Becker, G. F., Reconnaissance of the gold fields of southern Alaska: U. S. Geol. Survey Eighteenth Ann. Rept., pt. 3, pp. 36, 41–42, 1898.

[2] Dall, W. H., Report on coal and lignite of Alaska: U. S. Geol. Survey Seventeenth Ann. Rept., pt. 1, p. 800, 1896.

The best-developed Tertiary sediments on Kodiak Island are fresh-water deposits which contain beds of lignite and are generally referred to as of Kenai (Eocene) age. Sediments of this character are reported at several localities along the southeastern coast of the island, particularly in the vicinity of Kiluda Bay; and also on the high island of Sitkinak, situated a few miles south of Cape Trinity, the southwestern extremity of Kodiak. The lignite-bearing deposits of Sitkinak Island are reported to contain a number of coal beds, one of which is said to be 10 to 12 feet thick.

QUATERNARY DEPOSITS.

OCCURRENCE.

Unconsolidated deposits of Quaternary age are well developed in many parts of Kodiak Island, especially about its borders, and more particularly in its southwestern part, where they form a coastal plain of considerable extent. As the sediments of this coastal plain constitute a complete section of the Quaternary deposits, from the oldest to the youngest, a description of them may serve for the whole island.

The thick covering of volcanic detritus that was deposited over all the northeastern part of the island by the eruption of Mount Katmai in June, 1912, did not extend west of Uyak Bay in noteworthy amounts and need not be considered in connection with the strictly sedimentary deposits, although fragments of pumice occur in the beach deposits.

CLASSIFICATION.

The unconsolidated sediments of the island may be divided, according to the manner in which they have been formed and deposited, into four rather distinct but related classes. In sequence from oldest to youngest these classes comprise (1) the ground moraine or till deposited by glacial ice during the period when the ice was advancing over the island from the interior mountainous highlands to and beyond the present shore line; (2) the widespread sheets of outwash gravels, sands, and silts that rest upon or are incorporated with the till and were formed by streams that accompanied the melting of the glacial ice during its movements of retreat from its maximum limits back to the mountains; (3) the terminal and lateral moraines which were deposited by the glaciers at points where they halted temporarily during their retreat into the mountains, and the most prominent of which now form the dams that retain the large lakes occurring in many of the glaciated valleys; and (4) the sands and gravels of the present beaches and streams, which are the result of postglacial erosion and deposition and are derived chiefly from the three classes of glacial material just outlined. Some of the material, however, in both the streams and beaches is due to postglacial erosion of bedrock, especially in the higher mountains and along the rocky sections of the coast.

The first three classes of deposits here outlined are essentially aggradational, or are built up by the deposition of superimposed unassorted detritus. Only the deposits of the fourth or youngest class are of the degradational or assorted type favorable to the segregation of placer metals, and on Kodiak Island only the beach deposits are dominantly of this kind, for the present stream system has not materially eroded the unconsolidated deposits or the bedrock areas of the island.

CHARACTER.

The most extensive exposures of the unconsolidated Quaternary sediments on Kodiak Island are in the sea bluffs that bound the coastal plain along its western shore from Cape Alitak to Old Red River, a distance of about 30 miles.

These bluffs range from 25 to 250 feet in height and their continuity is broken at only a few points by the narrow valley mouths of the larger streams. Their base stands at the average level of high tide, and they are actively eroded by the waves whenever a surf is running, especially during violent storms, for this coast is open to the full sweep of the ocean from the southwest.

The bluffs are chiefly composed of typical till but in some sections contain also a considerable proportion of outwash gravels and sands. At several localities coarse morainal boulder trains are present. For the most part the till is compact and stands well in the bluff faces where freshly exposed. Where it is of uniform clayey composition, with little admixture of sand and gravel, it presents characteristic massive exposures that weather to a hackly surface owing to an irregular incipient fracturing that is developed in it. There are, however, large areas of the bluffs that have not been eroded recently, where the steep slopes are partly mantled by loose material that slumps and slides down from above to the upper edge of the beach. The till, besides making up the chief part of the bluffs, also forms most of the bedrock of the coastal platform upon which the loose beach sands and gravels rest. Without doubt the till extends some distance seaward as the floor of the coastal shelf upon which the surf is cutting, for it was noted that the sea was discolored by clay in suspension to a distance of 1,000 feet or more offshore whenever the surf was active.

The till is unoxidized and of a typical gray color, as are also most of the outwash sediments associated with it, although in places discontinuous strata in the outwash sediments and some portions of them near the tops of the bluffs are discolored brownish red and are slightly cemented with iron oxide. Springlike seepages are not uncommon at the contact of the underlying impervious till and the overlying porous outwash sediments. Along the greater part of the bluffs from 3 to 6 feet of peaty soil or turf overlies either the outwash sediments or rests directly on the till deposits, and disrupted masses of turf are strewn about on the bluff slopes where slumping has been pronounced.

Sand dunes 20 to 30 feet high occur locally on the tops of some of the higher bluffs.

In general the bluffs consist of a basal member of till overlain by gravels and sands which from their poor assortment and the cross-bedding are thought to consist of outwash material. Considerable sections, however, consist wholly of till, and some sections of lesser extent consist chiefly of gravels and sands with little typical till. There is also a section, about a mile long, in which two distinct members of till are developed that are separated by a more or less continuous but variable member of sands and gravels, parts of which at least have been subjected to wave washing as a beach, for they contain many water-worn fragments of marine shells, some specimens of which are complete enough to be identified specifically. A considerable number of water-rounded boulders of lignite are also embedded in the beach deposit. On weathering, these masses of lignite disintegrate into fragments that are strewn along the base of the bluffs. Evidently the presence of these masses led Becker to surmise that Tertiary lignite-bearing sediments were present in the bluffs of this vicinity, as noted by Dall,[1] but so far as the writer could learn lignite beds are absent. The lignite boulders apparently have been transported to this locality from a distance, together with the outwash deposits with which they are associated, and it is probable they once were morainal débris.

This assorted beach outwash material crops out along the northern part of the bluffs north of a higher part of the bluffs that is locally named Canvas Point, or from 1 to 2 miles north of Ayakulik Island. The following species of marine shells have been identified tentatively by W. H. Dall, of the Survey, from the collection made by the writer, with the comment that the specimens are rolled and broken fragments of forms now living in the vicinity and that the assembly indicates a colder temperature than that now normal to the locality.

Pecten (Chlamys) islandicus Müller.
Monia macroschisma Deshayes.
Tellina lutea Gray.
Macoma middendorffii Dall.
Venericardia crebricostata Krause.
Venericardia? paucicostata Krause.
Venericardia crassidens Broderip and Sowerby.
Mya intermedia Dall.
Latisipho halli Dall.
Tachyrhynchus polaris Beck.
Astarte borealis Schumacher.
Saxidomus giganteus Deshayes.
Chrysodomus sp. fragment.
Boreotrophon sp. fragment.
Balanus sp. fragment.

[1] Dall, W. H., Report on coal and lignite of Alaska: U. S. Geol. Survey Seventeenth Ann. Rept., pt. 1, p. 800, 1896.

The beach sand member that contains the marine shells just enumerated and with which the water-rounded masses of lignite are closely associated, ranges from 20 to 40 feet in thickness and is clearly interbedded with till deposits. The till deposit above the sands is from 50 to 100 feet thick, and the till below them is exposed along the base of the bluffs to heights of 20 to 30 feet above the present high-tide level. Thus the present position of this old beach deposit, lying above the present sea level, indicates that an uplift of 30 to 50 feet has taken place along this particular section of the coast. It is clear that the old beach deposit was formed after at least 30 to 40 feet of typical till, upon which it rests, was laid down by glacial ice; that the ice then receded sufficiently to allow beach washing and deposition to take place at this locality, and that this interval was followed by a readvance of the glacial ice accompanied by renewed deposition of till to a thickness of 50 to 100 feet on top of the old beach sediments. This wave-washed beach member resulted from sedimentation that took place in the interval between the deposition of the older and the younger beds of till.

The same relationship between beds of till and interstratified gravels is indicated along other sections of the bluffs, except that the absence of marine shells or similar fossil remains in the intertill sediments shows that they were not reworked or assorted by wave action or, in other words, deposited along a strand line. Yet in some exposures such sands and gravels, instead of being cross-bedded, like most of the outwash material, are fairly well assorted, as if deposited in ponded waters, and it is reported that some of the best placer concentrations occur in areas along the beach where these sands form the bedrock.

Although the assorted beach material that contains marine shells and occurs along about a mile of the bluffs is the only conclusive evidence that elevation has taken place on this coast during Quaternary time, the bluffs present certain structural features which indicate that slight deformational movements occurred. It was noted that the outcrop of the upper surface of the basal deposit of till, as it is exposed along the bluffs, has a broadly undulating configuration and that although the till has a considerable horizontal extent, there are sections where the surface of the till sinks below the present high-tide level, and in these sections the bluffs are composed wholly of outwash sands and gravels. This might be interpreted as indicating merely irregularities in deposition of the till and outwash deposits, such as often characterize glacial sedimentation of this kind. In view, however, of the evidence furnished by the older elevated marine beach along the northern part of the bluffs, it seems probable that a general but slight deformation of the unconsolidated sediments has occurred along this coast in late Quaternary time. This deformation is chiefly expressed by elevation of the lower bed of till to the extent of 30 to 50 feet above high tide, and in some places a corresponding depression in others. The coastal plain may then be considered to be made up of gently warped beds that form broad anticlines and synclines whose structure is possibly reflected in the generally rolling surface of the plain. However, it must be borne in mind that such features, with the exception of the elevated marine beach, may be fully accounted for by irregularities in the original deposition of the sediments.

ORIGIN.

As all placer deposits are directly or indirectly related to the topographic development of the region in which they occur, it is useful to note the physiographic processes that have affected the placer beach deposits of Kodiak Island, especially because here they are clearly evident. As all the gold-placer deposits so far discovered on Kodiak Island are confined to the present ocean beaches and as practically no valuable placer concentrations have been found in any of the present stream gravels, the topographic development of the whole island must be considered in a study of the origin of the placers. The physiographic history of the island is therefore treated somewhat more fully than might otherwise be considered necessary.

Glacial erosion.—In general the topography of Kodiak and the neighboring islands is the product of severe glaciation. The length and depth of the fiord inlets and channels are evidence of ice erosion that gave the major surface features their present form; and the numerous lakes in overdeepened or dammed-up sections of glaciated valleys afford further evidence on the former presence of ice streams which failed to erode their valley troughs to the depth of those now occupied by the sea. The arrangement and trends of the fiords, channels, and deep valley troughs, some of which contain large lakes, shows that the glaciation of Kodiak Island was essentially local in origin and had its center of development in the high mountainous interior, where it took the form of an ice cap that buried all but the highest summits and ridges. This ice cap was the source and feeding ground of numerous glaciers that flowed from it in all directions. At the stage of maximum glacial development some of the larger ice flows extended even beyond the present limits of the island. In fact, the whole of Kodiak Island appears to have been generally overridden by ice, with the possible exception of a small area situated in its northwestern part. There a group of low mountains, the western extremity of which forms Cape Ikolik, appears to have remained free from ice, as a nunatak area, in the western margin of the ice fields.

With particular reference to the western part of the island, Uyak and Alitak bays may be noted as examples of great fiords that were fully occupied by large glaciers, whose terminal lobes extended beyond the present headlands during the stage of maximum ice development. Olga Bay was occupied by a great ice lobe that extended to and beyond the present western shore line of the island in the vicinity of Low Cape, as shown by the morainal deposits that outcrop in the present coastal bluffs. The present western shore line of this bay is determined by a great crescentic terminal moraine that was deposited along the border of the ice lobe during a stand in the general retreat of the ice. The valley of Karluk River and lake was eroded by a long glacier, and likewise the valley basins now occupied by Ayakulik Lake and several other lakes of considerable extent, contiguous to Olga Bay, were eroded by glaciers and later dammed off by moraines.

Thus the whole of Kodiak Island is dissected by a ramifying series of glaciated valley troughs, some of which now stand above sea level but many of which are partly occupied by the sea. These valleys radiate from the high central mountainous part of the island, upon which the ice cap formerly rested. The ice cap that now occupies much of southwestern Kenai Peninsula illustrates in many respects a stage of glaciation through which Kodiak Island passed before the ice disappeared from it.

Glacial deposition.—The lowland features of Kodiak Island, as well as its highland features, are distinctly of glacial origin. Thus, all the lowland tracts in the western part of the island are the result of glaciofluvial sedimentation that accompanied glacial erosion in the highland areas. Primarily, the development of the lowlands depended upon the deposition by the glaciers, during their advance, of large quantities of detrital material that was eroded and transported from the bedrock of the highland areas. The greater part of this material was laid down about the borders of the island and along the larger valleys in the form of ground moraine or till—sediments composed chiefly of clays, with some sands and gravels—which contain scattered angular fragments of rock and subangular or fairly well rounded boulders and cobbles. The lowlands also contain widespread outwash deposits of silts, sands, and gravels that were formed during the retreat of the ice front from its maximum limit back into the valleys. Besides the outwash sediments that overlie much of the ground moraine there are also terminal and lateral moraine deposits, chiefly of the recessional type, whose form has been little modified since they were laid down.

Practically all the lowland deposits are of glaciofluvial origin. They are present at the heads of the fiord inlets and bays and along the bottoms of the valleys that extend inland from tidewater; but in the valleys that have not been eroded by glaciers below the present sea level the valley floors are flat marshy tracts that are poorly drained by the present streams and that contain many ponds and small lakes. Many of these valleys contain large lakes in basins which were formed either by unequal erosion of the bedrock or by the deposition of moraines that formed dams across the valleys. In some places both causes probably acted in combination.

The most extensive lowland tract on Kodiak Island extends along its western coast from Cape Alitak northward nearly to Cape Ikolik. This tract constitutes a typical fluvioglacial coastal plain, about 30 miles long and from 2 to 5 miles wide, made up of coalescent sheets of ground moraine and outwash sediments with some modified terminal and lateral moraine deposits. Its rolling surface stands from 25 to 200 feet above sea level and has the typical uneven configuration of glacial sedimentary deposits, little modified by the erosion of postglacial streams. The greater part of the surface of this coastal plain apparently stands to-day as it was deposited by the outwash drainage from the retreating ice. Numerous poorly drained ponds and small lakes lie on its surface, and the few large streams that flow across it from the highlands have eroded only narrow valleys into the plain.

Along its coastal margin this plain is bounded by practically continuous sea bluffs cut in the unconsolidated sediments by the waves. These bluffs range in height from 25 to 200 feet, but in most places along the greater length of the 30 miles of coast they are between 50 and 100 feet in height. This rather uniform line of steep wave-cut bluffs may indicate that the coastal plain was elevated since its formation. Some evidence to support this view was found in the bluffs at one locality, where marine shells occur in wave-deposited beach sands at a height of 20 feet above the present limit of high tide. For the most part, however, the wave-cut bluffs may be considered as a measure of the horizontal wave erosion that has occurred along this section of the coast since the coastal plain was formed, for it is probable that the original limit of the plain was seaward from its present position and that a marginal belt of the unconsolidated sediments, from 1 to 2 miles wide, has been cut away by postglacial wave action.

At any rate, it is clear that the unconsolidated deposits of this coast have been eroded and reworked by the waves, and it is logical to presume that the placer metals now found in the beach sands were concentrated by wave action, especially as no placers have been found in the narrow valleys cut by postglacial streams in the coastal-plain deposits. There are, however, several factors to be considered in this connection that will be discussed with reference to the bedrock sources of the placers.

Postglacial erosion.—The present drainage of Kodiak Island was conditioned by the drainage that preceded glaciation. All the larger streams flow in valley troughs which were deeply eroded by the glaciers that formerly occupied them, and most of the large streams are merely the overflow outlets of the glacial lakes that occupy basins in these valleys. There are only two large streams on the island, Karluk and Ayakulik or Red rivers, and both of these drain large glacial lakes. Consequently most of the stream systems consist of one or more headwater branches and their small tributaries, which empty into the lakes, and a trunk stream that drains the lake to the sea. In general, the present streams have performed an insignificant amount of erosion and have modified only slightly the dominantly glacial topography of the island. The sediments that the headwaters of these streams erode from the bedrock areas of the highlands are deposited chiefly in the lakes, and the sediments that are eroded by the streams below the lakes are transported to the sea to be incorporated in the beaches. The principal erosion going on now is the cutting of relatively narrow valleys across the unconsolidated glacial deposits of the lowlands. Thus little erosion or concentration either of mineralized bedrock or of older unconsolidated sediments which could form placer deposits of commercial value has been done by the present streams.

To sum up the evidence presented by the topographic development of Kodiak Island it may be stated that postglacial wave erosion and concentration along the shores of the island, especially along the shores composed of unconsolidated fluvioglacial sediments, is the most active agency favorable to the formation of placer deposits.

THE BEACH DEPOSITS.

GENERAL FEATURES.

The present beach along the foot of the bluffs that extend from Cape Alitak to Old Red River, a distance of about 30 miles, is the longest section of continuous sandy shore line on Kodiak Island. Sevenmile Beach, so named from its approximate length, which extends westward from Uyak Bay along the foot of similar bluffs of till, is the next longest beach on the island. None of the other beaches, most of which extend across the mouths of glaciated valleys, are more than 1 or 2 miles long, and the greater part of the coast line is characterized by rocky bluffs and headlands.

The width of the west coast beach, as exposed between average high and low tide levels, ranges from 200 to 500 feet. The thickness of the loose beach deposits is from 3 to 6 feet, but, as in all beach sands and gravels that are undergoing active washing by surf, the thickness differs from place to place and time to time according to the manner in which the deposits are shifted back and forth by the surf and the variations effected by the ebb and flow of the tide.

As the upper limit of the beach is determined in greater part by the base of the bluffs, which in turn is determined by the average limit of high tide, there is a comparatively small development of higher storm beach deposits along this coast. The only beach deposits of this kind are the short spits across the narrow valley mouths of a few large streams, which have cut down through the coastal plain to sea level, and several sections of barrier beach across the entrances to shallow tidal lagoons that occur between Cape Alitak and Low Cape, where certain tracts of the coastal plain are somewhat less elevated than elsewhere.

The bedrock or marine platform upon which the loose beach deposits rest is, for the most part, the compact clay till that forms the chief part of the bluffs. There are variations in the composition of the bedrock, however, that correspond to variation in the material in the bluffs and which are directly controlled by them. Thus, in the localities where morainal boulder deposits are incorporated with the till the beaches are characterized by boulder pavements that rest on the beach platform and the greater part of the beach deposits consist of coarse gravels, cobbles, and boulders. A few of these boulders are from 5 to 10 feet in greatest dimensions and a number of them reach dimensions of 2 to 3 feet. Where the more or less assorted outwash sands and gravels, which are associated with the till, extend below sea level the bedrock is commonly composed of sandy silt and somewhat resembles quicksand in behavior when excavated. This condition appears to be due to its being charged with considerable water, possibly derived from seepage and under hydrostatic pressure.

The typical till bedrock is said to be somewhat too slippery to retain the gold as well as the "quicksand" bedrock, but nevertheless good concentrations are made upon it under certain conditions, particularly during violent storms that sweep it quite clean of the loose beach sands. The so-called "quicksand" bedrock is said by the miners to be the most favorable for the retention of the placer gold and to afford the best yields, but the areas of such bedrock are not extensive. The boulder pavement areas of the beach platform are considered to be unfavorable for the concentration of the gold in profitable amounts, and besides they are the most difficult to mine.

DERIVATION OF THE BEACH PLACERS.

It is evident that marine wave erosion has produced the practically continuous line of till and outwash bluffs which extends for about 30 miles along the west coast of Kodiak Island, and that the present beach deposits along the bases of these bluffs are the result of concentration by the waves of the sediments that compose the bluffs, with the exception of the small proportion of similar sediments deposited on the beach by the larger streams that cross the coastal plain.

If the present configuration and extent of the coastal plain are accepted as a basis for estimating the former seaward extension of the original plain it would appear that before postglacial marine erosion set in the former shore line was from 1 to 3 miles west of the position it now occupies. If the composition of that part of the coastal plain that apparently has been thus eroded away was similar to that of the present bluffs some idea may be formed of the character and great quantity of sediments that have been acted upon by marine erosion during postglacial time in producing the present beach placers. If the placer deposits of the present beach represent the concentrations from a belt or strip of coastal-plain sediments about 30 miles long, 2 miles wide, and 40 feet thick, it would appear that more than 2,000,000,000 cubic yards of material has been reduced by wave erosion. Probably the average gold content of these deposits was not more than 1 cent in 50 cubic yards of the original coastal-plain deposits as laid down by glacial sedimentation. The small gold content of the gravels is indicated by the fact that practically no colors of gold have been obtained in prospecting the coastal-plain sediments as they occur in the bluffs, even in those parts where the outwash gravels and sands show evidence in the form of stratification of having been somewhat thoroughly assorted. The writer was informed that only in two or three places have even very fine colors of gold been obtained in such prospecting. The results obtained in prospecting along the beds of the present streams that cross the coastal plain are also reported to be wholly negative.

Apparently the slight stream erosion that the unconsolidated coastal-plain deposits have undergone since they were formed has contributed practically no placer metals to the beach deposits.

CONCENTRATION OF THE BEACH PLACERS.

Prospects show that finely divided gold is present along the whole length of the beach from Cape Alitak to Old Red River, as well as in the shorter beaches along other sections of the coast of Kodiak Island. However, the best concentrations occur chiefly in the form of local patches that are comparatively small and are not permanent as to position or richness, because the loose sands and gravels and the placer metals associated with them are being continually reassorted and shifted according to the direction and violence of the storms. Because of this unstable condition of the beach deposits the concentrated heavy minerals do not form pay streaks in the usual sense, although the heavier sands do have a tendency to accumulate along the upper limits of the beaches near the base of the bluffs that arrest the surf and regulate its backwash action.

The west coast of Kodiak Island is exposed particularly to storms from the southwest and northwest quarters and as a rule the best concentrations of the beach result from such storms. The storms of autumn and spring, together with the higher tides of those seasons, are considered to be the most effective in concentrating the placer metals in the beach sands. The waves induced by these storms cut away the basal parts of the bluffs and add small quantities of new material to the beach to be concentrated. Apparently the beaches have become enriched by this process, which has acted for a long period of time on a great quantity of sediment.

The ordinary range of tide on this coast is from 8 to 10 feet, and during the spring and autumn the extreme range is from 12 to 16 feet. Thus there is a considerable increase in the zone of wave attack during the spring and autumn that enables the surf to reach and erode the foot of the bluffs more strongly. The higher surf also sweeps the rather resistant compact clay bedrock quite clear of the usual overburden of gravel and sand and more thoroughly concentrates the fine gold with the heavier sands in patches that may be easily mined during the intervals of falling tide, provided they are found at once and recovered without delay.

"Banking up" and "washing down" are the terms used by the miners to describe the constant eroding and concentrating action of surf on the beach. The power of the storm surf on this coast is great enough to move boulders that weigh several tons, of which there are a few distributed here and there along the beach. Boulders of this weight have been noted to change their positions appreciably in the course of several years. It is said that a moderate surf, such as accompanies a "lazy summer swell," is often very effective in "washing down" small areas of the beach and concentrating the fine gold on the compact beach platform of till in patches that yield good returns in mining, although the surf that accompanies ordinary moderate weather usually "banks up" the loose sands and thus builds up an overburden of the lighter sands from 4 to 6 feet thick that is practically barren of placer.

Although the shifting about of the loose sands and gravels on the beach platform, together with the placer metals which they contain, is always more or less marked during a single storm and is carefully noted by the miners, the erosion of the compact till bluffs is rarely noticeable in a short period of time. Apparently there are periods of several years during which the appearance of the bluffs changes but little as a result of marine erosion. On the other hand, there are periods in which the accumulative effects of wave action are considerable, especially in conjunction with other factors. Miners who have resided on this coast say that for several years previous to a series of rather violent earthquakes late in October and early in November, 1912, which are supposed to be related to the eruption of Mount Katmai in June of that year, the bluffs along the west coast of Kodiak Island for considerable distances had the aspect of a smooth and even-sloped escarpment, the surface of which was mantled by a well-established growth of turf from high-tide level to the top. The earthquakes in 1912, however, were severe enough to disrupt not only the bluffs but the greater part of the coastal plain as well. The ground was frozen at the time, so that the surface fracturing was emphasized. The compact till was ruptured and slightly faulted, some blocks were displaced to the extent of 3 feet with relation to one another, and the turf-covered surface of the coastal plain was greatly broken far inland from the bluffs, so that some cracks stood open as much as a foot.

Since these earthquakes the bluffs have been eroded back by the waves 15 to 20 feet or more along practically their entire length, as is shown by well-established landmarks, such as cabins and other structures. In consequence of the concentration by the surf of the new material loosened from the face of the bluffs, it is stated that the gold content of the beach sands in recent years was noticeably greater than it had been for several years previous to 1912. This statement corroborates the view that the placer gold is derived chiefly from the bluffs of till and outwash sediments.

In 1917 the bluffs presented sheer cliff walls for long distances, and although some sections were much broken by steps or benches the faces of the bluffs are so steep that ladders have to be provided for their ascent. Slides or slumps, such as characterize steep banks that are largely composed of clay, are common features, and small trickling streams erode steep gullies back short distances. No doubt such agencies tend to reduce the bluffs to a more mature aspect during periods when they are not disturbed by earthquakes or very strong marine erosion. Although no data are at hand as regards their number, earthquakes of considerable violence are known to occur frequently in this part of Alaska, and they may accelerate erosion, especially in tracts of unconsolidated sediments such as the coastal plain here considered, where steep escarpments facilitate the delivery of loosened material upon a beach where it may be directly attacked by heavy surf. However, storms of unusual intensity or duration are the chief factors in concentrating the loose beach deposits and forming the temporary segregations of placer sands. The autumn of 1902 is stated to have been a particularly good season for mining on the Kodiak beaches, the good yields being attributed to a series of northwesterly gales that washed the upper parts of the beaches almost clean of the overburden of gravel and sand and left the gold concentrated in patches with a minimum of waste.

Thus the loose beach deposits are undergoing a never-ending assortment and reassortment with the addition of comparatively small quantities of new material from the bluffs at irregular intervals of heavy storm erosion. In this way the beach placers, whose aggregate content of placer metals is not great, pass through seasonal periods of temporary local enrichment that are more marked in some years than in others. These periods alternate with others during which erosion and concentration by the waves is not so vigorous. Successful mining therefore depends chiefly upon the opportune recovery of the better concentrations at localities that can not be selected beforehand and at times that can not be predicted.

THE PLACER MINERALS.

The chief minerals that make up the heavy concentrates of the beach comprise magnetite, pyrite, chromite, gold, and a little platinum. In most of the concentrates as mined there also is present a considerable percentage of artificially introduced metals, such as lead in the form of bird shot, solder from cans, and shoe nails of iron and brass. Some of the concentrates contain many heavy flakes of oxidized iron that probably are derived from disintegrated cans and nails. Amalgam lost from previous operations is recovered in small amounts.

By far the chief mineral of the concentrates is magnetic black sand (magnetite), which constitutes fully 95 per cent of several samples examined, the remaining 5 per cent of nonmagnetic material being pyrite and chromic sand, which in dried samples may be readily separated with a hand magnet.

For the most part the magnetite sand is fine grained; nine-tenths of it readily passes the 40-mesh screen, of which from one-third to two-thirds passes the 100-mesh screen.

The following analysis (No. 3214) of placer platinum from Canvas Point, west coast of Kodiak Island, was made by R. C. Wells, of the United States Geological Survey:

Analysis of placer platinum from Kodiak Island, Alaska.

SiO_2, etc	1.2
IrOs, Rh	26.9
Ir from part of IrOs	6.1
Rh from part of IrOs	.1
Pt	55.3
Ir	2.4
Fe	6.4
Au	.3
Rh	.7
Pd	.1
Cu	.6
Ni	.08
Zn and Ag	Trace.
	100.18

Specific gravity, 17.2.

MINING METHODS.

The mining practice has been that usually followed by beach miners, that is, rough washing of the sands in rockers or small portable sluice boxes which save only the coarser flake or scale gold and that part of the finer gold which amalgamates readily. It has always been realized that much of the fine or flour gold and also some of the light scaly gold was lost with the black-sand concentrates. Heretofore, the concentrates have been considered an unavoidable hindrance to the recovery of the gold, especially the flour gold, and, until recently, they have been discarded as soon as possible without secondary treatment. The platinum, which has been recently recognized in small amounts, in association with the gold, was overlooked in the earlier years of mining, for the manner of washing the sands was too crude to reveal it. Recently, however, secondary panning of the concentrates, followed by drying and blowing and crude separation with small horseshoe magnets, has been practiced by a few of the more careful miners with a view of saving more of the fine gold; and this has resulted in the recovery of a few pennyweights of platinum.

The use of undercurrents in treating the concentrates, or, better still, the use of some form of concentrating tables, would without doubt give a much greater saving of the gold in the sands and a better separation of the platinum metals. But such treatment of the concentrates on a commercial scale, to be fully effective, would require a community of interest in the mining operations that has not existed up to the present time and probably would be difficult to establish and maintain.

Mining operations can be conducted on the beaches of Kodiak Island only during periods of receding or low tides, because high tides, or at least the wash of the surf during such periods, reach to the base of the bluffs along practically the whole length of the west coast at all times. Consequently all mining equipment must be removed from the beach during high tide, and seldom can more than four or five hours actual mining be done on the beach in one day. Thus no preliminary preparation is possible beyond prospecting with a pan or shovel as the tide begins to ebb to determine a favorable place to mine. In former years rockers were used exclusively for such transient operations, but recently small portable sluice-box equipment has been used to a considerable extent along certain sections of the beach where water is obtainable. Rockers are still used where water is not available and during winter when the water supply for sluicing freezes; they are also used for washing rich sands, which are sometimes collected from the beach in small quantities and accumulated in holes on the bluffs for future treatment and for reworking concentrates.

The sluicing operations are generally carried on by two or three men working in partnership and depend upon a water supply obtained from the small lakes or ponds that lie on some parts of the coastal plain within short distances of the top of the bluffs. The water is brought to the edge of the bluffs in ditches, and thence it is conveyed to the beach, 40 to 70 feet below, by canvas hose; or, in favorable situations, where the bluffs are benched, a combination of ditches and flumes is built to carry the water along the face of the bluffs in either direction from the supply ditch, so that it is available for sluicing operations along a considerable section of the beach. The same result is also accomplished by extending canvas hose along the bluffs. Thus some of the miners are able to use the portable sluice boxes at any point along a section of the beach within half a mile of their main ditch, and, in a general way, such zones of operation are recognized as belonging to the claimants of water rights and main ditches.

The portable sluicing equipment consists of three boxes about 10 feet long, 10 inches wide, and 8 to 10 inches deep. The two lower boxes are fitted with wire grating on top of burlap. The third or upper box, into which the sands and gravels are shoveled, is provided with slat riffles. A little quicksilver is generally used in the upper part of the lower box. The box line is set up on four or five horses that admit of adjusting both the height and grade as desired. The usual grade is about 8 per cent. The water is led into the boxes by canvas hose, about 6 inches in diameter, that is connected with the permanent system by which it is conveyed along the bluffs.

The usual practice is to prospect the beach as the tide begins to fall and thus locate a spot where good concentration is taking place without too much overburden of barren sand and gravel. The boxes are set up on a satisfactory spot as soon as the tide has receded sufficiently. Generally a foot or so of the top sands is shoveled aside from a strip 6 or 7 feet wide along each side of the boxes, and 6 to 12 inches of the heavier sands that rest on the clay bedrock are shoveled into the boxes from both sides. The area of beach mined during one recession of the tide by three or four men working together is seldom more than may be properly shoveled into the boxes as they are set up in one position—an area about 30 feet long and 14 feet wide or from 400 to 450 square feet—although occasionally two set-ups or about twice this area may be mined. When the tide rises the equipment is removed to a safe place on the bluffs.

It is considered unprofitable to attempt to mine in places where the overburden is more than 2 feet thick, and if possible a locality is selected where the back wash of the surf has temporarily "washed down" the loose sands and gravels to a foot or less in thickness. Such "washing down" or transient concentration of the beach usually occurs in a marked manner as a result of the backwash of heavy surf, and occasionally it is so thorough that all but 1 or 2 inches of the heaviest placer-bearing sands are swept from the clay bedrock along the base of the bluffs. But the areas so concentrated are generally small and of little permanence, for often they may be covered by 2 feet of lighter sands during the next advance of the tide and the placer concentration may be dispersed with this change. Such concentrations are often scraped up hurriedly, shoveled into buckets, and placed in safe places on the bluffs, to be washed later with rockers.

The miners patrol the beach at frequent intervals, test it here and there by panning for the development of favorable conditions of concentration, and thus secure the best yields. But under such transitory conditions mining is uncertain, and a month or more may pass without opportune conditions for activity, particularly in the summer, during which many of the miners make little effort to work.

The compact till bedrock usually presents a surface that allows very little of the gold to become lodged within it, especially in those areas where it has been freshly scoured by the heavy surf that forms the best concentrations. Consequently it is seldom necessary to mine more than one-half to 1 inch of the somewhat softened surface of the bedrock in order to deliver practically all the gold-bearing material to the washing apparatus, except in localities where the bedrock is of the so-called "quicksand" variety, which consists essentially of a plastic mixture of sand, silt, and clay, charged excessively with water. In this quicksand bedrock the gold often finds lodgment to a depth of 6 to 12 inches below the ordinary surface of scour, and as the gold is retained by it to better advantage such areas are stated to be more enriched than those where the bedrock is of compact till. Such areas of bedrock are particularly searched for by the miners and are mined to a depth of about a foot. Apparently the patches of so-called quicksand bedrock occur chiefly along those sections of the bluffs where outwash sediments that are incorporated with the till deposits dip below sea level and thus form the beach platform upon which the surf scours. Sediments similar to the quicksand may be observed in the bluffs above high-tide level that do not contain prospects of gold, so it is probable that the richer concentrations of gold noted in this kind of bedrock are formed on the present beach. It appears that the quicksand bedrock favors enrichment, as contrasted with the compact till, simply because it is a looser-textured medium that offers more secure lodgment for and better retention of the heavier beach concentrates from the washing action of the surf as it shifts the loose sands and gravels about on the beach platform.

Mining is seldom attempted on those sections of the beach where boulders and cobbles are particularly abundant, and the comparatively small amount of coarse material that may occur in areas that are mined is shoveled or rolled aside, according to size, as it is encountered during the progress of digging.