Quicksilver Deposits of Southwestern Alaska

GEOLOGICAL SURVEY BULLETIN 1187

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By C. L. SAINSBURY *and* E. M. MacKEVETT, Jr.

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A description of the quicksilver mines and prospects, with special emphasis on the structural controls of ore deposition

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CONTENTS

ILLUSTRATIONS

[Plates are in pocket]

TABLE

QUICKSILVER DEPOSITS OF SOUTHWESTERN ALASKA

By C. L. Sainsbury and E. M. MacKevett, Jr.

ABSTRACT

Quicksilver deposits have been found at widely separated localities throughout southwestern Alaska, an area of several thousand square miles. The deposits consist principally of fracture fillings in faults in brittle rocks of diverse types, including graywacke, shale, granite, dolomitized limestone, and altered dike rocks. Current production (1960) is principally from ore bodies in or near faulted and altered diabase dikes, but promising deposits are found in dolomitized limestone and in massive graywacke. Individual ore bodies are localized by diverse structural or petrologic controls, yet features present in all the deposits are faults, which channeled ore-bearing solutions, and open spaces, in which cinnabar was deposited.

The ores consist of cinnabar, which may be accompanied in individual deposits by large amounts of stibnite or by pyrite or marcasite, native mercury, or realgar or orpiment. Nonmetallic gangue minerals are dolomite or ankeritic dolomite, quartz, calcite, limonite, and clay minerals, including dickite. Dark cinnabar, which is generally rimmed by light cinnabar, contains detectable amounts of iron; hematite in small amounts is intimately intergrown with some of the ore.

The ores were deposited probably where rising hydrothermal solutions met a copious flow of ground water. The localization of many generally richer deposits near altered diabase dikes probably resulted principally from rapid chemical changes involving dilution and acidification of alkaline ore solutions by acid sulfate waters derived from oxidation of the pyrite found in all altered dikes.

The limonite and hematite found with all the ores were probably in part deposited concomitantly with the cinnabar and stibnite and are considered here as hydrothermal minerals, even though the iron may have been brought into the hydrothermal system by ground water.

The deposits are found along an arcuate zone of tectonic activity containing Tertiary volcanic rocks that in turn are cut by faults of a still active system. Near one group of deposits, a cold-water spring containing sulfur and chloride is depositing a foul-smelling black mud that contains mercury, antimony, and all the rarer elements generally found in the ores.

The authors believe that additional prospecting will disclose more deposits and that continued exploration of known deposits and close attention given to factors outlined in this report will result in the discovery of minable ore bodies.

INTRODUCTION

The quicksilver mines and prospects of Alaska are scattered widely throughout an area of several thousand square miles, mostly within the drainage basin of the Kuskokwim and Nushagak Rivers (fig. 1). This region is generally referred to as southwestern Alaska, a usage adopted in this report. The productive properties comprise one major mine (Red Devil), which produced more than 20,000 flasks of quicksilver (1 flask=76 pounds of mercury) by 1960, two mines that produced more than 1,000 flasks, and three properties that produced more than 50 flasks. In addition, some two dozen lode prospects are known; these are generally grouped in areas that are referred to in this report as the Sleetmute, White Mountain, Cinnabar Creek, DeCourcy Mountain, Rhyolite, Kolmakof, Rainy Creek, Kagati Lake, and Marsh Mountain areas. Placer cinnabar has been found in many of the gold placers of the region, although no placers have produced more than a few flasks of quicksilver. The full extent of the quicksilver area cannot be stated accurately, for promising prospects in new areas are still being found by trappers or hunters. New deposits that will become producing mines will probably be found. This report was prepared to aid the continued development of the quicksilver industry.

Some of the quicksilver deposits of southwestern Alaska have been worked periodically for almost 50 years. During this time, many writers have described briefly several of the deposits, and both State (formerly Territorial) and Federal agencies have examined many of them. Interest in the deposits has been intermittent, and production has coincided principally with periods of unusually high prices for quicksilver or with local demand for quicksilver in the placer mines of Alaska. The production history, however, is due more to the fluctuating price of quicksilver and the lack of sufficient operating capital than to productive capacity. A factor contributing to the intermittency of production is without doubt the geologic complexity of the quicksilver deposits in Alaska, as elsewhere. Many of the first mine operators and prospectors of Alaska had neither previous experience with quicksilver mining nor sufficient funds for exploration. As a consequence, many prospects opened on promising leads were abandoned after the initial ore shoot was exhausted because neither geologic advice nor money to sustain a search for new ore shoots was available. Nevertheless, the prospectors, with the help of local capital, continued to explore old quicksilver deposits and to search for new deposits. Although the Red Devil, the Alice and Bessie (Parks property), and the DeCourcy Mountain mines had produced several hundred flasks of quicksilver each by 1943, the total production of quicksilver from the Alaskan deposits amounted to only 800 flasks

(Webber and others, 1947, p. 9). In 1944, the Red Devil mine produced 1,090 flasks of quicksilver (Webber and others, 1947, p. 10) and became Alaska's largest quicksilver mine. A decline in the price of quicksilver caused the mine to be closed in late 1944, and between 1945 and 1951, quicksilver production from Alaskan mines was small.

In 1952–53, renewed interest in the quicksilver deposits of southwestern Alaska coincided with the exploration programs of the Defense Minerals Exploration Administration (DMEA) and came when loans for exploration at the Red Devil, Red Top, and DeCourcy Mountain mines were granted. The total authorized amount of the three initial loans was $194,963.00, of which the largest amount went to the Red Devil mine. Private capital contributed $48,740.00 of this total. This amount of exploration money far exceeded the funds that had previously been available at any one time to private companies or individuals in Alaska for sustained exploration of quicksilver deposits, and significant discoveries resulted. Rich ore was discovered at the Red Devil mine, and in 1957 this mine yielded more than 5,000 flasks of quicksilver and became one of the largest producers in the United States. At the Red Top and DeCourcy Mountain mines, DMEA exploration discovered ore that has not yet been fully explored.

During the same period, Mr. Russell Schaeffer (now deceased), long active in the search for quicksilver, began to produce substantial amounts of quicksilver from his newly discovered lode at Cinnabar Creek. Under the impetus of both a continued high price for quicksilver and the commercially important continued production from Alaska, several large companies devoted a substantial amount of time and money to examining and exploring the cinnabar deposits of Alaska. Between 1954 and 1959, they took under option and explored several of the older prospects as well as several new ones.

By 1959, quicksilver mining was established as the only important lode-metal-mining industry of Alaska. Production from Alaska should exceed 3,000 flasks annually for several years, and Alaska will thus produce nearly 10 percent of the total United States production of quicksilver.

The Red Devil mine has done much to stabilize the economy of the central Kuskokwim Valley by providing year-round employment to a substantial number of people, many of whom had depended largely upon fishing, trapping, and part-time work for a living. (By 1964, the Red Devil mine had exhausted the known ore bodies, and additional exploration financed by an OME (Office of Mineral Exploration) loan failed to disclose minable ore. In late 1964, production from the Red Devil mine was limited to that obtained by small leasers.) The authors believe that quicksilver mining can be a continuing part of the economy of Alaska, and the desire to give all possible assistance to the new industry led to the work discussed in this report.

PREVIOUS WORK BY THE U.S. GEOLOGICAL SURVEY

Early descriptions of the quicksilver deposits of Alaska were based upon brief examinations made during regional reconnaissance surveys prior to 1941. During the years 1941–46, field parties of the U.S. Geological Survey, under the direction of Wallace M. Cady, undertook the geologic mapping of the central part of the quicksilver district, and detailed attention was given to the cinnabar deposits. This geologic information was made available in preliminary form to the U.S. Bureau of Mines for use during their exploration of the quicksilver deposits and was subsequently published (Cady, 1944, 1945, 1952; Webber, 1945). As a result of these studies, the geologic environments and the mode of occurrence, mineralogy, and obvious petrologic associations of the ores were clarified (Cady and others, 1955).

In 1957–58, MacKevett, assisted by H. C. Berg, mapped the Red Devil mine, and this report is based upon work proposed by MacKevett as a result of his work.

PRESENT INVESTIGATION

SCOPE AND OBJECTIVES

The main objectives of this report are (1) to bring up to date the published information on the quicksilver deposits of southwestern Alaska, (2) to evaluate existing ideas on the origin and genesis of the deposits, and (3) to prepare detailed geologic maps of those deposits that have been developed or extended since Cady's work and by interpreting these maps to draw attention to the structural and petrologic controls of ore deposition. A secondary objective is to assemble in one publication brief descriptions of the known quicksilver deposits of southwestern Alaska.

METHODS OF WORK

Most of the geologic maps were made on base maps prepared by planetable and alidade at suitable scales. The underground workings at the Red Top and Parks properties were mapped by compass-tape traverse but were tied to surface maps by planetable survey. The surface maps of the Parks property and the Kagati Lake property were made by compass-tape traverses.

The laboratory investigations consisted of the authors' study of thin sections of rocks and ores, study of polished sections of ores, and analyses and identification of ores and gangues by X-ray spectrometer and X-ray diffractometer and of study of ore samples by semiquantitative spectrographic methods by other workers in the laboratories of the U.S. Geological Survey.

ACKNOWLEDGMENTS

The studies of the U.S. Geological Survey in Alaska are made possible and are greatly facilitated by the valuable aid and assistance so freely given by individuals and organizations. We would like specifically to acknowledge the assistance of Robert F. Lyman, general manager, Alaska Mines and Minerals, Inc. (formerly the DeCourcy Mountain Mining Co.), who arranged for quarters and storage at Red Devil mine, provided transportation by automobile and air, held mail, and gave valuable information about the mines and prospects. Ed Hager, mining engineer of Cordero Mining Co., accompanied us to the prospects at White Mountain and provided information on the activities of his company and a map of the Alice and Bessie mine. Gordon Herreid, mine geologist at Red Devil in 1959, was the source of stimulating discussions on the origin and genesis of the quicksilver ores. Ray Maloney, mining engineer of the U.S. Bureau of Mines, gave information about the Rhyolite property. Russell Schaeffer made us welcome at his mine on Cinnabar Creek and collected the first fossils ever found in the volcanic section west of his camp. Clarence Wren, of Red Top Mining Co., provided transportation from Aleknagik to Dillingham and gave freely of his knowledge of the Red Top mine. George Willis made a riverboat available and provided information on the Willis and Parks properties.

Bud O'Donnell, of Vanderpool Flying Service, and Nick Mellick, Jr., of Nick Mellick and Sons, provided dependable air transportation, and their skill is herewith acknowledged.

M. C. Taylor prepared most of the topographic and base maps and assisted in the geologic mapping.

REGIONAL GEOLOGIC SETTING OF THE DEPOSITS

The quicksilver deposits discussed herein lie in an area some 250 miles long and 75–100 miles wide along the northwest side of the Alaska Range (fig. 1). The rocks of the area are mostly sedimentary and are assigned to the Holitna (Ordovician(?), Silurian, and Devonian), Gemuk (Carboniferous to Cretaceous), and Kuskokwim (Cretaceous) Groups (Cady and others, 1955). The major structural features of the area strike northeast; they consist of parts of two anticlinoria and synclinoria (Payne, 1955) and of major faults, some of which are hundreds of miles long. The faults are part of an arcuate

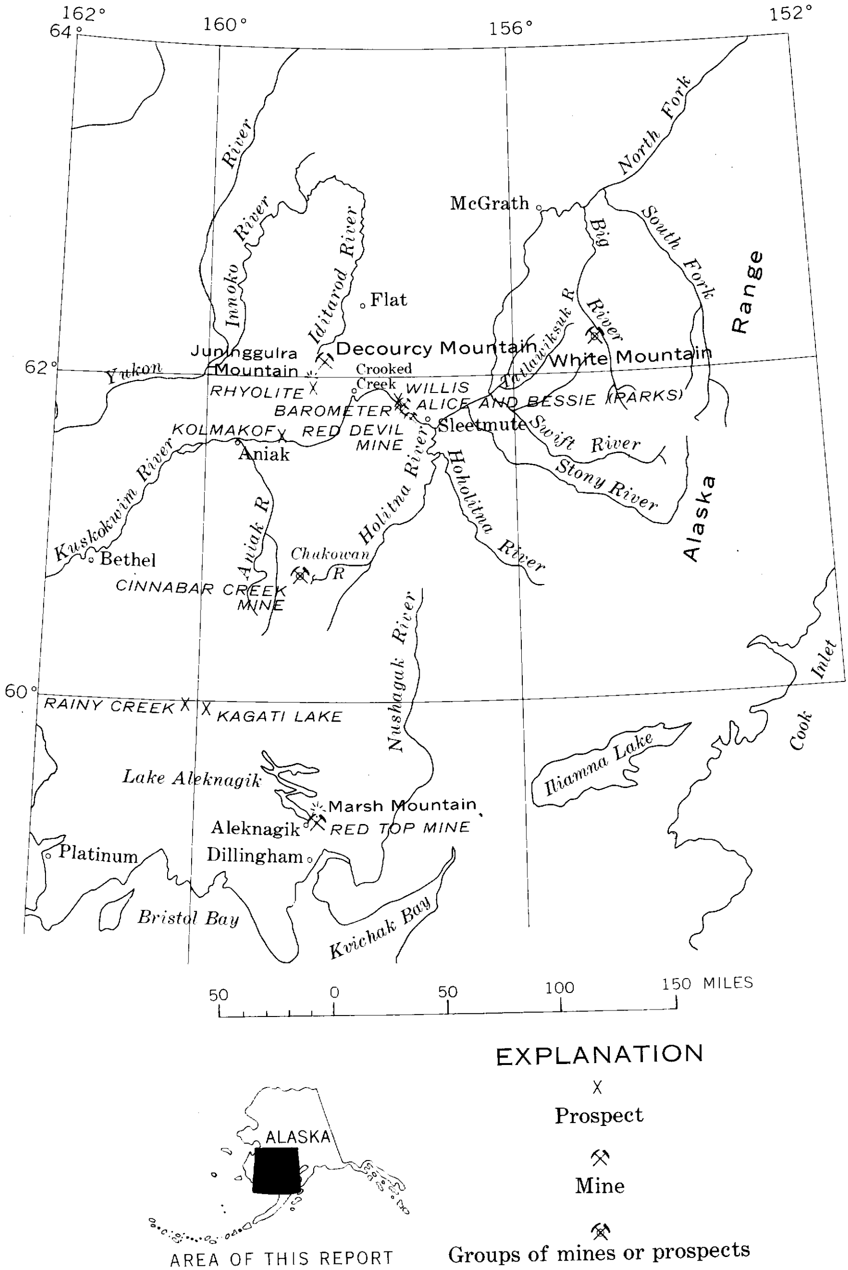

Figure 1.—Location of quicksilver mines and prospects in southwestern Alaska.

system that crosses Alaska from the Bering Sea eastward and continues into Canada parallel to the Continental border (Capps, 1940; Moffit, 1954; Cady and other, 1955; Dutro and Payne, 1957; St. Amand, 1957; Twenhofel and Sainsbury, 1958; Hoare and Coonrad, 1959). Smaller folds impressed upon the anticlinoria and synclinoria cause structural complexities that control the attitude of the rocks at each quicksilver deposit. The sedimentary rocks are intruded by numerous dikes, stocks, and batholiths that range in composition from diabase and tholeiite to albite rhyolite and granite. Extrusive rocks consisting of olivine basalt and rhyolite of Late(?) Cretaceous and Tertiary age are common in the central part of the quicksilver area, where they lie disconformably on deformed rocks of the Kuskokwim and Gemuk Groups. The basalt areas are remnants of what was probably an extensive basalt plateau more than 3,000 feet thick (Cady and others, 1955, p. 53). All the rocks are cut by faults of the arcuate system, some of which are still active.

Many of the deposits are closely associated with altered dikes that intrude the graywacke, shale, and siltstone of the Kuskokwim and Gemuk Groups, but some deposits found since 1957 occur in granite and in the carbonate rocks of the Holitna Group. Hence, all types of rock within the district may be considered as potential host rocks for quicksilver.

The geologic and tectonic setting of the quicksilver deposits of southwestern Alaska is similar in most respects to that of most other deposits of the world (Becker, 1888; Bailey, 1959). The Alaskan deposits lie in the northern part of the circum-Pacific belt of Tertiary to Recent tectonism and volcanism, which contains many quicksilver deposits (Becker, 1888).

Details of the geologic setting of each deposit are given under the descriptions of the individual properties.

DESCRIPTIONS OF MINES AND PROSPECTS

SLEETMUTE AREA

The Sleetmute area is here defined to include the area on the Kuskokwim River between Sleetmute and a point 10 miles downstream extending a mile or two on each side of the river (fig. 2). This area contains many quicksilver deposits, including the Red Devil, Barometer, and Alice and Bessie mines and more than a half-dozen prospects. The area is underlain by graywacke and shale of the Kuskokwim Group, which is tightly folded and intruded by altered dikes and sills that include diabase, amygdaloidal basalt, and quartz porphyry. Nearby terranes to the south are characterized by extensive masses of albite rhyolite (Cady and others, 1955). The location of mines and prospects in the Sleetmute area is shown in figure 2, and descriptions of them follow:

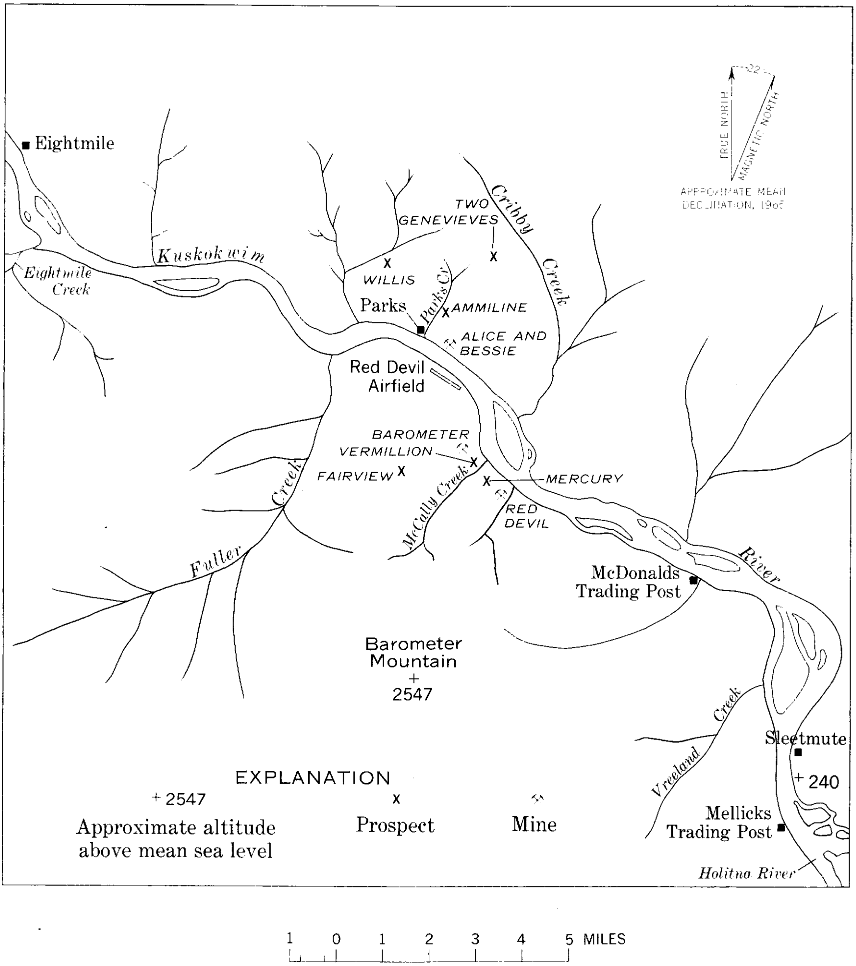

Figure 2.—Location of mines and prospects in the Sleetmute area. From Cady and others (1955, pl. 3).

RED DEVIL MINE

HISTORY AND PRODUCTION

The Red Devil mine was described in detail in reports by Cady and others (1955) and by MacKevett and Berg (1963), and only its essential features will be summarized herein.

The Red Devil mine is Alaska's premier quicksilver producer; the total yield by 1960 was more than 20,000 flasks of quicksilver. The surface workings of the mine are at altitudes between 260 and 570 feet above sea level on the left bank of the Kuskokwim River 6 miles below Sleetmute (figs. 1, 2). The mine is supplied by aircraft from Anchorage some 250 miles south-southeast and by shallow-draft boats from Bethel at the mouth of the Kuskokwim. The deposits were located in 1933 and have been mined intermittently since 1939; most production has come after 1951. The mine was being operated by Alaska Mines and Minerals, Inc., in 1960. By 1964, the ore was largely exhausted, and operations were limited to individual leasing.

Most of the mine workings are accessible from the main shaft or from the Dolly shaft, which is 1,082 feet N. 43½° W. of the main shaft. The main shaft is inclined at an angle of about 64° and extends from an altitude of 311 feet at the surface to an altitude of −143 feet at the 450-foot level. Five levels are driven from the main shaft; most of the ore has been mined by stoping between levels.

GEOLOGY

The host rocks at the Red Devil mine are graywacke and shale of the Kuskokwim Group and altered diabase(?) dikes. As the mine is on the southwest limb of the Sleetmute anticline, which trends northwest, the strata at the mine have a fairly uniform attitude, striking N. 30°–45° W. and dipping 45°–60° SW. The dikes strike northeast and dip 40°–65° SE. Ore shoots formed at and near intersections of the altered dikes and abundant northwestward-trending faults that mainly parallel the bedding of rocks of the Kuskokwim Group. This structural control, which was first recognized probably by John D. Murphy, former manager and resident geologist at Red Devil, is illustrated in figure 3. The typical ore bodies that formed along and near the fault-dike intersections are elongate and pencil shaped and plunge about 40° S. They range from a few inches to about 4 feet in stope width and from a few feet to several hundred feet in stope length.

The numerous faults have right-lateral offset and individual displacements that range from a few inches to about 40 feet and have a cumulative right-lateral displacement of several hundred feet. The critical intersections between these faults and the altered dikes occur throughout a zone that is at least 600 feet wide and 1,500 feet long. At least two altered dikes occur in the mine; they consist of fine-grained masses of calcite, chalcedony, sericite, and subordinate amounts of quartz and clay minerals. These dikes are probably altered diabase, as similar but less extensively altered dikes nearby have diabasic textures and contain relict minerals characteristic of diabase. The Red Devil ore consists of cinnabar and stibnite; realgar and orpiment are local minor constituents. The cinnabar and stibnite form massive aggregates, encrustations, breccia fillings, and vug linings. In places, crystals of both minerals are exceptionally well formed. The stibnite

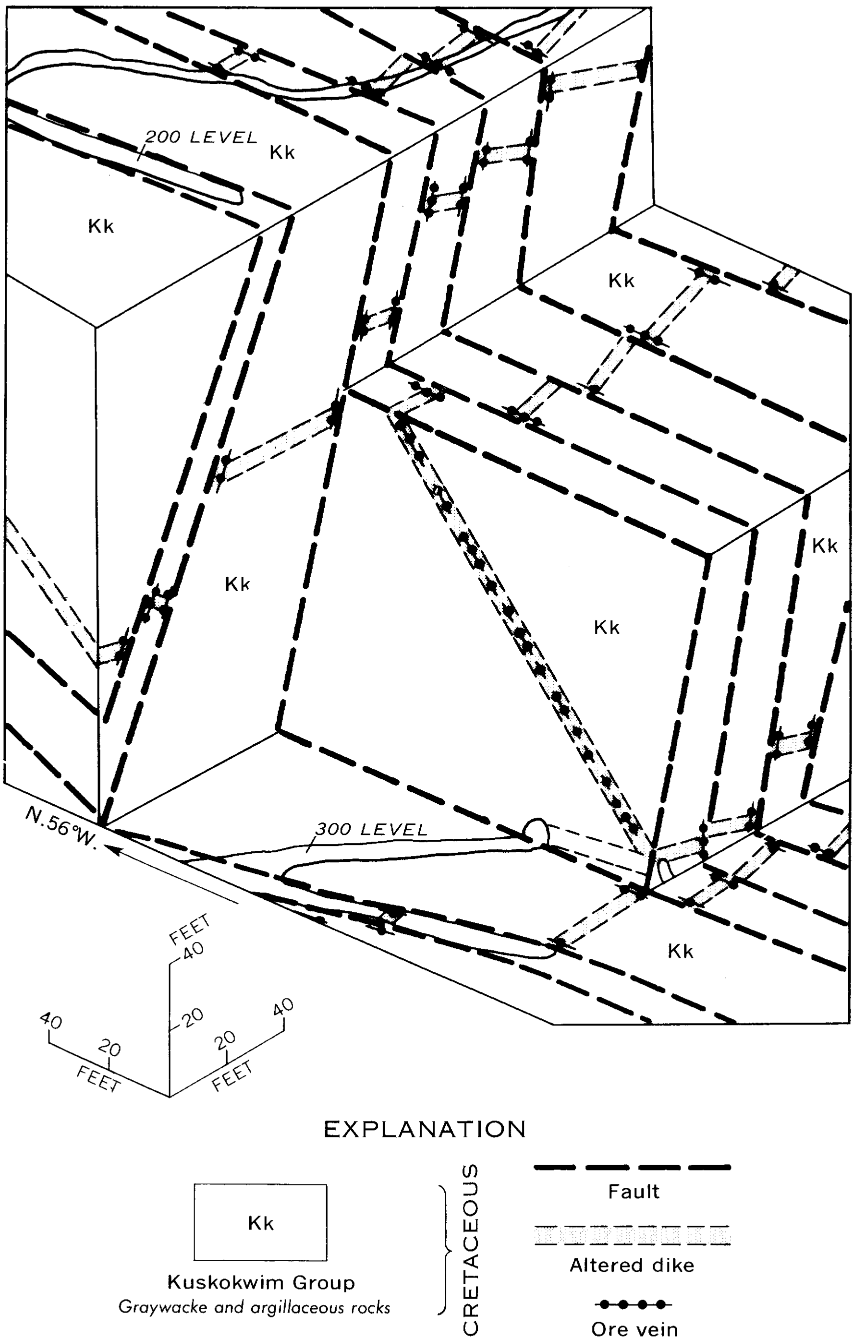

FIGURE 3.—Generalized isometric block diagram of part of the Red Devil mine.

is commonly more abundant than the cinnabar, but as of 1960 no antimony has been recovered from the mine. Quartz, dickite, and minor amounts of calcite are associated with the deposits. Most of the ore formed by filling of open space, although some of the cinnabar and stibnite replaced altered dike rock.

ALICE AND BESSIE MINE (PARKS PROPERTY)

LOCATION AND ACCESSIBILITY

The Alice and Bessie mine, also known locally as the Parks property, is on the north bank of the Kuskokwim River midway between the Red Devil mine and the Willis property (fig. 2). The mine is easily reached by small boat from Red Devil airfield.

HISTORY AND PRODUCTION

The Alice and Bessie mine was staked by W. W. Parks in 1906. By 1923, Parks had produced 120 flasks of quicksilver, which was used by the gold-placer operators at Iditarod and Georgetown (Webber and others, 1947, p. 19). Most of this quicksilver was recovered from ore obtained in surface pits and trenches. By 1914 an adit 200 feet long had been driven by Parks. In 1936, after Parks' death, lessees extended the adit to 525 feet and drove 240 feet of drift. In 1942, under the impetus of war demand for quicksilver, the U.S. Bureau of Mines trenched and sampled the property; this work was described by Webber and his coworkers (1947, p. 22–23). In 1957, Cordero Mining Co. took an option on the property, extended the trenches, sank a small inclined shaft from the surface, and explored the main dike exposed underground by means of percussion long-hole drilling. Cordero relinquished their option in December of 1958. In August of 1959, Sainsbury, assisted by C. M. Taylor, prepared the accompanying map of the trenches and the underground workings. In 1960, the property was owned jointly by Nick Mellick and George Willis; Mellick's interest was under purchase contract to Robert F. Lyman.

No recent production has been reported from the mine, although some rich ore has been stockpiled in surface trenches.

GEOLOGY

The bedrock at the Alice and Bessie mine consists of graywacke and shale of the Kuskokwim Group intruded by several dikes and sills. The bedded rocks strike northwestward and dip northeastward at angles ranging from 20° to nearly 90°. The intrusive rocks include diabase and altered dikes having a relict trachytic texture but an unknown original composition. Most of the intrusive rocks are extensively altered to a mixture of clay minerals, quartz, carbonate minerals, and limonite, and except where weathered, they contain small fuzzy specks of pyrite.

Plate 1 is a composite geologic map of the new trenches and the underground workings. The principal ore-bearing sills are well exposed in a continuous trench more than 700 feet long, and the complex relations of ore, intrusive contacts, and cross faults are so well exposed that the mapping was done on a scale large enough to depict these relations in detail. The principal intrusive rock is a sill of diabase that strikes N. 15°–40° W., dips 70°–85° NE., and averages about 20 feet in thickness. At the west end of the main trench, the sill changes strike by almost 90° around the nose of a fold (pl. 1). Small offshoots of the sill irregularly intrude the enclosing strata, and small isolated patches of altered igneous rock exposed in the trenches are probably similar offshoots. The sill exhibits angular and blocky contacts that coincide in orientation with joints in the bedded rocks. Other irregular dikes and sills are exposed in trenches not continuous with the main trench.

The underground openings penetrate the main sill and several other intrusive rocks that may be related to the main sill. A dike trending N. 50° E. at right angles to the bedding and dipping 35°–60° NW. is exposed in the central section of the adit. The dike is offset by several bedding-plane faults, most of which have had left-lateral movement.

ORE DEPOSITS

SURFACE EXCAVATIONS

Most of the cinnabar at the Alice and Bessie mine occurs in the main sill and the adjacent rocks in veins and veinlets that trend a few degrees east of north. Some cinnabar occurs in shattered graywacke near contacts with igneous rock or along minute veinlets or joints in the intrusive rocks. The longest vein seen in surface exposures is at the southeast end of the main trench (A, on pl. 1) and is traceable for 50 feet. One end is covered by spoil and dump material. The vein, which attains a maximum width of about 1 foot, consists of brecciated graywacke and intrusive rock cemented by quartz, cinnabar, and stibnite. The vein strikes north and dips 52° E. A prospect shaft was sunk along the intersection of the vein and the sill to a slope distance of 50 feet. Some cinnabar was seen in the shaft to a slope distance of 25 feet below the collar, where the shaft is caved. Several smaller veinlets having a similar mineralogy to that of the vein northwest of the shaft are found generally near the margins of areas of rocks so intensely argillized that one cannot tell if they were once dike rock or graywacke, or both.

Two veins about 20 feet long and locally as much as 6 inches wide are exposed in a deep trench approximately 200 feet northwest of the caved shaft (B, on pl. 1). They consist of quartz, cinnabar, and stibnite, and in places they are composed solidly of sulfide.

About 200 feet farther northwest, a deep trench in bedrock discloses several sills (C, on pl. 1). The sills and the bedded rocks are moderately argillized and contain small cinnabar-stibnite-quartz veinlets not more than 1 inch thick that occur along joints. Specks of cinnabar are disseminated in the argillized rock.

Cinnabar and stibnite veinlets occur at the northwest end of the main trench (D, on pl. 1) along distinct faults that offset the sill several feet. The ore consists of broken and argillized intrusive rock and graywacke cemented by quartz that contains cinnabar and stibnite. Some of the stibnite is oxidized, but the cinnabar is unaltered.

The outlying trenches north and west of the main trench are mostly sloughed, and bedrock is poorly exposed in the areas where the trenches were mapped. Several dikes and sills are exposed in these trenches, but only one has associated cinnabar (E, on pl. 1). The cinnabar was deposited with quartz in brecciated graywacke at the dike contacts, which are angular and are controlled in part by joints in the graywacke. The shale beds are not brecciated and are barren. The volume of mineralized graywacke exposed is too small to have commercial value, but the preferential concentration of cinnabar in porous or brittle rock is well illustrated.

UNDERGROUND OPENINGS

The underground workings at the Alice and Bessie mine consist of a single adit about 540 feet long driven N. 30° E. from the north bank of the Kuskokwim River (pl. 1). The adit transects the bedded rocks almost at right angles to their strike; it intersects a dike subparallel to the adit, as well as several small sills, before penetrating the sill exposed in the surface trenches. A drift some 220 feet long was cut to explore the hanging wall of the sill, which is altered and cut by small quartz-carbonate-cinnabar veinlets. Longholes were drilled by the Cordero Mining Co. to explore the sill beyond the drift walls.

According to Cady and others (1955, p. 110), some ore was mined from a small drift along the dike exposed by the adit where the structural setting is identical with that at the Red Devil mine.

The only potential ore that has been located is in the altered sill where cut by a well-defined fault striking N. 40° W. and dipping almost vertically. This ore is inferred from cuttings collected from the percussion drill holes in the western part of the drift (F, on pl. 1). Most of these holes intersected cinnabar and thus indicated that the sill is mineralized over a length of almost 100 feet. The degree of alteration of the sill in this area as well as the small cinnabar veinlets exposed in the drift, is additional evidence suggesting potential ore. Additional exploration will be required to determine the grade of this ore.

MINERALOGY

Cinnabar, stibnite, and pyrite are the most common sulfide minerals at the Alice and Bessie mine. Stibnite is generally intricately intergrown with cinnabar in the larger veins, particularly in those containing quartz gangue. Small veinlets may contain cinnabar as the only sulfide in a carbonate or quartz and carbonate gangue. A little pyrite is disseminated widely in the altered intrusive rocks and is associated with cinnabar in some parts of the intrusive rocks. A few specks of hematite were noted with cinnabar in some specimens of ore.

The gangue minerals are quartz, calcite, dolomite or ankeritic dolomite, clay minerals, and limonite. The earliest carbonate to form is dolomite or ankeritic dolomite, whereas many of the younger veinlets contain calcite, much of which was deposited after the ore. The clay minerals include dickite, which occurs in many places in the veins as pure masses as much as half an inch thick, and in some places dickite surrounds cinnabar crystals. The clay alteration seems to have been most intense in the mineralized parts of the dike. Weathering extends to a depth of only a few feet, for hard bleached intrusive rocks are exposed in the bottoms of most trenches.

Limonite at the Alice and Bessie mine is more abundant near the surface than in the adit, but all the highly argillized rocks contain some limonite. The relations observed in thin sections suggest that the limonite is mostly supergene in origin.

STRUCTURAL CONTROL OF ORE DEPOSITION

Fractures that formed in brittle rock localized most of the ore at the Alice and Bessie mine. One set of these ore-bearing fractures strikes slightly east of north across the main sill, which strikes N. 15°–40° W. Some of the fractures offset the sill; others do not. Ore occurs along and in these fractures, irrespective of the type of wallrock.

A second set of ore-bearing fractures are caused by bedding-plane faults that extend into the igneous rocks. Ore in these fractures is confined almost entirely to the igneous rocks. The few flasks of quicksilver produced by 1959 came from veins in this second set, although the richest ore exposed in 1959 is in veins in the first set.

Analogy with the Red Devil mine (see p. 9) indicates that the intersections of intrusive rocks and bedding-plane faults may be especially favorable sites for ore shoots.

SUGGESTIONS FOR EXPLORATION

The surface exploration of 1957 at the Alice and Bessie mine disclosed veins that are as rich as those mined at the nearby Red Devil mine but are not as wide or continuous. Additional stripping of the intrusive rocks will probably disclose other veins. Whether these veins constitute minable ore shoots depends upon their vertical continuity, width, length, and grade. Future exploration should be directed first toward determining the vertical continuity of the exposed veins.

It may be significant that the line of intersection of the well-defined fault seen underground (at F, pl. 1) and the sill slopes upward shallowly in a S. 30° E. direction. A line connecting the mineralized sill near the fault underground and the highly altered area (at A, pl. 1) in the surface trench would slope upward at about 25° in a S. 10° E. direction. These lines are close enough in orientation as to suggest that a continuous pipe of alteration and mineralization may lie along the intersection of the sill and the fault. In the nearby Red Devil mine, the intersections of bedding-plane faults and dikes are especially favorable sites for ore. If future work is done underground at the Alice and Bessie mine, a short crosscut should be driven through the sill near the easternmost percussion drill holes that intersected ore, and a short raise should be driven to test the intersection area. If ore is found to lie along the intersection, the other areas of intense alteration found in surface trenches could be explored with more confidence, for these altered areas are probably the tops of hydrothermally altered areas closely connected with ore.

WILLIS PROPERTY

LOCATION AND ACCESSIBILITY

The Willis property is about 1 mile north of the Kuskokwim River at a point some 3 miles below the Red Devil mine (fig. 2). A tractor road leads from the property to the Kuskokwim River, which is navigable to this point by vessels drawing 10 feet of water or less. The property can be reached by small boat from Red Devil airport, which accommodates twin-engine turboprop aircraft.

HISTORY AND PRODUCTION

The Willis property was staked in 1909 by Oswald Willis and Jack Fuller (Cady and others, 1955, p. 111). Ownership passed to George Willis, a nephew of Oswald Willis, and in 1959 the property was under option to Alaska Mines and Minerals, Inc.

Development prior to 1942 consisted of several pits, trenches, and short adits. In 1942, the U.S. Bureau of Mines excavated six bulldozer trenches and exposed four dikes. Between 1942 and 1958, only assessment work was performed by Willis. In 1958 Willis excavated many new bulldozer trenches, several of which exposed ore, and Sainsbury, assisted by C. M. Taylor, mapped the property by planetable and alidade in late August 1959 to preserve data on the geology exposed by the trenches. The area explored by trenches is about 1,300 feet by 1,000 feet.

The property has produced only a few flasks of quicksilver, although some additional rich ore was stockpiled during the 1958 exploration.

GEOLOGY

The bedrock at the Willis property is covered to a depth of 6–8 feet by perennially frozen silt, and the only bedrock exposures are in the trenches. The bedded rocks consist of graywacke and shale of the Kuskokwim Group and strike northwestward and dip 55°–80° SW. The bedded rocks are complexly intruded by several altered dikes and sills, the original composition of which is unknown but which probably contained feldspar and, possibly, quartz phenocrysts (pl. 2). Trench exposures are not continuous enough to allow accurate projection of all the intrusive rocks, but the main intrusive appears to be a complex dike striking northwestward and dipping about 15° NE. The dike is at least 20 feet thick where both contacts are exposed in the long trench at the northwest end of the trenched area, but the thickness elsewhere cannot be determined. Several other dikes and sills, which could be offshoots of the main dike, outcrop in the trenches. As some dikes crosscut others, they cannot all be contemporaneous. The bedded rocks and the dikes are cut by bedding-plane faults, which displace the dikes as much as 20 feet, and by faults that trend N. 10°–30° W. obliquely across the bedding (geologic section, pl. 2).

DISTRIBUTION OF CINNABAR

Cinnabar-bearing veins exposed at the Willis property range from a few feet to more than 50 feet in length and are as much as 6 inches in width. The veins lie in or near the igneous rocks. Most of the larger veins strike N. 30°–65° W. and dip steeply either northeastward or southwestward. Smaller veinlets within the dikes occupy joints that strike north to N. 30° E. Cinnabar is disseminated locally in small amounts in the argillized walls of fractures in the dikes and nearby sedimentary rocks or in the irregularly argillized rock at the contacts between intrusive rock and graywacke.

The relations between veins, faults, and contacts are particularly well displayed in the long sloping trench trending N. 20° E. at the northwest end of the trenched area. The central part of the trench follows the upper contact of a dike dipping shallowly to the north (pl. 2). Bedding-plane faults offest the dike, and small veinlets containing cinnabar cut the dike subparallel to the bedding of the enclosing rocks. Exposures in short prospect tunnels driven along the upper and the lower contacts of the dike show that the dike is almost horizontal. A rather considerable amount of cinnabar is disseminated in rocks exposed by the trench, but this disseminated ore is low in grade. The veinlets exposed in the trench are too narrow for individual mining.

MINERALOGY OF THE ORE

Cinnabar and stibnite are intimately intergrown in many of the veins, but in others, cinnabar is the only sulfide mineral. Pyrite occurs in small amounts in the altered dikes and is abundant on the dump of one old prospect tunnel. A little stibiconite(?) has replaced stibnite in one of the veins. Hematite is a minor but very widespread mineral in the ore.

The gangue minerals are quartz, carbonate, deep-red limonite, and dickite (listed in order of decreasing abundance). The dickite, which was identified by X-ray diffractometer, commonly forms pure masses that surround cinnabar and stibnite in a veinlet. In some of the veins, feathery quartz contains dispersed cinnabar and limonite so intricately associated as to suggest that they are contemporaneous.

The cinnabar at the Willis property ranges from clear brilliant red to deep purple black. The microscope discloses that the dark centers of many of the cinnabar grains are surrounded by clear red cinnabar. The dark cinnabar may contain dispersed hematite or pyrite, for it consistently gives a test for iron.

The altered dikes contain a carbonate mineral, sericite, quartz, clay minerals, and a rather large amount of apatite and sphene. The limonite that stains the dikes may, in part, be contemporaneous with the ore deposition.

STRUCTURAL CONTROLS OF ORE DEPOSITION

The ore at the Willis property formed principally in veins along fractures made where bedding-plane faults intersected the intrusive rocks. These veins lie principally in a shallowly, dipping dike, and hence their longest dimension may be horizontal, in contrast with veins in Red Devil mine and the Alice and Bessie mine, which are elongated down the dip of the dikes. An analogy with other deposits in southwestern Alaska indicates that the veins probably do not extend far above or below the shallow-dipping dike and hence should not be projected far down dip in calculating ore reserves.

SUGGESTIONS FOR EXPLORATION

Future exploration at the Willis property should be determined by the attitude of the intrusive being trenched. Trenches oriented northeast transverse to the bedding of the sedimentary rocks along one contact of a steeply dipping dike should uncover any ore bodies in the dike. Exploration of the main dike, which dips shallowly north, will require stripping of large areas if veins are not to be missed. Any well-defined faults found in the bedded rocks should be projected to determine their intersection with all known intrusives, and these intersections should be tested. Areas of intense clay alteration extending below the weathered zone probably should be exposed by trenching. A shallow shaft on the largest vein in the central trenched area could allow determination of the vertical continuity of the vein and collection of information that would be valuable in evaluating other veins.

BAROMETER MINE

LOCATION AND ACCESSIBILITY

The Barometer mine property consists of 10 claims lying at altitudes between 300 and 500 feet about a mile northweast of the Red Devil mine (fig. 2). The mine is reached via the road between the Red Devil airfield and the Red Devil mine.

HISTORY AND PRODUCTION

The Barometer mine, which was staked in 1921 by Hans Halverson, produced 10 flasks of quicksilver in 1938 and 6 flasks in 1940 (Cady and others, 1955, p. 110). Several pits and trenches and an adit 122 feet long were excavated in 1922 and 1923. During 1931 a short crosscut was driven from the adit. Subsequent exploration consists of nine hand-dug trenches as much as 80 feet long that were excavated during a U.S. Bureau of Mines exploration program in 1943 and a bulldozed trench several hundred feet long that was excavated in 1957 under DMEA sponsorship. The Alaska Mines and Minerals, Inc., the owners of the property in 1960, dug additional trenches during 1959 and 1960 and plan additional exploration of the deposits. If commercial ore is developed, it will be treated in the furnace at the Red Devil mine.

The mine was visited briefly by MacKevett in 1957 during the DMEA exploration and by Sainsbury in 1959.

GEOLOGY

The Barometer mine is on the southwest limb of the Sleetmute anticline in a geologic setting similar to that at the Red Devil mine. The host rocks are shale and graywacke of the Kuskokwim Group (Cretaceous) that are cut by altered dikes. The sedimentary rocks strike N. 45° W. and dip about 55° SW. The attitudes of the dikes were not ascertained because of poor exposures, but like similar dikes at the Red Devil mine, they probably strike northeastward and dip southeastward. Numerous faults trending northwestward are nearly parallel to the bedding of the strata and cut the dikes and the bedded rocks.

No detailed geologic maps of the Barometer mine are available, and the extent and relationships of the quicksilver deposits are not known. The U.S. Bureau of Mines cut and analyzed 68 samples, each 5 feet long, from their exploration trenches and the underground workings. Three of these samples contained 10–20 pounds of mercury per ton, 19 contained 1–10 pounds per ton, and 46 assayed less than 1 pound per ton (Webber and others, 1947, fig. 8, table 8). The results of this sampling indicate several discrete quicksilver-bearing zones. The distribution of these zones makes tenable the assumption that the structural control is similar to that at the Red Devil mine, where most of the ore is localized at and near intersections between altered dikes and right-lateral faults trending northwest and about parallel to the bedding. Based on analogy with the Ded Devil mine, the Barometer deposits should form elongate, pencil-shaped bodies that plunge about 40° S. The Barometer deposits consist of cinnabar that is commonly associated with stibnite and realgar in a quartz-rich gangue near areas of altered iron-stained rock containing abundant quartz, carbonate minerals, and clay minerals. Such rock was termed "silica-carbonate rock" by Cady and others (1955, p. 105).

The postulated similarity to the Red Devil mine is in part borne out by a statement made by Gordon Herreid, mine geologist at the Red Devil mine, who reported (oral commun. 1959) that trenching done in 1959 near the Kuskokwim River disclosed promising cinnabar-stibnite veins in altered dikes cut by bedding-plane faults.

FAIRVIEW PROSPECT

The Fairview prospect is 1⅔ miles N. 76° W. of the Red Devil mine on the south side of the Kushokwim River (fig. 2) at an altitude of about 850 feet. This description of the prospect is taken from Cady and others (1955, p. 111) and from Webber and others (1947, p. 27, 28), for no work has been done at the property since these writers described it. The workings consist of several shallow trenches and pits. The three longest trenches, respectively 125, 130, and 175 feet long, were hand dug as part of a U.S. Bureau of Mines exploration program in 1943.

The prospect is in a sill of porphyritic albite rhyolite that is about 120 feet thick. The sill intrudes interbedded shale and graywacke of the Kuskokwim Group (Cretaceous) that forms the southwest limb of the Sleetmute anticline. The quicksilver deposits, which are localized near the central parts of the sill in a zone of fracturing that cuts across the sill at a small angle, consist of cinnabar-stibnite veinlets.

The following description of the exploration work done by the U.S. Bureau of Mines is quoted from Webber and others (1947, p. 28):

> Trench 1 is normal to the strike of the dike (sill) and revealed a 35-foot width of material containing an average of 0.7 pound of mercury a ton. The maximum degree of mineralization occurring in any one 5-foot width was 1.0 pound of mercury a ton.
>
> Trench 2 is parallel to trench 1 and is 225 feet northwest of it. A 50-foot zone intersected by this trench contains an average of 2.88 pounds of mercury a ton. Two contiguous 5-foot samples in this zone contain 8.0 and 4.6 pounds of mercury a ton, respectively. A second zone 5 feet wide is 35 feet (measured normal to the strike) from the first and contains 5.4 pounds of mercury a ton.
>
> The third trench, parallel to trenches 1 and 2 and 205 feet northwest of trench 2, contained no observed seams of cinnabar and was not sampled. Probably this trench was too far from trench 2 to intersect the zone of mineralization found in that trench.

These trenches were sloughed and partly filled by slope wash in 1959, and satisfactory geologic maps of them could not be made.

OTHER QUICKSILVER DEPOSITS IN THE SLEETMUTE AREA

Several other quicksilver claims have been staked in the Sleetmute area and nearby (fig. 2), but none of them was examined during the present investigation, as no work had been done on them since Cady's visit in 1944. The brief descriptions of these prospects are taken from Cady and others (1955, p. 111) and are included here for completeness. Most of these claims have been prospected by shallow pits and trenches only.

The Vermillion and Mercury claims, which are near the mouth of McCally Creek on the south side of the Kuskokwim River (fig. 2), have been rather systematically trenched. These prospects are in graywacke and shale of the Kuskokwim Group on the southwest limb of the Sleetmute anticline. The small amount of cinnabar that was found occurred chiefly as stringers along the bedding planes in the shale.

At the Two Genevieves prospect, which is on the north side of the Kuskokwim River southwest of Cribby Creek (fig. 2), cinnabar is localized in vugs in a breccia zone near the upper contact of an altered sill. The country rocks are graywacke and shale of the Kuskokwim Group. At the Ammiline prospect, near Parks Creek (fig. 2), cinnabar occurs in fractures in albite rhyolite that intrudes the sedimentary rocks of the Kuskokwim Group. This mode of occurrence is similar to that at the Fairview prospect.

Other prospects that are reported to contain cinnabar (Cady and others, 1955, p. 111) include one southwest of the head of the small creek that flows past the Barometer mine, another at Mellick's trading post (fig. 2), and a third at an altitude of about 1,000 feet on the northeast slope of Barometer Mountain (fig. 2). None has been explored sufficiently to evaluate it. In addition, many claims have been staked in the Sleetmute area on discoveries of float of quicksilver ore.

WHITE MOUNTAIN AREA

LOCATION AND ACCESSIBILITY

The White Mountain area is about 60 miles south-southeast of McGrath on Chunitna Creek, a small fork of an unnamed tributary of the Tatlawiksuk River (fig. 1). The name White Mountain is used by local residents to refer to a prominent mountain capped by white dolomite that is the northernmost of a series of hills that rise to an altitude of 3,300 feet between the Big and Swift Rivers.

The mineralized area is accessible by foot from natural landing areas on river bars in the Big River some 6 miles to the northeast or by aircraft, which land on a gravel airfield at the main prospect. Small boats can be "lined" up Chunitna Creek to points about 10 miles southwest of the prospects.

Abundant spruce timber grows in the valley bottoms near the prospects, but slopes above an altitude of about 1,800 feet are covered by tundra and bullbrush or are bare. Foot travel in the lower areas is rather slow and difficult because of muskeg and deadfalls.

HISTORY AND PRODUCTION

The prospects at White Mountain were staked in 1958 by Jack Egnaty, an Eskimo from Sleetmute, and were immediately taken under option by Cordero Mining Co. Cordero Mining Co. trenched by hand several of the prospects in 1958 and reopened several of the trenches in 1959. No production had been attempted by 1963. In 1964, Robert F. Lyman was mining the deposits on a lease basis.

MacKevett visited the property in 1958 and mapped several of the trenches, and in 1959 Sainsbury and C. M. Taylor spent 17 days at the property mapping the main prospect area by planetable and alidade and preparing a reconnaissance geologic map of a larger area.

In early 1960, the geologic maps made by the Geological Survey were made available to the U.S. Bureau of Mines for use in exploration begun in 1960. The Bureau of Mines used a hand auger to test favorable areas outlined on the basis of the geologic map, and results were sufficiently encouraging that a larger scale program using a bulldozer was undertaken in 1961. By September 1961, when Sainsbury revisited the property, rich ore had been found in several trenches, all of which were along a fault believed by the writers to represent the main ore channel (Sainsbury and MacKevett, 1960, p. B37, B38). The trenches near the north ore zone had exposed an altered dike south of the area trenched previously by Cordero Mining Co. The dike is not shown on the accompanying geologic map, which was prepared in 1960.

GEOLOGY

GENERAL GEOLOGIC SETTING

The geology of the White Mountain area is described in some detail in this report because the quicksilver prospects are very promising and because there is no published geologic information about the area. Before 1958 no quicksilver deposits were known in limestone in southwestern Alaska, and therefore the finding of deposits in limestone at White Mountain substantially widened the scope of known host rocks of the quicksilver deposits.

During early surveys, two reconnaissance parties of the Geological Survey passed approximately 50 miles south (Smith, 1917) and 50 miles north (Spurr, 1900) of the area. The northeastern margin of the area mapped by Cady and others (1955, pl. 1) is about 50 miles west. The White Mountain area lies on the Alaska Yukon geanticline (Payne, 1955) in the northwest foothills of the Alaska Range. The Farewell fault, one segment of a major fault zone that can be traced for a distance of 1,400 miles (Twenhofel and Sainsbury, 1958, p. 1434), cuts through the area and causes major disparity of structure and stratigraphy on opposing blocks. A reconnaissance geologic map of the White Mountain area is shown on plate 3.

SEDIMENTARY ROCKS

The sedimentary rocks at White Mountain include strata of Middle(?) Ordovician, Silurian(?) and Cretaceous(?) ages. The Farewell fault everywhere separates the Paleozoic rocks from the Cretaceous(?) rocks. The Middle(?) Ordovician rocks comprise an estimated 4,600 feet of marine limestone and argillaceous limestone; minor shale and calcareous sandstone occur near the base of the section. The Silurian(?) rocks include at least 1,500 feet of limestone and massive dolomite. The Cretaceous(?) rocks are quartz conglomerate and interbedded black to brown shale grading upward into microconglomerate, and coarse sandstone and interbedded coarse conglomerate and shale. The Cretaceous(?) rocks are at least 8,100 feet thick. Coal fragments, crossbedding, and the high proportion of vein-quartz pebbles are evidence of deposition in continental or brackish-water environments. Hand specimens of the conglomerate are indistinguishable from specimens of the Cantwell Formation (Lower Cretaceous) collected by Clyde Wahrhaftig from the central Alaska Range. The conglomerate at White Mountain is provisionally correlated with the Cantwell Formation on the basis of lithologic similarity, although the nearest known exposures of the Cantwell Formation lie some 100 miles east in the Alaska Range (Capps, 1927, p. 93).

The Middle(?) Ordovician rocks are dated by ostracodes and a brachiopod (USGS 3149–SD) that were studied, respectively, by Jean M. Berdan, of the U.S. Geological Survey, and G. A. Cooper, of the U.S. National Museum. Berdan (written commun., 1960) concluded:

> Although none of the forms listed here, with the possible exception of *Pyxion*, is confined to the Middle Ordovician, the general aspect of the fauna and the absence of Upper Ordovician species suggests that this collection is more probably Middle rather than Late Ordovician in age.

The Middle(?) Ordovician rocks are in part similar to the Ordovician part of the Tatina Group of Ordovician and Silurian(?) age described by Brooks (1911, p. 69–71) from the South Fork of the Kuskokwim River and the Tatina River some 50 miles east in the Alaska Range, the nearest known exposures of Ordovician rocks.

The Silurian(?) rocks are dated by fossil corals and Archaeocyatha, which were studied, respectively, by W. A. Oliver, Jr., and Helen Duncan of the U.S. Geological Survey. Oliver reported (written commun., 1960):

> Collection USGS 5592–SD includes four rugose corals referable to a single species of a type which is certainly post-Ordovician and probably Silurian or Devonian in age. The species appears to be close to genus *Leptoinophyllum*, which is of Devonian age, but the material is inadequate for positive identification, and a Silurian age cannot be ruled out.

Helen Duncan reported (written commun., 1960):

> The fossil is a very unusual organism that has been named *Aphrosalpinx* and that is considered to be an Archaeocyathid by the Russian specialists who work on the group. So far as I know, the only species of *Aphrosalpinx* described came from the Upper Silurian (Ludlow equivalent) of the northern Ural Mountains. * * * The occurrence of an *Aphrosalpinx* that closely resembles the Russian Late Silurian form suggests that the rocks are Late Silurian in age.[1]

The rocks here designated Silurian(?) are lithologically similar to dolomitic rocks described by Cady and others (1955, p. 24–27) and assigned to the Holitna Group of Ordovician(?), Silurian, and Devonian age. The nearest named exposures of the Holitna Group are some 70 miles southwest of White Mountain.

The stratigraphy of the Middle(?) Ordovician and Silurian(?) rocks is based in part on planetable measurements and in part on photogrammetric measurements and is summarized in figure 4.

[1] After further study, Duncan concluded that fossils in colln. 5592–SD are Devonian(?).

System	Map symbols (Plate 3)			Thickness (Feet)[1]	Description
Silurian	Sl			1100	Dolomite, massive, gray-white to pinkish, dense, fine-grained, cliff-forming; locally contains vugs coated by pink dolomite crystals; weathers dazzlingly white; contains local areas of partly dolomitized limestone
Silurian	Sl		Fossils 0 59-ASn-16	400	Limestone, medium- to thick-bedded, light-gray; abundant recrystallized fossils; few interbeds of brown-weathering chert or siliceous siltstone. Base of unit is brecciated
					Possible unconformity or fault
Ordovician	Upper part of Middle(?) Ordovician rocks	Not shown on Plate 3		250?	Limestone, thin- to medium-bedded, light-gray, dense, fine-grained, interbedded with argillaceous limestone and chert that weathers into dark-brown ribs. Limestone weathers light gray
Ordovician	Upper part of Middle(?) Ordovician rocks	Not shown on Plate 3	Fossils 0 59-ASn-20	1100	Limestone, thin-bedded, dark-gray, dense, fine-grained, interbedded with argillaceous limestone and chert that weathers into dark-brown ribs. Limestone weathers dark gray. Near base contains three units approximately 30 feet thick of medium- to thick-bedded limestone, which is sparingly fossiliferous. Beds locally reach 3 feet in thickness
Ordovician	Upper part of Middle(?) Ordovician rocks	Not shown on Plate 3	Covered	600	Limestone, thin-bedded, dark-gray, dense, fine-grained, interbedded with argillaceous limestone and chert. Zone of black shaly limestone approximately 100 feet thick near base
Ordovician	Upper part of Middle(?) Ordovician rocks	Not shown on Plate 3	Covered	475	Limestone, thin-bedded to shaly, dark-greenish-gray, argillaceous; highly calcareous siltstone; and claystone that weathers to sticky greenish-yellow clay that does not support vegetation
					Break in line of section
Ordovician	Upper part of Middle(?) Ordovician rocks	Not shown on Plate 3		?	Limestone, thin-bedded, gray-black, fine-grained; oolitic limestone and interbedded shaly limestone with quartz in matrix between oolites; graded bedding and crossbedding noticeable. Oolitic beds contain specks of pyrite and opaque hydrocarbon(?)
Ordovician	Upper part of Middle(?) Ordovician rocks	Not shown on Plate 3	Covered	650	Limestone and argillaceous limestone, thin- to medium-bedded. Lithology inferred from isolated exposures
Ordovician	Upper part of Middle(?) Ordovician rocks	Ol_7		500	Limestone, medium-bedded, dense, fine-grained, blue-gray; weathers to bluish white
					Possible fault
Ordovician	Ol	Ol_6		60	Limestone, shale and sandstone: thin-bedded argillaceous limestone predominant; laminated and in part calcareous sandstone; and sandy shale
Ordovician	Ol	Ol_5		50	Siltstone, gray-black to black, siliceous breaks into small cubic fragments
Ordovician	Ol	Ol_4' or Ol_{4a}		305	Limestone, thin-bedded, dense, fine-grained, and argillaceous limestone; pinkish cast on fresh surface. Local hydrothermal dolomite
					Fault
Ordovician	Ol	Ol_3		100	Shale, red to black; a few cherty beds less than 1 inch thick
Ordovician	Ol	Ol_3		40	Limestone, medium-gray, argillaceous; has crinkled partings
Ordovician	Ol	Ol_3		85	Shale, red to black shale, and a few cherty beds less than 1 inch thick
Ordovician	Ol	Ol_3		40	Sandstone, calcareous quartzo-feldspathic; weathers brownish gray to yellowish brown
Ordovician	Ol	Ol_{3a}		30	Limestone, dense, fine-grained, medium- to thin-bedded, gray-black
Ordovician	Ol	Ol_2			Limestone and shale; thin-bedded grayish-black fine-grained limestone and dark shale in thin interbeds; some limestone contains clear quartz fragments. Entire unit weathers to a limonitic color and gives red soil
Ordovician	Ol	Ol_1	Covered	500 to 1000	Limestone and shale; similar to above but deformed and broken
Ordovician	Ol	Ol_{1a}	Covered	500 to 1000	Limestone, medium-gray, dense, fine-grained, in beds averaging about 6 inches thick; position and thickness not definitely known because of discontinuous exposures
Ordovician	Ol	Ol_1		500 to 1000	Limestone and shale; thin-bedded grayish-black fine-grained limestone and dark shale in thin interbeds; some limestone contains clear quartz fragments; weathers to a limonitic color. Intensely deformed and broken owing to proximity to the Farewell fault
		Farewell fault			

[1]Determined by photogrammetric measurement and by measurement from planetable maps

FIGURE 4.—Lower Paleozoic rocks, White Mountain. Note: Redetermination indicates that fossils in collection 59–ASn–16 are probably Devonian.

IGNEOUS ROCKS

The only igneous rocks found at White Mountain within the area illustrated by plate 3 consist of a small granite pluton that intrudes the Middle(?) Ordovician rocks about 2 miles south of the main quicksilver prospects, two fresh and one altered diabase dikes about 1 mile west of the prospects, and one altered dike at the north ore zone that was disclosed by a bulldozer trench in 1961. The pluton consists of medium-grained biotite granite composed of 65–70 percent perthite, 10–20 percent quartz, 5–8 percent clear albite, 1–2 percent biotite, and 1 percent opaque minerals grouped in or near the biotite. The perthite crystals average 5 mm in length, and the quartz, 1 mm The granite has thermally metamorphosed the limestone—converted pure limestone to marble and impure limestone to hornfels and calc-silicates. These contact-metamorphic rocks contain abundant pyrite and pyrrhotite and are heavily stained with limonite. The thermal aureole reaches a maximum width of about three-eighths of a mile on the southwest side of the pluton, where the beds dip shallowly southwestward away from the pluton.

Granite has been reported (R. P. Maloney, oral commun., 1961) from the north side of the divide between Chunitna Creek and the Big River; granite may form much of the bedrock in this area, but such occurrence is unknown, for glacial deposits cover the bedrock almost completely.

The fresh diabase dikes strike northeast and dip 70°–80° SE. The westernmost dike is about 60 feet thick, and the easternmost is about 2 feet thick. The altered diabase forms an irregular outcrop only about 15 feet across on the south slope of White Mountain. The larger dikes were intruded probably along faults. The fresh diabase dikes consist of augite, labradorite, and minor amounts of olivine that is partly altered to antigorite and iddingsite(?). Opaque ore minerals, chiefly magnetite, constitute about 2 percent of the rock. The texture is ophitic, and the largest plagioclase phenocrysts are as much as 2 mm in length. The altered dike, which is similar to altered dikes near quicksilver deposits elsewhere in southwestern Alaska, consists of an iron-stained mass of clay minerals, carbonate minerals, and fine-grained silica. Thin sections disclose that the rock also contains many small apatite crystals and that it has a relict diabasic texture. No cinnabar could be found in the altered dike, but small specks of pyrite are abundant. No intrusive rocks were found in the conglomerate east of the Farewell fault.

BRECCIA

A thick tectonic breccia at the base of the east flank of White Mountain merits discussion. The breccia forms conspicuous outcrops for nearly a mile that almost parallel the trace of bedding in the Middle(?) Ordovician rocks. The breccia consists of a porous mass more than 200 feet thick composed of semiangular to subrounded fragments of limestone ranging in size from less than 1 inch to 2 feet. The breccia fragments are recrystallized to marble and are cemented by fine-grained banded carbonate and minor amounts of fine-grained silica, which forms sinterlike coatings on many fragments. Many of the fragments are stained deep red brown by iron oxide. The breccia dips at an angle of about 5°–10° E. obliquely across the platy limestone that it cuts. Rounded boulders of fresh diabase are scattered throughout the breccia for several hundred feet near the point where the large diabase dike should cut the breccia. The breccia is conclusive evidence that flat faulting occurred since the injection of the diabase dikes, which are probably Late Cretaceous or Tertiary in age. The breccia is cut off probably by a high-angle fault on the west side, which suggests that the flat faulting predated at least some of the movement along faults parallel to the Farewell fault.

A thin section of the breccia discloses numerous small clots of an opaque mineral, too small to identify, associated with limonite in the coatings on the breccia fragments. These opaque minerals were introduced along with the coating of carbonate in which they are enclosed. The authors consider the marmorization of the breccia, the sinterlike coatings on the breccia fragments, the abundant iron stain, and the opaque minerals to be evidence that the breccia has been hydrothermally altered.

The breccia is similar to breccias in rocks of the Holitna Group in the Kulukbuk Hills about 120 miles southwest that are described as intraformational breccias and conglomerate (Cady and others, 1955, p. 25). Because of the similarity in appearance, the breccias in the Kulukbuk Hills may possibly also be tectonic breccias, and perhaps such breccias are common in rocks of the Holitna Group.

SURFICIAL DEPOSITS

Surficial deposits consisting of glacial moraine and glaciofluvial gravels of Quaternary age mantle the bedrock near the quicksilver deposits. These deposits are part of a continuous mantle of drift that was deposited by the glaciers that flowed from the Alaska Range westward down the valley of the Big River. Two distinct glacial advances are recorded by the deposits. The earlier is the more extensive; ice from the older glaciation completely filled the valley of the Big River, and tongues of ice were pushed across the divides on the east and north of Chunitna Creek (pl. 3). The younger glaciation was confined to the valley of the Big River. The moraine from the earlier glacial stage remains as a veneer, locally 25 feet thick, on the flat hills north and west of the quicksilver deposits, where it interferes with the surface exploration of the quicksilver prospects. Granite and metamorphic rocks that are characteristic of the Alaska Range in the headwaters of the Big River form a large part of the moraine of both stages. Abundant granite cobbles found in all the streams tributary to Chunitna Creek on the east are glacial erratics.

GEOLOGIC STRUCTURE

FAULTS

The most striking structural feature of the area is the Farewell fault zone, which contains a zone of clay gouge more than 150 feet wide along the main break. This fault separates the conglomerate from the limestone throughout the area shown on plate 3. Many smaller faults subparallel to the main fault cut the Middle(?) Ordovician rocks and are presumed to be part of the Farewell fault zone. The trace of the main gouge zone indicates that the fault dips northwest almost vertically, but the smaller faults dip steeply southeast toward the main fault.

The block southeast of the fault, in which younger rocks are preserved, is presumed to be downthrown, but the net slip on the fault could not be determined because similar rocks were not found on both sides. However, as an estimated 8,100 feet of conglomerate is cut out along the fault, the minimum stratigraphic throw is 8,100 feet. On the basis of the complete absence of conglomerate west of the fault in the area traversed, the minimum horizontal offset on the fault is determined to be at least 17,000 feet. Quartz conglomerate has been reported by C. F. Herbert (oral commun., 1960) to occur west of the fault some 15 miles north of the main prospects, and hence the total amount of offset since the Cretaceous(?) may have been 15 miles.

No evidence of recent movement on the fault can be seen, although frost boils that lift clay from the gouge zone into the overlying tundra create linear scars that superficially resemble faults cutting the tundra. The fact that no faults parallel to the main Farewell fault are known to cut the conglomerate—whereas several such faults cut the Middle(?) Ordovician rocks to the west—may indicate that movement along the fault zone was taken up along numerous faults prior to the deposition of the conglomerate but that subsequent movement was localized along the main break. On the basis of its relations in the White Mountain area, the Farewell fault is provisionally interpreted to be a right-lateral transcurrent fault having a component of downthrow on the southeast block.

FOLDS

A marked disparity of fold structures exists on opposite sides of the Farewall fault. The conglomerate is folded into a fairly symmetrical syncline whose axis trends roughly parallel to the Farewell fault and plunges northeastward.

The Middle(?) Ordovician and Silurian(?) rocks west of the Farewell fault are more intricately deformed than are the Cretaceous(?) rocks on the east side. The main structural features in the Ordovician and Silurian rocks along the line of the cross section (A–A′, pl. 3) are an anticline and a syncline trending northeastward. The structure is doubtless more complicated than is shown on the cross section. The east limb of the syncline progressively steepens from White Mountain toward the Farewell fault to a point where the beds are overturned and dip southeast. The west limb of the anticline dips more steeply than does the east limb. From the top of White Mountain, one can see that the beds on the west limb continue southwestward for several miles, gradually swinging to a southeast strike and shallow southwest dip south of the granite pluton, characteristics which indicate that the anticline is the major regional feature. The anticline plunges shallowly to the southwest, and south of the pluton the east limb is cut off by the Farewell fault.

A rather abrupt change in the attitude of the beds from a northeast strike and northwest dip north of the pluton to variable strikes and dips at the northwest margin of the pluton may reflect structural complexity caused by the intrusion of the pluton, or it possibly indicates faulting as yet unrecognized in the reconnaissance of the area. Minor folds and structural complexity caused by faulting have been observed at many places within the area shown on plate 3. Southwest of the pluton, the structure seems uniform for several miles, and the beds dip shallowly to the southwest around the nose of the main anticline.

QUICKSILVER DEPOSITS

The known quicksilver deposits at White Mountain are distributed along a belt about half a mile wide and 2 miles long along the west side of the Farewell fault (pl. 3). The beds in this zone are the lower part of the Ordovician rocks below the argillaceous limestone and claystone unit. (See stratigraphic column, fig. 4.) The rocks in general strike northeastward almost parallel to the Farewell fault and dip vertically southeast at angles as low as 36° (pl. 3). The lesser dips to the southeast reflect the overturning of beds. Many of the beds are repeated by faults striking northeastward parallel to the Farewell fault. The quicksilver deposits are found in or near these faults, generally where shale is faulted against limestone.

Exploration prior to 1961 was confined to a group of contiguous claims at the north end of the deposits and covered three distinct mineralized areas. These three areas have been called the south, center, and north ore zones. An area 8,800 feet long that includes these deposits was mapped by planetable at a scale of 1 inch to 400 feet (pl. 3), and the area near the south ore zone was mapped at 1 inch to 60 feet (pl. 3) to show more clearly the details of the structure and stratigraphy. Each of the three ore zones is discussed in more detail on the following pages.

SOUTH ORE ZONE

In the south ore zone, the rocks strike mainly N. 25° E. and dip vertically to 80° either northwestward or southeastward (pl. 3). These rocks include black limestone, calcareous sandstone, argillaceous limestone, and shale on the east that are separated by a fault from limestone on the west. The fault contact between shale and limestone can be traced for almost 1,000 feet. The fault dips about 80° SE. and transects the shale at a small angle. A second fault having a similar orientation is exposed 200 feet west and lies within the platy limestone. Locally between the two faults, the platy limestone has been brecciated, dolomitized, and silicified, and the cinnabar is found in these brecciated areas.

The main prospect is in a brecciated dolomite exposed for about 240 feet along the faults. The prospect is explored by several deep trenches, in all of which cinnabar is exposed.

The cinnabar occurs as small dark-red crystals coating open spaces in the brecciated dolomite, as paint on breccia surfaces, and as small irregular veinlets. The ore is noticeably richer within 30–40 feet of the east fault, although cinnabar occurs throughout much of the dolomite. Cinnabar coats slickensided surfaces of the breccia but is not itself slickensided. Locally, the silicified dolomite is finely crushed and contains clay, dark-red limonite, and cinnabar.

The trenches outline an ore body 150–200 feet by as much as 40 feet that is estimated to contain as much as 1 percent mercury.

The dolomite in the upper parts of the trenches is composed of shingled lensoid fragments that are coated with carbonate on the undersides. Cinnabar crystals coat the dolomite but were not found on the coatings, a fact indicating that the coatings were probably deposited from surface water percolating downward into the breccia.

A shallow pit in a small outcrop of dolomite 100 feet north of the south ore zone discloses a few scattered specks of cinnabar. Brecciated silicified dolomite lacking cinnabar is exposed in a small pit on the fault some 600 feet south of the main outcrop of dolomite in the south ore zone. Brecciated dolomite may be continuous between these outcrops and the south ore zone.

CENTER ORE ZONE

The center ore zone (pl. 3) extends about 1,000 feet northeast of the south ore zone along the strike of the faults and of the beds exposed in the south ore zone. The center ore zone, which is explored by pits and trenches grouped about the head of a steep gully, contains brecciated silicified limestone and dolomite and some cinnabar. The dolomitization is more irregular than in the south ore zone, and coarse white calcite forms a conspicuous part of the altered limestone. The richest ore is associated with a small irregular fracture trending about N. 70° E. across the northern trenches. The cinnabar coats fractures and breccia fragments of dolomite. According to Ed Hager, of the Cordero Mining Co. (oral commun., 1960), additional trenching of a small outcrop of brecciated dolomite about 150 feet N. 40° W. of the trenches in the gully exposed some very rich ore; continued exploration probably will find more ore. Trenching in an outcrop of brecciated dolomite about 300 feet southeast of the center ore zone exposed specks of cinnabar. The dolomite is slightly silicified.

Exploration by trenching by the U.S. Bureau of Mines in 1961 exposed very rich ore in this area. The ore crops out in an oval about 30 feet by 35 feet along a fault in brecciated and silicified dolomite. Cinnabar has been found in drill holes at depths of as much as 75 feet below the surface outcrops (R. P. Maloney, oral commun., 1961). The digging of other trenches in this area along the contact between shale and limestone has revealed cinnabar in brecciated dolomite near the fault.

NORTH ORE ZONE

The north ore zone is half a mile northeast of the center ore zone and about 450 feet west of a sharp strike ridge formed by nearly vertical beds of black limestone that were traced almost continuously from the south ore zone (pl. 3). West of the limestone ridge the stratigraphic succession is calcareous sandstone, sandy shale, thin-bedded argillaceous and sandy limestone, black shale, and sandy argillaceous limestone, all dipping almost vertically. A thin layer of till covers bedrock west of the pits—several trenches and pits in the ore zone expose brecciated silicified and dolomitized limestone in fault contact with the sandy argillaceous limestone.

The trenches were sloughed and filled with ice in 1959, and the relation between ore and breccia is known only in the main trench, which was mapped by MacKevett in 1958. Unlike the occurrence in the south ore zone, the cinnabar here occurs on both sides of the fault, which is marked by several inches of blue gouge consisting of montmorillonite clay. Cinnabar is disseminated on the surfaces of the breccia fragments and in discrete veins trending eastward. The richest vein disclosed consists of about 1 foot of silicified dolomite and chalcedony and locally contains several percent of mercury. Cinnabar pieces as large as 4 inches thick occur in the veins and in the weathered rubble beneath the tundra. Cinnabar also replaces dolomite and chalcedony to a greater degree than in the south ore zone. Clots of cinnabar as much as 1 inch across occur in open spaces between breccia fragments. Some of the cinnabar grains have very dark centers surrounded by translucent red cinnabar. Deep-red limonite is closely associated with the ore, and other gangue minerals are dolomite, chalcedony, calcite, and dickite.

Exploration by the U.S. Bureau of Mines in 1961 disclosed that the main vein can be traced for at least 100 feet and that it contains rich ore throughout. This exploration also disclosed an altered diabase dike southwest of the old trenches in the area mantled by till. This dike is not shown on the maps that accompany the present report.

A small outcrop of bleached and dolomitized limestone was found on a steep hillside about 1,200 feet northeast of the north ore zone during the mapping done by the Geological Survey in 1959. The dolomite is on the projection of the fault at the north ore zone and near the west contact of the shale. The outcrop indicates that ground favorable for exploration continues to the northeast beneath the glacial moraine, for in all the ore zones discussed, cinnabar occurs in dolomitized limestone.

OTHER QUICKSILVER PROSPECTS

Several prospects have been staked southwest of the main prospect area discussed, and although none had been explored by 1960, the surface exposures are not as encouraging as are those in the main ore zone. The prospects lie west of the main Farewell fault, which marks the east limit of placer cinnabar, according to Ed Hager of the Cordero Mining Co. (oral commun., 1959).

Peggy Barbara prospect.—The Peggy Barbara prospect is about half a mile south of the south ore zone, on the west margin of a prominent outcrop of shattered blue-gray limestone just west of the Farewell fault (pl. 3). The limestone dips eastward and is overturned. Along the steep cliffs on the west side of the limestone, cinnabar is restricted to an area measuring roughly 40 feet long and 50 feet high. Cinnabar occurs as widely spaced coatings and irregular clots on fracture surfaces in unaltered limestone veined by white calcite. Individual clots of cinnabar have a maximum size of ½ by 2 inches, and individual coatings may be as much as 6 by 2 by ⅛ inch. The blue-gray limestone and white calcite are the only gangue minerals, and the absence of dolomite is considered to be an unfavorable indication. Striations on slickensided surfaces parallel to the Farewell fault plunge 31° N., 44° E., and indicate right-lateral movement.

Cinnabar has been panned by Ed Hager (oral commun., 1959) from the gouge zone of the Farewell fault where the fault is intersected by the stream just south of the Peggy Barbara prospect. Placer cinnabar in the creek west of the fault terminates abruptly at the fault zone. A few scattered clots of cinnabar have been found in blue-gray limestone on the hill just south of this creek. The occurrence is similar to that just described.

Mary Margaret prospect.—The Mary Margaret prospect is a little more than 1 mile southwest of the south ore zone on a prominent outcrop of blue-gray limestone on the south side of a tributary of Chunitna Creek. The limestone is equivalent to that east of the south ore zone (Ol_{2a}, pl. 3), for the same lithologic sequence is recognized, ranging from limestone through calcareous sandstone to purple shale. The entire sequence is overturned and dips at angles as low as 36° SE. The blue-gray limestone is repeated three times in surface exposures by faults that parallel the main Farewell fault.

Cinnabar, in veinlets ⅛–½ inch thick and a few inches long, occurs at scattered spots in limestone veined by white calcite. The veined areas do not exceed a few feet in length, and cinnabar veinlets form a very small part of the veined rock. Cinnabar is the only ore mineral, and calcite is the only gangue.

An interesting feature of the Mary Margaret prospect area is the cold-water sulfur spring that issues from fractured limestone on the east side of Chunitna Creek north of the small stream that enters from the east at the prospect. This spring is depositing black foul-smelling mud that contains mercury and most of the other elements found in the quicksilver ores. (See the spectrographic analyses, table 1.) The authors infer that this spring is related to the general epoch of deposition of cinnabar at White Mountain, which indicates that the deposits are young—possibly Recent in age.

MINERALOGY OF THE ORES

Cinnabar is the only sulfide mineral identified in the ores from all the deposits at White Mountain, and spectrographic analyses of ore specimens confirm the absence of antimony and arsenic. Much of the cinnabar is reddish black in reflected light and practically opaque in transmitted light in thin section. Such cinnabar suggests metacinnabar, but X-ray examination of selected dark fragments failed to confirm the presence of metacinnabar. The dark cinnabar is everywhere surrounded by more translucent cinnabar. Red-brown limonite is closely associated with the ores, as is a small amount of hematite; the relation between the cinnabar and the iron minerals is sufficiently intimate to suggest simultaneous deposition.

The cinnabar in some specimens both replaces dolomite and is cut by dolomite veinlets. Both cinnabar and dolomite are cut by calcite veinlets. In one specimen examined, cinnabar replaces some of the clay in the interstices between breccia fragments. The clay in one ore specimen was identified by X-ray diffractometer as dickite.

The silica in the ores bears no clear-cut relation to the cinnabar, for cinnabar occurs in brecciated dolomite lacking silica. In other specimens, brecciated dolomite has been replaced in large part by fine-grained silica prior to deposition of cinnabar in open spaces in the breccia.

STRUCTURAL AND PETROLOGIC CONTROLS OF ORE DEPOSITION

As the best prospects at White Mountain have the same structural and petrologic features, such features are probably significant and should be considered during exploration and prospecting. The structural and petrologic features are as follows:

1. The best deposits are associated with faults in brecciated, silicified, and dolomitized limestone. The deposits in unaltered limestone are small and erratic.
2. The best deposits lie at or near the fault contact between calcareous rocks and a relatively thick shale, which crops out in a continuous belt throughout the area.
3. All the deposits lie in complexly folded and faulted rocks west of the main gouge zone of the Farewell fault. The fault gouge in places contains traces of cinnabar, but no cinnabar has been panned from streams east of the fault zone.
4. None of the deposits is associated closely with igneous rocks, although both granite and diabase occur in the general region. Some of the diabase is altered to clay-carbonate-limonite rock similar to that composing altered diabase dikes in the other cinnabar deposits studied by the writers, but no cinnabar is found in or near the altered rock.
5. A sulfur spring is depositing mercury.

The significant mineralogic characteristics of the ores at White Mountain are as follows:

1. Cinnabar is the only sulfide mineral.
2. Small but detectable amounts of hematite occur intimately intergrown with the dark cinnabar.
3. Dark-red limonite is closely associated with the ore, although no iron sulfide minerals have been found.
4. The best prospects are in rock composed of chalcedony and a lesser amount of dolomite. This rock may have been derived from diverse types of limestone. Some deposits contain notable amounts of clay.
5. Dickite was identified by X-ray diffractometer as the clay in one sample.

ORE GENESIS

The ore solutions at White Mountain were derived from an unknown source, which was probably near or west of the Farewell fault. The solutions migrated through channels created by faulting and deposited cinnabar in shattered rock against or near impervious shale or fault gouge. The main deposits were formed at the thick shale bed that forced the solutions to rise along channels at or near the contact between shale and limestone. Some of the ore-bearing solutions rose along the Farewell fault and through fractured limestone near the fault, but none penetrated east of the thick gouge of the fault.

Cinnabar deposited from the solutions in an environment where conditions favored the formation of hematite and limonite—rather than pyrite—from iron. The chemical composition of the solutions was such that cinnabar, dolomite, hematite, silica, and, probably, limonite and calcite could be deposited virtually simultaneously from the solutions. These conditions are discussed in more detail on pages 68–70.

SUGGESTIONS FOR EXPLORATION

Future exploration at White Mountain should have the best chance of finding new ore or extending known ore bodies if it is directed along the westernmost shale-limestone contact in areas of dolomitized and silicified limestone.

Exploration by the U.S. Bureau of Mines during the summer of 1961 disclosed rich ore along this contact in areas of dolomitized and silicified limestone. Some of the ore, exposed in trenches over distances of as much as 30 by 35 feet, assays as much as 30 percent mercury (R. P. Maloney, oral commun., 1961). This exploration consisted of trenching and diamond drilling. The trenching is facilitated by the generally thin cover of till and is hindered by the permafrost, which is present everywhere at depths of a few feet. Only a very small part of the ore-bearing fault-shale contact had been explored and tested by 1964.

The critical factor to be determined by future exploration, however, is the vertical continuity of the ore bodies already disclosed by existing trenches. If the ore bodies exposed at the surface continue to even shallow depths along the shale contact, commercially important tonnages of ore exist at White Mountain. In future exploration a shaft or two should be sunk along the shale contact to test the vertical continuity of the ore.

The general geologic setting of the White Mountain quicksilver deposits is similar to that of the Pinchi Lake quicksilver district in British Columbia, Canada, where important deposits occur along a regional fault on which limestone rests against Triassic argillaceous and arenaceous sedimentary rocks and against quartz diorite (Armstrong, 1942). The main deposit occurs near a fault that splits from the main fault zone.

On the basis of the suggested similarity between the Pinchi Lake and White Mountain areas, additional prospecting along the Farewell fault, both north and south of the deposits described herein, is desirable. A study of aerial photographs to locate splits and subsidiary faults of the Farewell fault should prove helpful in outlining areas especially favorable for deposits. Ground prospecting could be done by use of the gold pan, and particular attention should be paid to areas of alteration (silicification and dolomitization) near the fault zone. Initial exploration should be directed southwestward along the fault where bedrock is relatively well exposed.

CINNABAR CREEK AREA

LOCATION AND ACCESSIBILITY

The Cinnabar Creek area is about 90 miles southwest of Sleetmute on Cinnabar Creek, a small stream that flows into the Gemuk River (fig. 5). The Gemuk River enters the Holitna River through various intermediate streams; the Holitna River flows into the Kuskokwim River near Sleetmute. Access to the area is by small planes, which land on a dirt airstrip near the Cinnabar Creek mine, by tractor along a winter tractor trail that leads from Aniak on the Kuskokwim River to the mine, and by riverboats via the rivers and creeks named in this paragraph. Several cinnabar prospects in this area have previously been described (Cady and others, 1955, p. 113–115; Rutledge, 1950). All occur in a belt about 5 miles long and are considered together in this report.

HISTORY AND PRODUCTION

Cinnabar was found in this area in 1941 by Russell Schaeffer and Harvey Winchell (Rutledge, 1950, p. 3). Twenty-six flasks of quicksilver were produced prior to 1955, mostly from the Lucky Day prospect, Schaeffer's original discovery (Rutledge, 1950, p. 4). In 1954, Russell Schaeffer began to develop the Cinnabar Creek mine in a newly discovered lode on Cinnabar Creek near the placer claims he had staked in 1941. Production from the lode began in 1955 and continued to 1960; total production had amounted to several hundred flasks, according to Schaeffer. No other deposits in the Cinnabar Creek area were being developed or exploited in 1959, although Schaeffer had trenched several prospects near his mine.

Mr. Schaeffer died from a heart attack suffered while alone at the mine in 1960. His estate and claims passed to surviving relatives, who continued exploration of the deposits by diamond drilling during the summer of 1961. Mr. Schaeffer's death was an unfortunate blow to the budding quicksilver mining industry in Alaska, for the success of his mine had contributed substantially to the interest in quicksilver mining in Alaska.

AREAL GEOLOGY

The geology of the Cinnabar Creek area has been described by Cady and others (1955, p. 113), on the basis of their reconnaissance mapping. The areal geology shown on figure 5 of this report was compiled from their work and from additional field observations made by Sainsbury in 1959.

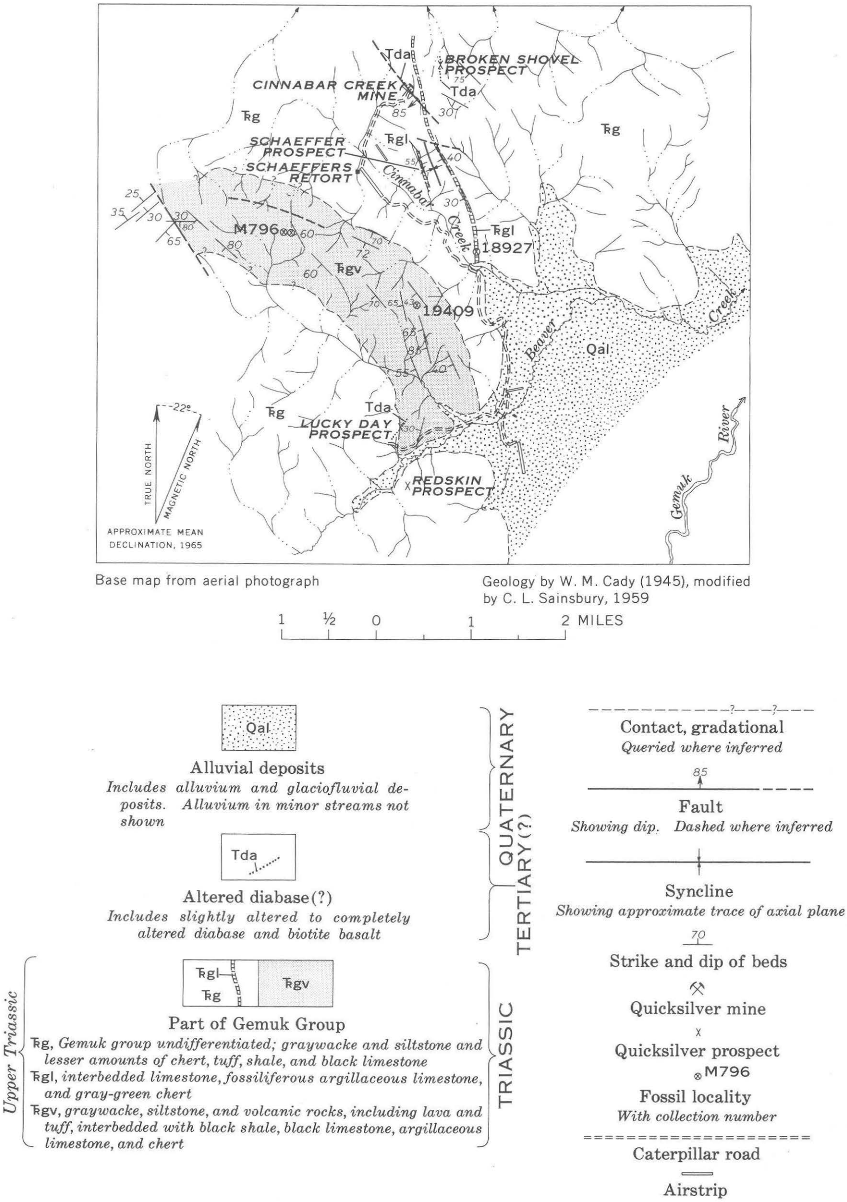

FIGURE 5.—Reconnaissance geologic map of the Cinnabar Creek area.

The area is underlain by rocks of the Gemuk Group, which include strata ranging in age from Carboniferous to Cretaceous (Cady and others, 1955, p. 32–34). In the Cinnabar Creek area, the Gemuk Group consists of interbedded graywacke, massive siltstone, volcanic rocks, and minor chert and limestone, all Late Triassic in age. Except for beds dipping northeastward on the southwest limb of the syncline near Schaeffer's prospect (fig. 13), the rocks dip southwestward and strike northwestward.

Cady and others (1955, p. 30) interpreted the structure as a homocline dipping southwestward and exposing 10,000–15,000 feet of beds.

The main changes made by Sainsbury in Cady's map are the including within the Gemuk Group on the present map of rocks shown by Cady as the Kuskokwin Group and the detailing of more structural complexity than was reported by Cady. The recognition of a fold that repeats the fossiliferous limestone unit northeast of Cinnabar Creek and the general convergence of the beds toward the southeast indicate a large-scale structural complexity of the rocks in the Cinnabar Creek area that probably involves major folding as well as faulting. In fact, part of the beds northeast of Cinnabar Creek may be overturned; however, as no direct evidence of overturning is known, the beds are shown as right side up. Two additional fossil collections made in 1959 confirm the Late Triassic age of the beds near Cinnabar Creek. Fossil localities are shown in figure 5, and the identifications are summarized as follows:

Fossils from the Gemuk Group at Cinnabar Creek

[USGS loc. 18927 and 19409: identified by J. B. Reeside, Jr., and R. W. Imlay, U.S. Geol. Survey (Cady and others, 1955, p. 33). USGS loc. M796 and field No. 59–ASn–129c: identified by N. J. Silberling, U.S. Geol. Survey]

USGS loc.	*Collector, locality, identification, and age*
18927	W. M. Cady, 1943; about 1 mile northwest of the mouth of Cinnabar Creek. Coquina composed of *Monotis subcircularis* Gabb from the Upper Triassic Noric Stage.
190409	W. M. Cady, 1943; about 2 miles west of the mouth of Cinnabar Creek. Float fragments from a burrow containing *Halobia* sp. undent, *Myophoria* aff. *M. vestita* Alberti, and ?*Mysidioptera* sp. from the Upper Triassic.
M796	C. L. Sainsbury, 1959; from argillaceous limestone between lava flows 1 mile S. 43° W. of Schaeffer's retort at Cinnabar Creek. Fragmentary *Halobia* resembling *H. ornatissima* Smith and a terebratuloid and a spiriferid (?*Psioidea*) brachiopod. The age is definitely Late Triassic, probably late Viarnian.
Field No.	
59–ASn–129c	Russell Schaeffer, 1959; from black limestone and shale 0.9 mile S. 45° W. of Schaeffer's retort at Cinnabar Creek. Fragments of *Halobia* and a more coarsely ribbed pelecypod that may be *Monotis*. Only a general age assignment of Late Triassic can be made.

LODE QUICKSILVER DEPOSITS

CINNABAR CREEK MINE

The Cinnabar Creek mine was owned and operated by Russell Schaeffer in 1960. Between 1955 and 1959, ore was mined from an open pit (pl. 4) and retorted in a modified Scott-type furnace having a capacity of 2 tons per day. The furnace was fired by wood obtained from timber in the lower reaches of Cinnabar Creek. According to Mr. Schaeffer (oral commun., 1959), the ore was furnaced at 1,400° C and the quicksilver condensed in an air-cooled stainless-steel condensing system. The furnace operated under a stack-induced vacuum of approximately 1 inch of mercury. Ore was mined during the summer, transported to the camp by tractor and skid-mounted bin, and stockpiled; during the winter it was furnaced. Mr. Schaeffer stated that he mined selectively to obtain ore that averaged 3–4 percent mercury. Light supplies and quicksilver were freighted by air to and from Aniak by Mr. Schaeffer in his own single-engine aircraft.

The Cinnabar Creek mine is a model mine showing that an efficient operation by an aggressive and capable man on a quicksilver deposit typical of those found widely in southwestern Alaska can result in a very substantial profit. Mr. Schaeffer stated that his yearly operating costs "averaged about $5,000," during years that he shipped more than 200 flasks of quicksilver.

GEOLOGY

The geology of the main pit is shown on plate 4. The ore in the main pit occurs along two or more parallel faults striking N. 30° W. and dipping nearly vertically parallel to an altered diabase dike. The wallrocks at the main pit consist of interbedded graywacke and siltstone striking N. 20°–25° W. and dipping steeply southwestward. The sedimentary rocks are extensively sheared and altered; the dike is less deformed, although it is highly altered. Much of the movement on the faults preceded the injection of the dike, for the dike is not offset where crossed by one of the faults. Striations on the fault plane plunge 22° NW., a fact indicating a large lateral component of movement.

The dike is traced northwestward by pits and trenches for about 1,000 feet. The degree of alteration of the dike decreases away from the main pit. In the northwest trench a banded quartz vein containing abundant stibnite follows the fault along the dike, and the dike is altered to clay. Between the altered parts the dike is hard and contains specks of pyrite.

A dike 1,000 feet southeast of the main pit is altered to clay and limonite at the surface but does not contain visible cinnabar, quartz, or stibnite. Whether this dike is a continuation of that at the main pit cannot be determined, for the intervening area is covered by tundra.

The ore in the main pit consists mainly of sheared, argillized, and iron-stained graywacke and siltstone cut by many small irregular veinlets of cinnabar and stibnite. Cinnabar also occurs disseminated in the altered rocks and as smeared paint on slickensided shears. Locally, rich ore occurs along rolls in the faults. According to Mr. Schaeffer, the richest ore occurred along the roll in the north fault, and some rich ore remained in the altered rocks in this area when the pit was mapped. Good ore occurs along splits from the main faults. The tenor of the ore changes abruptly both vertically and horizontally along the faults, giving rise to ore bodies having assay boundaries.

Unlike the Red Devil mine and other prospects near Sleetmute, the altered dike is not good ore. Locally, the altered dike contains small cinnabar veinlets in sufficient number to constitute ore, but the dike has furnished a very minor part of the ore.

Cinnabar is associated with abundant free mercury in a gouge and quartz vein as much as 2 feet thick that branches from the southern fault and curves off into the hanging wall. The native mercury is so abundant that it collects in a small pool when about a pound of broken quartz is crushed and shaken vigorously in a plastic bag. Mr. Schaeffer did not attempt to recover the native mercury, for he considered it a health hazard and too difficult to handle in the furnace.

Some cinnabar is colloidally dispersed in cryptocrystalline silica, forming brilliant-red hard ore, which, however, is not as rich as it appears to the eye.

Microscopic study of thin sections of hard ore from the altered rocks in the main pit discloses that the brecciated siltstone and graywacke is cemented by fine-grained quartz. Cinnabar, stibnite, and, to a lesser degree, pyrite replaced the quartz and graywacke, as well as filled small fractures in them. Clay minerals replaced and coated the breccia fragments, and cinnabar in part replaced the clay, which was determined to be dickite by X-ray diffraction. Dark red-brown limonite forms discrete veinlets in the siltstone fragments and coats quartz grains in the matrix. One such veinlet contains specks of cinnabar.

ALTERATION OF DIABASE

The alteration of the diabase can be studied to advantage at the Cinnabar Creek mine because of the continuous gradation from almost fresh to completely altered rock. The fresh diabase consists of labradorite, augite, iron-ore minerals, and some olivine, which is partly altered to iddingsite(?). With moderate alteration, the pyroxene and olivine crystals broke down and were completely replaced by carbonate, iddingsite(?) and minor muscovite and opaque ore minerals including some pyrite, rutile(?) and leucoxene. At this stage of alteration, the labradorite crystals became rimmed by carbonate, but the centers remained fresh. The carbonate is dolomite or ankeritic dolomite.

With still greater alteration, the labradorite was replaced by quartz, carbonate, and clay minerals generally stained and cut by limonite veinlets and containing specks of iron sulfide in many places. The limonite and clay suggest surficial alteration, but X-ray diffraction shows that much of the clay is dickite. Dickite containing cinnabar also occurs in apple-green masses along the argillized iron-stained ore veinlets, a fact suggesting that the clay alteration was hydrothermal in origin and that it accompanied the introduction of ore. Late barren carbonate veinlets, generally calcite, cut the altered rock, and these may be either hydrothermal or supergene in origin.

BROKEN SHOVEL PROSPECT

The Broken Shovel prospect (fig. 5) is on the ridge about 0.5 mile N. 45° E. of Cinnabar Creek mine. A few shallow bulldozer trenches were made by Schaeffer since Cady visited the prospects in 1943 (Cady and others, 1955, p. 115). The trenches expose a vertical diabase dike or sill 1–3 feet wide trending N. 5°–20° E. down a ridgetop for a distance of 320 feet. A fault follows the dike, and white quartz, commonly barren but locally containing stibnite, forms discontinuous veins along the fault. No cinnabar was observed in place in the trenches, although Schaeffer panned cinnabar from the stream that drains the north slope of the ridge. The quartz veins containing stibnite are similar to those on the northwest extension of the dike at the Cinnabar Creek mine.

The exploration of the Broken Shovel prospect is not sufficiently far advanced to allow any statement regarding the economic worth of the prospect.

SCHAEFFER PROSPECT

Cinnabar was found by Schaeffer in 1958 near the fossiliferous limestone and chert on the west limb of the syncline approximately 1 mile southeast of the mine (fig. 5). This prospect is here called the Schaeffer prospect. The prospect was explored by digging a few shallow trenches, one of which uncovered a breccia zone of variable width striking N. 20° W. parallel to the bedding of the chert and gray-black siltstone country rock.

Cinnabar and stibnite are disseminated in a quartz gangue that cements a breccia composed of fragments of chert and siltstone. The cinnabar and stibnite are in part interstitial to quartz grains and in part replace both quartz and breccia fragments. Some cinnabar is so finely dispersed between quartz grains that in hand specimen these areas appear light pink. The cinnabar is generally distributed erratically in the breccia, some parts containing an estimated 1–2 percent and others containing isolated specks. Russell Schaeffer stated (oral commun., 1959) that he had found fossils replaced by solid cinnabar in this area, but the authors did not observe any.

Thin sections disclose that the gangue filling the breccia is entirely quartz. Many of the breccia fragments of siltstone are stained by limonite. Some of the altered siltstone fragments contain a few minute specks of pyrite or marcasite that are not altered. No pyrite is found in the quartz gangue or intergrown with the cinnabar and stibnite.

Additional exploration will be required to determine if the Schaeffer prospect contains sufficient ore to have economic value.

LUCKY DAY PROSPECT

The Lucky Day prospect, which yielded the first quicksilver in the Cinnabar Creek area, is 3 miles south of the Cinnabar Creek mine on the divide between Beaver Creek and an unnamed tributary parallel to Cinnabar Creek (fig. 5). By 1943, Russell Schaeffer and Harvey Winchell had produced 26 flasks of quicksilver from hand-sorted ore obtained from residual placers at the prospect (Cady and others, 1955, p. 114). The U.S. Bureau of Mines explored the property by trenching in 1944 (Rutledge, 1950). In 1954, Schaeffer mined and stockpiled at the prospect more than a ton of rich ore that came from altered intrusive rock. The prospect was examined briefly in 1959, but most of the trenches, pits, and old adits in alluvium were sloughed or caved. The following description is based in part on published descriptions of the prospects.

The rocks at the Lucky Day prospect consist of massive gray-green siltstone and graywacke that were believed by Cady and others (1955) to be part of the Kuskokwim Group but that are here referred to the Gemuk Group. The strata strike N. 5°–10° E. at the prospect but swing to a more westerly strike to the northwest (fig. 5). The prospect lies within massive siltstone that is near the top of a thick succession of siltstone, graywacke, volcanic rocks, and minor shale, chert, black limestone, and argillaceous limestone containing Upper Triassic fossils. At the prospect, the bedded rocks are intruded by sills or dikes nearly parallel to bedding; some of the dikes and sills are altered to the common silica-carbonate-clay rock characteristic of the quicksilver deposits of the Kuskokwim area.

The principal intrusive body—probably a sill—explored by 1959 strikes N. 15° E. and is explored discontinuously for a distance of 1,000 feet by means of trenches, pits, and shallow shafts. At the north end of the explored zone, a trench 180 feet long exposes a fault contact dipping vertically between the sill and the siltstone. The sill and siltstone are sheared, altered, and replaced by quartz and clay minerals, and cinnabar and stibnite occur in quartz veinlets and as disseminations in the altered rocks. Native mercury in small amounts occurs in the quartz. The cinnabar and stibnite are intergrown intimately and in places are surrounded completely by quartz. Apple-green dickite is common with the ores. The ore stockpiled by Schaeffer came from this trench.

Thin sections disclose that some of the cinnabar preferentially replaced the clay minerals. The intimate relation of limonite and cinnabar suggests simultaneous deposition. A few minute specks of pyrite occur in the altered sill but are not confined to the ore.

Although the Lucky Day deposit has yielded but a small amount of quicksilver, it resembles the Cinnabar Creek deposit in many respects, and additional exploration may disclose a commercially important ore body. The deposit certainly should be explored more before the furnace at the Cinnabar Creek mine is dismantled and moved out of the area.

REDSKIN PROSPECT

The Redskin prospect is about 1 mile south of the Lucky Day prospect (fig. 5). No work has been done at it since about 1942, and it was not visited during the present investigation. Rutledge (1950, p. 8) described it as follows:

> Mineralization at the Redskin lode is almost identical to that along Canary Gulch (Lucky Day lode). The cinnabar occurs as sparse films along bedding planes, cross joints, and zones of brecciation in the graywacke and shale.

PLACER QUICKSILVER DEPOSITS—CINNABAR CREEK MINE

Small placer deposits of cinnabar have been found near all the prospects in the Cinnabar Creek area. Schaeffer (oral commun., 1959) stated that from his experience, any outcropping lode deposit large enough to be of interest can be found by conventional methods of panning of streams. To date, however, placer cinnabar has not been commercially important in the southwestern Alaska quicksilver region.

The Cinnabar Creek placer, however, may prove to be an exception. Schaeffer stated, prior to his death, that he intended to mine the placer below the Cinnabar Creek mine after he exhausted the lode ore that could be mined by open pit. The placer was described by Cady (Cady and others, 1955, p. 115). The placer extends downstream from the open pit in modern stream gravels and in remnants of terrace gravels. For a distance of 600 feet downstream from the open pit, the placer is buried beneath slope wash and colluvium. Test pits sunk by Schaeffer and his partner, Harvey Winchell, and by the New York–

Alaska Gold Dredging Corp. (NYAC) showed a mining section ranging from 5 to 14 feet in thickness and containing mercury ranging from less than 0.10 pound to 0.84 pound per cubic yard of gravel (Rutledge, 1950, fig. 7).

STRUCTURAL CONTROLS OF ORE DEPOSITION IN THE CINNABAR CREEK AREA

The lodes in the Cinnabar Creek area are closely associated spatially with faulted dikes and sills. The igneous rocks were probably injected along faults and were themselves fractured by later fault movements. The lodes were localized within fractured zones, generally near the igneous rocks.

The general alinement of the known lodes in a belt several miles long trending about N. 5°–10° W. seems significant. No single major fault or fault zone is known to intersect all the lodes. A possible explanation is that the lodes are localized between major stratigraphic units of the Gemuk Group. Massive to thin-bedded siltstone as much as several hundred feet thick forms belts northeast and southwest of the known prospects, whereas the intervening rocks are interbedded siltstone and graywacke. Faulting in the graywacke-siltstone sequence would create greater porosity than faulting in the siltstone and thus would direct dikes as well as the ore-forming solutions into the slate-graywacke sequence.

A second possible function of the graywacke-siltstone sequence, discussed in more detail on pages 70–73, was to direct large amounts of ground water into the ore-bearing solutions; the water thus caused dilution, rapid cooling, and major chemical changes leading to the deposition of cinnabar and quartz.

DeCOURCY MOUNTAIN MINE

LOCATION AND ACCESSIBILITY

DeCourcy Mountain mine is about 50 miles N. 45° E. of Aniak at an altitude of 700–1,000 feet (fig. 1; pl. 5). The mine is accessible by small aircraft and by trail from Flat, about 45 miles to the northwest, and from Crooked Creek on the Kuskokwim River, about 23 miles to the southeast.

The DeCourcy Mountain mine was not studied by the writers during the fieldwork of 1959 because the trenches were badly sloughed and the underground workings were full of ice. The following description is based upon the work of Cady and others (1955) and Webber and others (1947) supplemented by observations by MacKevett and R. S. Velikanje of the U.S. Geological Survey during the DMEA exploration between 1953 and 1957. Gordon Herreid of Alaska Mines and Minerals, Inc., logged the drill core from the DMEA exploration, and information from his logs has been used in compiling drill-hole data for this report.

HISTORY AND PRODUCTION

The deposits were discovered by Matt DeCourcy during the winter of 1910–11 and staked by him in 1919. The mine was operated intermittently from 1920 until recently and produced more than 1,200 flasks of mercury, most of which was produced by R. F. Lyman between 1942 and 1949 (Cady and others, 1955, p. 111). After 1949, activity at the mine was confined to exploration consisting of diamond drilling and surface stripping under a contract between the DeCourcy Mountain Mining Co. and the Defense Minerals Exploration Administration, which authorized 2,600 feet of drill hole to explore the downward extent of the zone of productive veins mined previously. A second stage of exploration was authorized to explore ore found by drilling, but owing to operational difficulties, the second stage of exploration was not utilized by the company. In 1961 the mine was inactive and was owned by the Alaska Mines and Minerals Co., owners of the Red Devil mine.

The underground workings consist of several adits, as well as minor drifts, crosscuts, and stopes. The main adits are the 820 adit (about 910 ft long), the 910 adit (about 200 ft long), the 871 adit (about 175 ft long), a caved adit 85 feet long on the principal vein, and a short adit southeast of the A vein. Surface workings consist of several pits, bulldozer cuts, and trenches, most of which were excavated by the U.S. Bureau of Mines in 1943. A sketch map of the mine area, adopted from Cady and others (1955), is shown as an inset on plate 5.

GEOLOGY

Bedrock at the DeCourcy Mountain mine consists of interbedded graywacke and shale of the Kuskokwim Group and numerous sill-like bodies of basalt or diabase that cut the sedimentary rocks. The sedimentary rocks strike between north and N. 25° E. and dip steeply northwestward. At and near the deposits both the intrusive rocks and the sedimentary rocks have been extensively but not completely altered to silicified fine-grained masses, which Cady and others (1955, p. 11, 112) termed "silica-carbonate rock." A mantle of unconsolidated frost-broken rock fragments conceals most of the bedrock.

Most of the quicksilver ore, which consists of cinnabar and minor stibnite in a gangue of silica, carbonate, and clay minerals, occurs in the silica-carbonate rock, commonly in or near the sill-like intrusive bodies. The ore bodies consist of small irregular lenses, veins and networks of veinlets that are localized in breccia zones, along contacts between the intrusive rocks and the sedimentary rocks, and, to a lesser extent, along bedding surfaces. Ore bodies occur throughout a zone that is at least 2,000 feet long, 250 feet wide, and 60 feet deep. Generally the ore zones strike parallel to the bedding. Some of them dip steeply northwestward nearly parallel to the bedding, and others dip steeply eastward or southeastward across the bedding. The distribution of these ore bodies is shown on plate 5. The Top and Retort veins dip steeply northwestward, the Tunnel vein dips steeply eastward, the DeCourcy vein mainly dips northwestward but locally southeastward, and the A vein mainly dips steeply eastward but locally westward.

The veins pinch and swell both vertically and horizontally and range in thickness from a few inches to several feet.

The Tunnel vein (pl. 5) and its associated mineralized zones was the largest productive ore body at the mine. The Tunnel vein, which averaged 3.2 feet thick, is 200 feet long at the surface and extends through a vertical range of 130 feet. The vein is not continuous, for it is disrupted by barren fractures formed before ore deposition and by minor faults formed after ore mineralization. Other very rich deposits as much as 15 feet long and 1 foot wide surrounded by low- or medium-grade ore were mined.

The exploratory diamond drilling of 1953–54 tested only the projected downward continuation of the Tunnel, Retort, and Top veins (pl. 5). The data for the drill holes are not complete, owing to the fact that appropriate technical guidance and interpretation of drill cores was not available during the drilling program. However, the drilling, which was undertaken from the 820-adit level, demonstrated that cinnabar ore continues to a depth of at least 100 feet below the land surface in the general area of the Tunnel, Retort, and Top veins. Drill-core assays show a mercury content reaching a maximum of 6.29 percent in a vein more than 2 feet wide. The available information from the drill holes is summarized on plate 5. Cinnabar mineralization forming probable ore was found in altered graywacke and shale in several holes, particularly beneath the Tunnel and Top veins. These areas are as yet untested by additional underground exploration. and the size and tenor of the ore bodies found by drilling are unknown. Minable ore will undoubtedly be found in this area.

A little cervantite and arsenopyrite were reported by Webber and others (1947, p. 33) to occur in some of the cinnabar deposits.

Placer cinnabar occurs in a tributary of Return Creek south of the known lodes, but the placer deposits are not sufficiently explored to allow determination of the size and tenor of the paystreaks.

SUGGESTIONS FOR EXPLORATION

The future exploration needed at DeCourcy mine is obvious. The initial work should require crosscuts from the 820 adit to test the ore found by drill holes, accompanied by geologic mapping or logging of all new openings and drill core. Favorable ore shoots may be found at intersections of faults with altered dikes and sills, although ore shoots mined in the past occur in altered graywacke and shale as well as in dikes.

RHYOLITE PROPERTY

LOCATION AND ACCESSIBILITY

The Rhyolite property lies on the south slope of Juninggulra Mountain about 45 miles west-northwest of Sleetmute on the divide between the Iditarod and Kuskokwim Rivers (fig. 1). Juninggulra Mountain is underlain by rhyolite that weathers to a blocky rubble thickly covered by black lichen. The resulting black mountain, barren of tundra, is a striking feature of the area.

The property can be reached by small aircraft that can land on a coarse-gravel runway on the top of Juninggulra Mountain or by foot along a tractor trail that leads from Crooked Creek on the Kuskokwim River, approximately 20 miles distant.

HISTORY AND PRODUCTION

The Rhyolite property was staked in 1957 by Joe Struver and Robert Lyman and was taken under option by the Cordero Mining Co. In 1959 the U.S. Bureau of Mines explored the property by means of several thousand feet of bulldozer trenches. Sainsbury, assisted by C. M. Taylor, mapped the property by planetable and alidade in August 1959. No production from the property was recorded by 1960.

GEOLOGY

SEDIMENTARY AND IGNEOUS ROCKS

The geology of the trenched areas is shown on plate 6. The bedrock consists of interbedded graywacke and shale of the Kuskokwim Group that is intruded by numerous dikes and sills of at least three distinct types and by a large mass of rhyolite porphyry. The bedded rocks strike generally westward and dip steeply southward in the central and southern parts of the trenched area and vertically to steeply northward in the north trenches near the rhyolite-porphyry intrusive. This difference in dip may reflect a major fold or merely an oversteepening near the rhyolite porphyry. Minor folds plunge down the dip of the beds and cause the strike of the beds to vary between N. 70° E. and N. 70° W.

The intrusive rocks range in size from the large mass of rhyolite porphyry that forms the bedrock of Juninggulra Mountain to dikelets a few inches thick. The smaller intrusive bodies exposed in the central and south trenches are complexly oriented and crop out in the trenches in patterns too intricate to explain as simple sills or dikes. A few smaller bodies are definitely sills whose attitudes change with the enclosing beds. Many of the small dikes trend between N. 40° W. and N. 30° E., but dips are difficult to determine on the flat bottoms of trenches. A very complex pattern of instrusion is indicated.

Except for the rhyolite porphyry, which retained characteristic quartz phenocrysts, all the intrusive rocks are so altered that the original composition is difficult to determine. The most common dike is an altered yellowish-gray porphyritic rock containing specks and blebs of pyrite. In thin section the rock has a faint relict trachytic texture. The larger phenocrysts are almost entirely replaced by carbonate and consisted originally of a tabular mineral that was either feldspar or pyroxene. A few relict quartz phenocrysts are corroded and were replaced by carbonate. Iron-ore minerals are common, and minute apatite crystals are very common. These dikes could have been quartz diabase, trachyte or lamprophyre.

Dikes very similar to those described but having a distinct amygdaloidal texture are common, and one such dike cuts a nonamygdaloidal dike. The alteration of the amygdaloidal dikes is similar to that of the massive dikes, and a faint diabasic or trachytic texture persisted.

The youngest dikes, whose composition is readily decipherable, consist of rhyolite porphyry. Phenocrysts of quartz and zoned plagioclase constitute about 20 percent of the rock. The groundmass is very fine grained, and the coarser grained parts consist of muscovite and an interlocking mosaic of quartz and feldspar. Laboratory staining tests show abundant potash feldspar. These dikes are undoubtedly offshoots of the main rhyolite porphyry that forms Juninggulra Mountain. All the dikes are older than the quicksilver mineralization, for cinnabar is found in the rhyolite, which cuts the other dikes.

DISTRIBUTION OF CINNABAR

Relatively small amounts of cinnabar were disclosed by the extensive trenching at Rhyolite. Much of the cinnabar in place was found near pits sunk in the overburden by Joe Struver. No ore was found in the north trenches, although cinnabar could be panned from the overburden in this area. The central trenches disclosed cinnabar at three widely spaced points. In the widest center trench, cinnabar occurs along small veinlets in fractured dike rock and graywacke and disseminated in the altered dike (loc. A, pl. 6). The cinnabar in the veinlets is as much as half an inch thick; pods as much as 4 inches thick occur at intersections of veinlets. The veinlets are associated with distinct faults that strike about N. 50° W. and dip steeply. The gangue minerals are dickite, carbonate, limonite, and some quartz.

About 200 feet east (loc. B, pl. 6) irregular cinnabar veinlets as much as half an inch wide and several inches long occupy fractures in a sulfide-bearing amygdaloidal dike. The sheared dike contains specks of cinnabar. The associated gangue minerals are carbonate, dickite and kaolinite, limonite, and minor quartz.

In the northeast trench of the central area (loc. C, pl. 6), cinnabar veinlets and irregular pods of cinnabar as much as a few inches thick are associated with an altered dike cut by a fault trending about N. 75° W. and an irregular sheared zone trending N. 45° W. Cinnabar occurs in the dike and in the shattered graywacke near the dike. The alteration minerals form the common kaolinite-limonite-quartz- carbonate assemblage.

The south trenches expose small amounts of cinnabar that are alined for the most part along a fault trending about N. 50° W. The cinnabar occurs disseminated in altered dikes near the fault and as small veinlets and pods in dikes and wallrocks that are locally a graywacke breccia cemented by dike rock. The alteration minerals are kaolinite, dickite, carbonate, quartz, and limonite.

MINERALOGY

Cinnabar is the only sulfide ore mineral of value identified to date at Rhyolite, although the spectrographic analyses show silver in the ore and may reflect the presence of arquerite (silver amalgam), which was not identified. Much of the cinnabar is a deep purple-black color, and the microscope and chemical tests suggest that the dark color of the cinnabar is caused by a dispersed iron-bearing mineral. Some of the dark grains contain centers having a relict hexagonal shape suggestive of a basal section of hematite and having a faint grid structure. Small grains of hematite are intergrown with the cinnabar. One thin section examined shows a fuzzy patch of opaque minerals that under the microscope is seen to be an intimate mixture of cinnabar and limonite.

SUGGESTIONS FOR EXPLORATION

The trenching done at the Rhyolite property disclosed small amounts of cinnabar in a geologic environment similar to that at other quicksilver deposits in southwestern Alaska. If additional trenching is done, a wide trench should be dug northwestward along the fault that is probably continuous through the south trenches. Ore may be found elsewhere along this fault, particularly where the fault intersects dikes. The stripped area near the faults in the northeast trenches of the central zone should be extended to the north where the shearing cuts dike rock.

Any trenching program here, or elsewhere in the central Kuskokwim, should be planned with consideration of problems caused by permafrost. Trenching in permafrost requires either a leisurely rate of trenching or an extensive amount of trench to allow thawing of the ground ahead of the bulldozer. If trenching is to accomplish its end of exploring favorable ore zones, it must be continually reoriented as exploration proceeds. This reorienting is difficult to do if the trenches are laid out at the beginning of the exploration and the bulldozer is kept busy lowering all the trenches as thawing proceeds. By the time ore is disclosed in one trench, most of the exploration effort is used up. On the other hand, stripping done at a leisurely rate to follow ore-bearing structural features results in considerable idle time for the bulldozers and, hence, in high unit costs. This type of trenching is necessary, however, if potential ore zones are to be explored fully.

KOLMAKOF PROSPECT

The Kolmakof prospect is in the bluffs along the north bank of the Kuskokwim River about 18 miles upstream from Aniak (fig. 1). The deposit is probably the earliest known lode occurrence of cinnabar in Alaska—Russians from the Redoute Kolmakoffski (Fort Kolmakoff) were probably aware if it as early as 1838 (Cady and others, 1955, p. 116). Workings at the prospect consist of a caved adit and a caved shaft, 29 trenches having a cumulative length of about 600 feet that were hand dug during a U.S. Bureau of Mines exploration program in 1944, and a few bulldozed trenches that were excavated in 1959. According to R. P. Maloney of the U.S. Bureau of Mines (oral commun., 1959), none of the trenches excavated in 1959 reached bedrock; therefore, the deposits were not revisited by the writers in 1959. The only reported production was in 1909 or 1910, when about two flasks of quicksilver was recovered (Cady and others, 1955, p. 116). In 1960 the property was owned by the Western Alaska Mining Co. of Spenard, Alaska.

The rocks at the prospect are interbedded graywackes and shales of the Kuskokwim Group and altered sills. The sedimentary rocks have an average strike of about N. 30° E. and dip 35°–60° NW. (Cady and others, 1955, p. 116). The largest of the three altered sills at the prospect is 25–30 feet thick and is exposed over a horizontal distance of 400 feet. The cinnabar deposits are mainly associated with this sill.

According to Webber and others (1947, p. 50), the cinnabar at the prospect has three structural and geologic settings:

1. Cinnabar in a veinlet half an inch thick forms a narrow and persistent stringer that is at least 250 feet long within the sill. Local small kidney-shaped bodies of this stringer are as much as 3 inches thick. Webber's sample KM–1, a composite sample taken from this stringer, assayed 404 pounds of mercury per ton.
2. Small pods of cinnabar occur intermittently in a narrow shear zone that locally forms the hanging wall of the sill. Webber's sample KM–2, which assayed 191.2 pounds of mercury per ton, was from a pod of ore 5 inches in maximum thickness and 6 feet in length and width.
3. Small amounts of cinnabar occur locally in cross fractures near the hanging wall of the sill.

Cady and others (1955, p. 116) noted that the ore occurs both as fracture fillings in brecciated zones, particularly at the upper border of the large sill, and disseminated in the altered sill and adjacent graywacke. Quartz is the principal gangue mineral.

RAINY CREEK PROSPECT

LOCATION AND ACCESSIBILITY

The Rainy Creek deposits are about 80 miles southeast of Bethel (fig. 1) and about 7 miles northwest of Mount Oratia (fig. 7). The deposits are near Arsenic Creek, a short tributary of Rainy Creek, about 3½ miles southeast of the confluence of Rainy Creek and the north fork of the Eek River. Access is by airplane to an airstrip about 2 miles west of the prospect or, during the winter, over a tractor trail approximately 120 miles long from Bethel. The deposits are between 1,700 and 1,850 feet above sea level in a tundra-covered area.

HISTORY AND PRODUCTION

According to Rutledge (1948, p. 3), the deposits were probably discovered by Ed McCann of Bethel some time between 1910 and 1920. During the 1920's, Neal Corrigal of Bethel, who was engaged in placer-gold mining on Rainy Creek, staked and explored the lowermost deposit (fig. 6, deposit I). Corrigal subsequently allowed his claim to lapse.

No lode production is recorded from the prospect, but during placer-gold mining operations on Rainy Creek below the mouth of Arsenic Creek, about 2,000 pounds of high-grade cinnabar concentrates was recovered.

Except for a small cut in the lowermost deposit, the workings were excavated during the summer of 1947 as part of a U.S. Bureau of

Mines exploration program. The workings, most of which are shown on figure 6, consist of 1,499 feet of bulldozed trenches and 1,439 feet of hand-dug cuts and trenches. The workings were badly sloughed and caved in 1959 and were not revisited by the authors.

This description of the Rainy Creek prospect is largely abstracted from a report by F. A. Rutledge (1948) of the U.S. Bureau of Mines.

GEOLOGY

The area at the prospect is underlain by sedimentary rocks of the Kuskokwim Group of Early and Late Cretaceous age (figs. 6, 7), which crop out in the bluffs along Arsenic Creek. Most of the prospect pits and trenches reached bedrock within a few feet of the surface. The rocks consist of interbedded graywacke and shale and some conglomerate. They strike N. 20°–31° E. and have an average dip of 72° SE. According to J. M. Hoare (oral commun., 1960), altered dikes occur near the prospect.

The location of the principal deposits is shown in figure 6. These deposits, which were designated "deposits I, II, and III" by Rutledge (1948, fig. 4), are associated with faults that strike northeast approximately parallel to the strike of the bedding but dip steeply, generally northwestward, across the bedding. Less promising quicksilver deposits at the prospect are in quartz veins along bedding surfaces.

At deposit I (fig. 7), the largest and best exposed deposit, cinnabar occurs mainly in a zone of fractured graywacke that is bounded by two faults about 16 feet apart. The faults strike N. 30°–35° E. and dip 73° NW. The deposit has the shape of a rhombohedral parallelepiped in which most of the cinnabar is in a short segment of the sheared and fractured graywacke between the two faults. The highest assay values from deposit I were from a zone about 6 feet wide that is adjacent to the western fault. The weighted average of four samples across this zone is 8.22 pounds of mercury per ton and 6.08 percent arsenic. Deposit I contains leaner ore. A small lens of cinnabar and realgar occurs adjacent to a fault about 70 feet east of deposit I. The fault strikes N. 30° E. and dips 70° NW.

Deposit II (fig. 6) is similar to deposit I. It is bounded by two faults striking northeastward and dipping northwestward and is shaped roughly like a parallelepiped. The richer ore, which yielded as much as 44.6 pounds of mercury per ton over a sample width of 6 inches, is in a narrow zone near the western fault.

Deposit III consists of three small lenses of ore adjacent to a vertical fault (fig. 6). The largest lens is 4 feet by 3 feet by 3 inches. A composite sample representative of the three lenses contained 45.8 pounds of mercury per ton (Rutledge, 1948, p. 6). Trenching along the fault on each side of the ore failed to uncover more cinnabar.

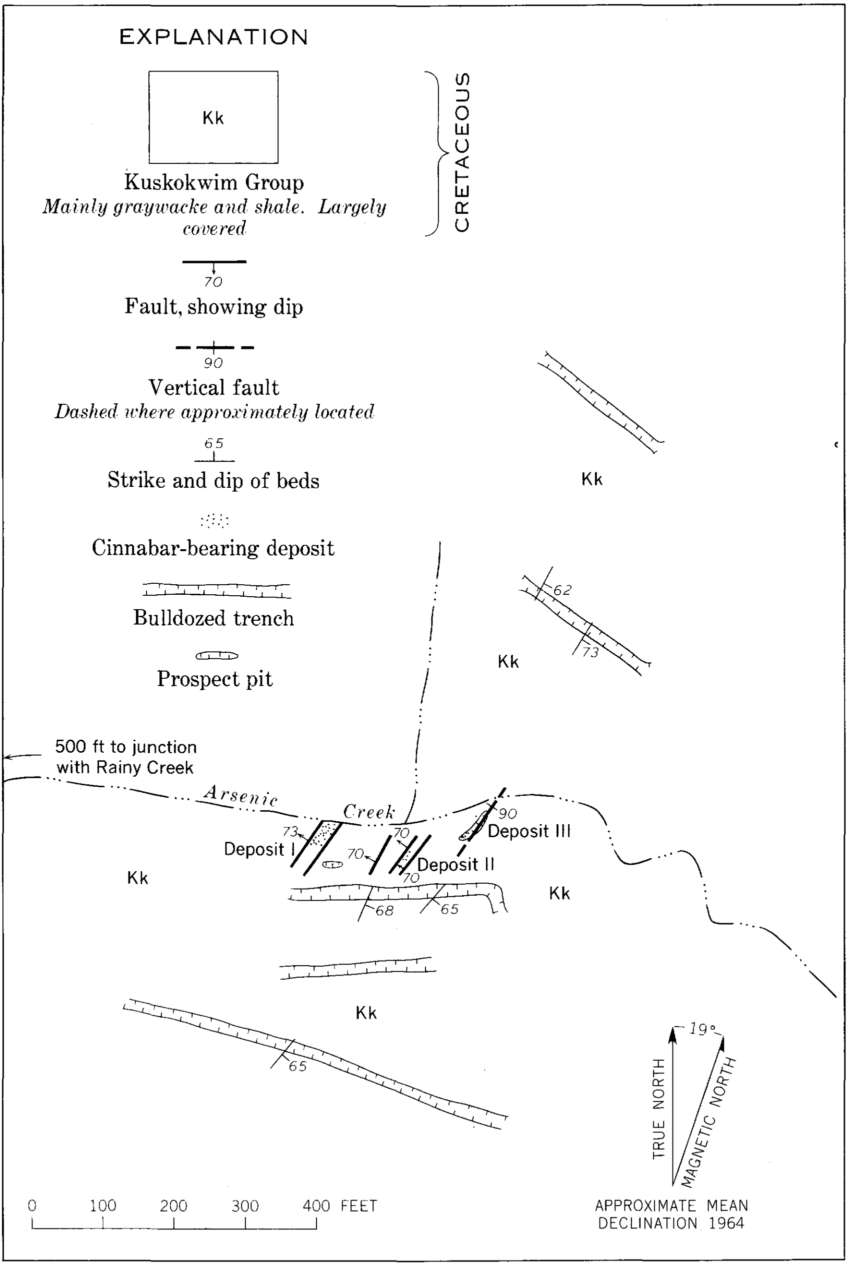

FIGURE 6.—Geologic sketch map of the Rainy Creek prospect. Modified from Rutledge (1948, fig. 4).

At the Rainy Creek prospect the cinnabar is generally associated with quartz, realgar, and, locally, small amounts of orpiment and limonite. Quartz deposited in two stages: the first formed fine-grained gray quartz, and the second formed white vein quartz cutting the gray quartz.

KAGATI LAKE PROSPECT

LOCATION AND ACCESSIBILITY

The Kagati Lake prospect is about 90 miles southeast of Bethel and about 6 miles northeast of Kagati Lake. The prospect is about 3,000 feet above sea level in an area where much of the bedrock is covered.

The prospect is accessible by aircraft having floats; they land on Kagati Lake or, in good weather, on a small lake about 1 mile from the prospect. A tractor road 8 miles long leads from Kagati Lake to the prospect. During winter, when the ground is frozen, tractors may travel from Bethel to the prospect over several unmarked routes.

HISTORY AND PRODUCTION

The property consists of 12 claims staked in 1956 by Noah Jackson and John Long of Bethel; in 1957 the claims were owned by the Bethel Exploration Co. and were under option to the Sunshine Mining Co. The prospect has been explored by about 15 prospect pits and trenches that are as much as 20 feet long and 4 feet deep, most of which are partly filled with sloughed rock debris. Bedrock was exposed by bulldozer stripping over areas of several hundred square feet. No quicksilver has been produced from the prospect.

The deposit was mapped by MacKevett in 1957 during an examination of the property made for the Defense Minerals Exploration Administration. E. W. Parsons, of the U.S. Bureau of Mines, and Pat DeWilliams and John Magura, of the Sunshine Mining Co., assisted during the examination.

GEOLOGY

The quicksilver deposits are in a stock composed chiefly of biotite quartz monzonite and hornblende-biotite granodiorite that is probably Tertiary in age (J. M. Hoare, oral commun. 1959). Interbedded graywacke and shale of the Kuskokwim Group crops out some 10 miles northwest of the prospect. The stock is intruded into the upper part of the Gemuk Group, which here includes graywacke, shale, and volcanic rocks (fig. 7). Near the stock the argillaceous rocks are converted to hornfels. The Gemuk Group is intruded by mafic dikes, chiefly diabase, of Tertiary age. Unconsolidated glacial and glaciofluvial deposits of Quaternary age mantle extensive areas of the bedrock. Surficial deposits generally less than 2 feet thick cover much

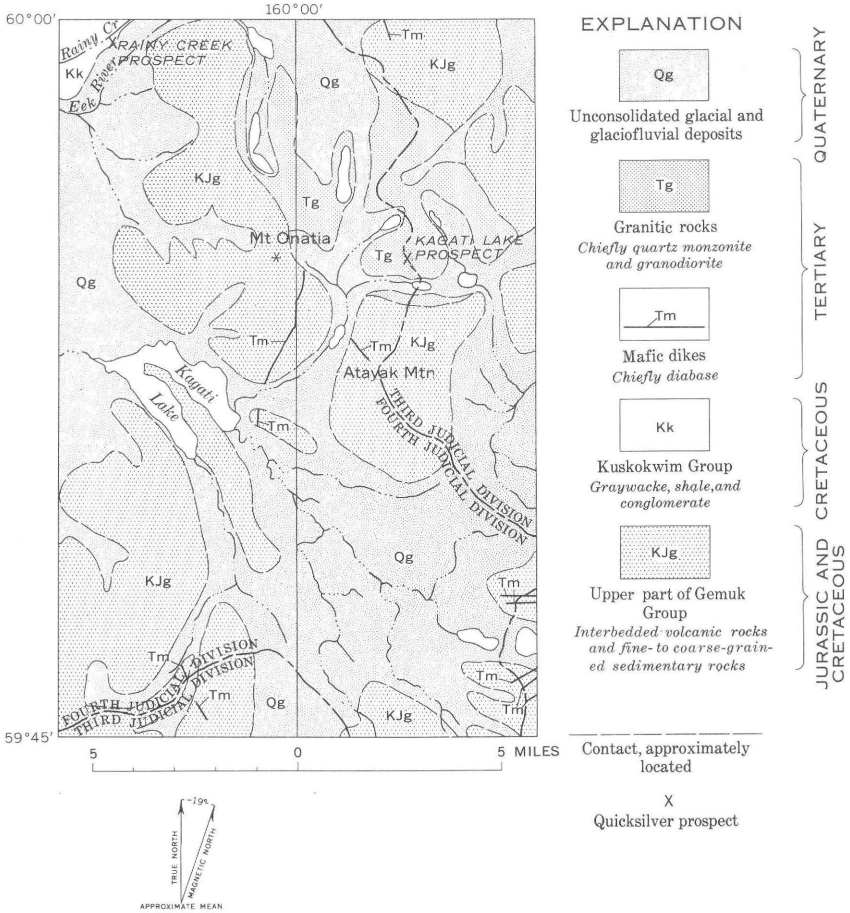

FIGURE 7.—Generalized geology near the Kagati Lake and the Rainy Creek quicksilver prospects. Geology by J. M. Hoare and W. L. Coonrad, 1950.

of the bedrock near the prospect, although bedrock is well exposed in outcrops along cliffs and on knobs near the quicksilver prospects.

STRUCTURE

The main structure at the Kagati Lake deposits consists of fractures in the stock. The most continuous fracture zone, called the main shear zone, strikes N. 20° W. and consists of multiple steep minor faults and joints striking northwestward (fig. 8). The main shear zone is marked by a depression about 2–10 feet deep eroded into the weathered, altered, and fractured rocks along the zone. The depression is partly filled by large granitic boulders and rubble transported by glaciers and glaciofluvial action from a hill north of the prospect.

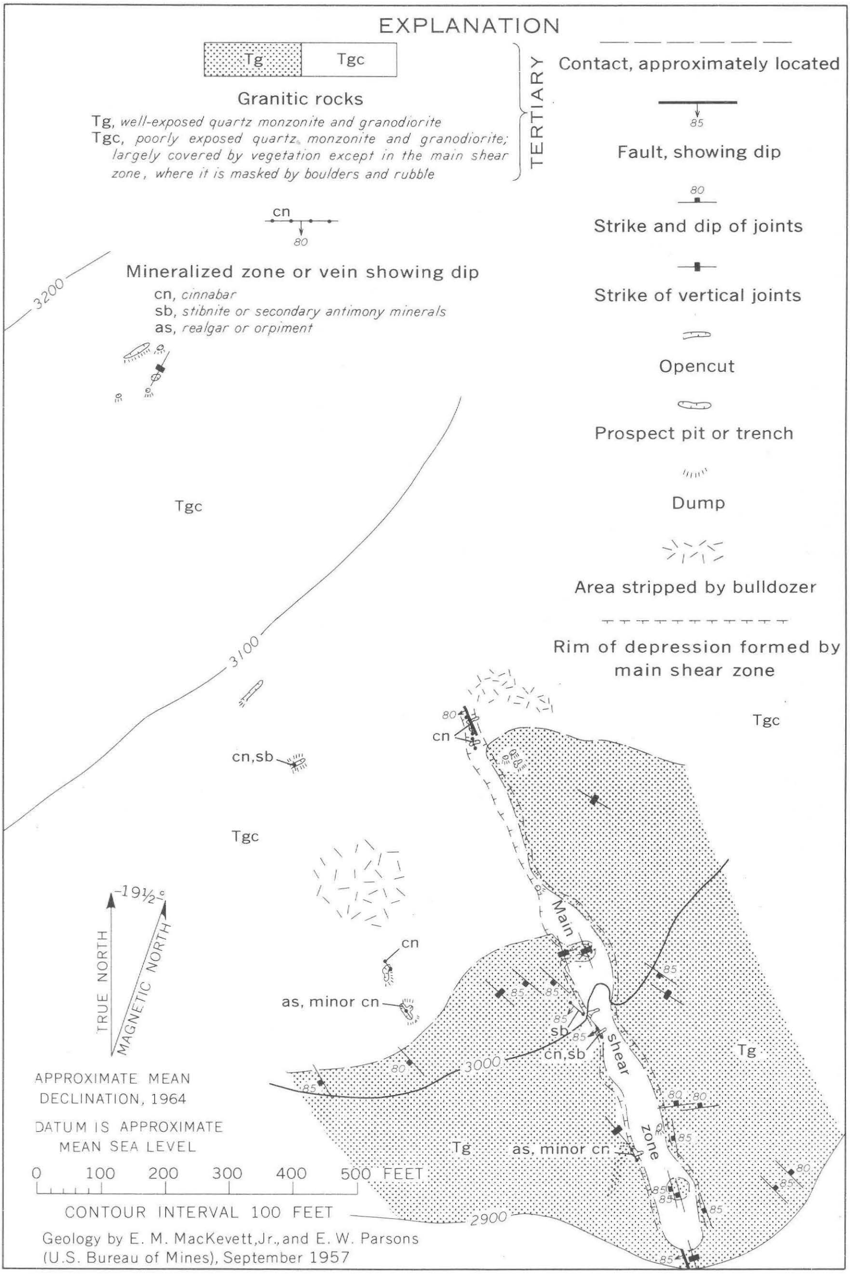

FIGURE 8.—Geologic sketch map of the Kagati Lake quicksilver prospect.

A well-defined set of joints in the stock strikes N. 15°–25° W. and dips vertically. A poorly defined set strikes N. 50°–65° W. and dips 80° NE. Many of the joints are slickensided; some are marked by gouge, and others, by veins a few inches thick. Some of the fractures that trend N. 50°–65° W. probably diverge from the main shear zone.

A set of closely spaced fractures similar to those in the main shear zone is exposed by a line of pits about 270 feet west of the main shear zone, but because of poor outcrops, it can be traced only about 450 feet. Most of the joints probably resulted from the same forces, and resultant movement on some joints produced the faults.

ORE DEPOSITS

Most of the ore at the Kagati Lake deposits consists of cinnabar that fills veinlets and coats fractures and fault gouge along the main shear zone. A few deposits are in the shear zone to the west. Some of the cinnabar is closely associated with realgar, stibnite, and, uncommonly, subordinate orpiment and secondary antimony minerals in a gangue consisting of quartz and minor iron sesquioxides. The most persistent veins are in fractures in the main shear zone or in the fractures that trend more westward. Individual ore bodies range from 2 inches to 2 feet in thickness, but none has been traced for more than 10 feet along the strike because of the poor exposures and because of the boulders that lie in the main shear zone. None of the known ore bodies has been completely delineated.

Quartz is the predominant mineral in the veins. In places it lines vugs and forms crystals as much as 1 inch long having the shape of well-defined prisms terminated by rhombohedrons and having the external symmetry of alpha (low) quartz. Some quartz crystals are automorphic. Cinnabar crystals in the form of rhombohedron penetration twins are perched on quartz crystals and line open spaces, modes of deposition indicating that cinnabar is the youngest hydrothermal mineral in the veins. Clay minerals, probably formed by both hydrothermal alteration and surface weathering, accompany most of the deposits.

Assay data indicate that some of the veins are of economic grade (under price conditions existing in 1959) but that others are submarginal. The chief detriment to the development of the property is the small size of individual ore bodies, which makes it difficult to outline sufficient ore to warrant installation of mining and furnacing facilities. The location of the prospect in an area remote from low-cost transportation is also a deterrent.

RED TOP MINE

LOCATION AND ACCESSIBILITY

The Red Top mine, also known as the Marsh Mountain mercury deposit, is 17 airline miles north of Dillingham, a steamship port on Bristol Bay (fig. 1). The mine is at an altitude of about 1,100 feet near the top of the southernmost peak of Marsh Mountain, less than 5 miles from the village of Aleknagik (fig. 26). A bulldozer-and-truck road less than 5 miles long leads from the mine to a point on the Wood River about 2 miles below Aleknagik. Boats and barges drawing 5 feet or less of water can ascend the Wood River to Lake Aleknagik, a few miles northwest of the mine. Landing strips suitable for light planes have been built near the base of the mountain approximately 3 miles from the property. Aircraft on floats can land on the Wood River and taxi to the trail leading to the mine.

HISTORY AND PRODUCTION

Placer cinnabar was discovered by Frank Waskey in Arcana Creek, which drains Marsh Mountain, in 1941, and the lodes were found by Charles Wolfe and Clarence Wren, who, at Waskey's suggestion, traced the placer cinnabar to its source. Prior to 1952, development work on the lode consisted of a few small pits and trenches. In 1952, an exploration contract was signed between the Defense Minerals Exploration Administration and the Red Top Mining Co., and almost 10,000 feet of trenches were excavated by bulldozer (fig. 9). This work outlined the main breccia zone and uncovered cinnabar in economic grade and tonnage. Twenty-two flasks of mercury was recovered from ore stockpiled during the trenching.

In 1955, Moneta-Porcupine Mines, Ltd., a Canadian company, took an option on the property from the Red Top Mining Co., and a second contract for underground exploration was signed between Moneta-Porcupine Mines, Ltd., and the Defense Minerals Exploration Administration. Approximately 560 feet of underground workings were driven during the period of the second contract (upper adit, pl. 7). Subsequently, a lower adit was driven under a joint agreement by the DeCourcy Mountain Mining Co. (now Alaska Mines and Minerals, Inc.), owner of the Red Devil mine, and Moneta-Porcupine Mines, Ltd. Longholes were drilled from the walls of the lower adit in 1958. Sainsbury, assisted by C. M. Taylor, mapped the underground workings and the surface in August 1959. At this time the property was inactive, although the lease and option agreement between the Red Top Mining Co. and Moneta-Porcupine Mines, Ltd., was still in effect (Clarence Wren, oral commun., 1959).

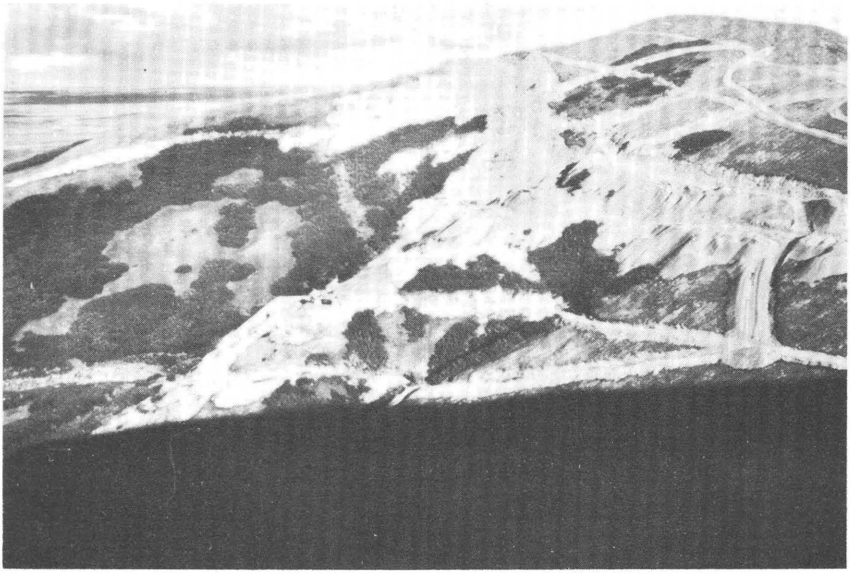

FIGURE 9.—Trenches at Red Top mine; the complex mine trench follows the main breccia zone. Most trenches are about 15 feet wide. The view is to the southeast.

According to Clarence Wren, a partner in Red Top Mining Co., production to 1959 had amounted to 60 flasks of mercury, and rich ore that will yield at least this much was stockpiled at the property in 1959.

GEOLOGY

AREAL GEOLOGY

Marsh Mountain is underlain entirely by graywacke and siltstone of the Gemuk Group (fig. 10), which, according to Cady and others (1955, p. 32–34), includes rocks ranging in age from Carboniferous to Early Cretaceous. The graywacke is generally tinted a somber green and ranges from very fine grained to very coarse grained. Some beds contain calcareous clots that weather out, leaving solution cavities; many beds are slightly calcareous throughout. The graywacke contains abundant ferromagnesian minerals. Siltstone, which ranges from chocolate brown to greenish gray, is interbedded with the graywacke throughout the exposures on Marsh Mountain. Individual beds of graywacke and siltstone may reach a thickness of several hundred feet, although more commonly they are interbedded on a smaller scale.

The strata of the Gemuk Group trend generally east-northeast throughout Marsh Mountain. Variations in the strike from N. 30° W. to N. 60° E. are caused by relatively open folds that plunge southward. The beds along the northern part of Marsh Mountain are

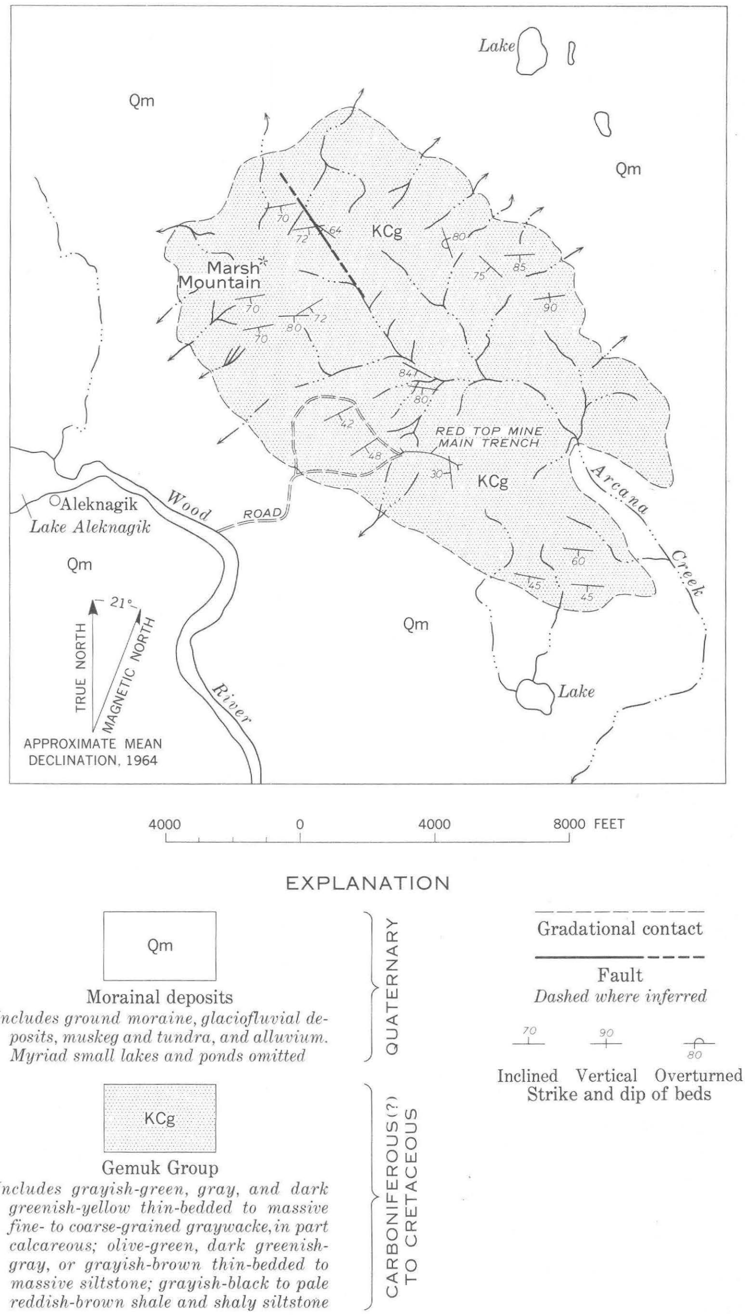

FIGURE 10.—Reconnaissance geologic map of Red Top mine area, Aleknagik. Geology by C. L. Sainsbury, 1959. Base map from an aerial photograph.

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locally overturned and dip northward at steep angles; elsewhere the beds dip generally to the south.

Much of the bedrock of Marsh Mountain is covered by a frost-riven regolith and by tundra, and good outcrops are found only on the mountain tops. At the mine area, bedrock is exposed sufficiently well in most of the trenches and in outcrops in the hill east of the adits for the major structure to be delineated. The main structural feature appears to be an open syncline trending east of north and plunging south and that is faulted off by a complex fault zone. The syncline is best known south of the fault zone. The east limb of the syncline dips about 30°, and the west limb dips 20°. Smaller folds trending nearly east are impressed upon both limbs of the syncline. A sharp anticlinal fold on the west limb of the syncline near the fault zone complicates the structure in the mine area.

The fault zone is a zone of complex shearing and brecciation that is more than 100 feet wide. The complexity of the faulting is best seen in the underground workings, where the fault consists of many branching and interlacing segments containing abundant gouge and brecciated rock between individual faults. The faults have right-lateral displacement. In the western part of the trenched area, the fault zone is parallel or subparallel to the bedding, but in the eastern part it transects the bedding at a high angle, and gives rise to thick breccia in the massive graywackes. The fault zone has been trenched for about 2,000 feet, but no lithologic correlation can be made across the fault zone.

A minette dike or sill about 10 feet thick having chilled borders that are diabasic in texture intrudes the bedded rocks in the lowest trenches in the northwestern part of the mine area. The minette probably represents diabase altered by contact with water-rich sedimentary rocks (Barth, 1952, p. 82–85, 185–188). The minette is not altered to silica-carbonate rocks. The bedded rocks in the northwestern part and in the easternmost part of the mapped area (pl. 7) are veined intricately by small white veinlets of quartz and prehnite. This type of alteration is unrelated to the deposition of ore but is distinguished on the geologic map, for it is conspicuous and widespread.

QUICKSILVER DEPOSITS

GENERAL MINERALOGY OF THE ORES

Cinnabar is the only ore mineral at Red Top, and it is completely free of stibnite. The cinnabar ranges in color from clear brilliant red to dark, almost opaque, purple black. Many of the clear-red grains have centers of dark cinnabar. The relationship of the two types is so intimate that there can be no question that both were deposited during the same period of ore deposition, although the dark cinnabar is older than the light cinnabar. The dark cinnabar gives good tests for iron by X-ray fluorescence, and when heated several hours at 650°C, it leaves a spongy mass having a high iron content. The dark color is probably caused by dispersed hematite, magnetite, or pyrite. Discrete grains of hematite in close association with cinnabar can be seen in several thin sections.

Brown to red limonite is intimately intergrown with the cinnabar, but iron sulfides are very rare. Carbonate of two ages is closely associated with much of the ore. The earliest carbonate, which is typically pale yellowish orange, is dolomite or ankeritic dolomite containing sufficient iron to give a good iron test. The later carbonate, much of which was deposited after the ore, is white crystalline calcite. It forms masses as much as 10–12 feet wide and 100–150 feet long. Locally calcite cements breccia fragments of wallrock, cinnabar, and dolomite. Most of the cinnabar found in calcite is breccia ore in which cinnabar replaced dolomite and was then broken up and cemented by calcite.

Quartz is a scarce gangue mineral at the Red Top mine, but it forms the bulk of one barren vein 2 inches wide that was intersected underground. The detrital quartz grains in brecciated and altered graywacke containing cinnabar are little corroded and were apparently stable during ore deposition.

Clay minerals are found in fairly large volume in much of the ores. Locally, as much as one-half inch of apple-green dickite lines the walls of ore veinlets. Fractured, iron-stained, and argillized rock in an area south of the fault zone is associated with carbonate veinlets barren of cinnabar. The argillized rock contains specks of pyrite.

ORE EXPOSED BY THE MAIN TRENCH

Cinnabar ore is exposed, or has been mined out, at several places along the breccia zone that follows the fault in the main trench. Most of the ore is in the western part of the breccia zone. The following descriptions of ore occurrences refer to the areas marked by circled letters on plate 7.

At the west end of the main trench, a split from the main fault zone curves into the footwall and is represented by a breccia zone in graywacke and siltstone (loc. A, pl. 7). The breccia occurs on both walls of the fault, which is marked by clay gouge 2 inches thick dipping 45° SE. The breccia on the hanging wall is about 10 feet thick; the breccia on the footwall is partly covered by surficial material, and its thickness cannot be determined. Cinnabar occurs as a solid veinlet about 4 inches wide on the west end of the breccia and as disseminations in the carbonate gangue cementing the brecia. Some cinnabar replaced breccia fragments of graywacke. The northeast end of the vein consists of a large pod of barren white calcite.

The main fault and the breccia zone lie on the south side of the main trench east of the split and are barren of ore to a point about 200 feet east. At this point (loc. B, pl. 7) the breccia widens, and a small vein dipping 40° S. splits into the hanging wall of the main fault. The small vein consists of 4 inches of barren white calcite and 6 inches of brecciated graywacke cemented by dolomite on the footwall. Cinnabar occurs in the brecciated wall of the vein as a replacement of both dolomite and graywacke fragments. The cinnabar ranges from thin films in dolomite to solid fragments as much as 3 or 4 inches in diameter. Similar ore formed in the breccia on the footwall of the main fault at the intersection with the small vein. Carbonate-cemented breccia extends eastward along the fault, and small amounts of cinnabar replaced brecciated dolomite for approximately 100 feet.

At the first cross trench east of point B, the breccia on the footwall of the main fault contained an ore shoot 30 feet long that consisted of approximately 4 inches of solid cinnabar (Clarence Wren, oral commun., 1959). Only the edges of this ore shoot were still in place when the trench was mapped in 1959. A small fracture extends from the main fault into the hanging wall near the center of the ore shoot and may have localized the ore shoot.

More ore occurs at a point approximately 100 feet east (loc. C, pl. 7), where a small fault dipping 35° SW. branches from the main fault. Near the intersection the wallrocks were brecciated and extensively replaced by dolomite and white calcite. Rich ore, now mined out, occurred in a vein on the footwall side of the small fault (Clarence Wren, oral commun., 1959), but only discontinuous ore is exposed in the bottom of the pit on the vein. Cinnabar also occurs in the main fault breccia on the footwall of a large pod of massive white calcite about 100 feet long. Small fragments of ore occur in the breccia for a distance of 50 feet east of the calcite pod; Clarence Wren reported that good ore was mined from this area. Ore estimated to contain more than 70 percent cinnabar is stockpiled at the portal of the upper adit, and much of this ore was obtained from the veins described.

The main breccia zone is barren for the next 300 feet, as far as can be determined from trench exposures. The fault and the breccia zone dip 45° S.; both are traceable continuously up the steep slope to the east and are marked throughout by abundant carbonate. Near the top of the hill, the trench widens to almost 100 feet and exposes the fault, the breccia zone, and a large barren calcite pod in the fault.

A branching cinnabar vein lies at the south side of the trenched area on the hilltop (loc. D, pl. 7). The vein is traceable for almost 200 feet and averages 4 inches in width. On its west end the vein dips 37° S. A split traceable for 150 feet curves off to the south but is not continuous in the central part. The main vein and the split consist of a porous mass of brecciated graywacke cemented by limonite and minor calcite. Cinnabar occurs discontinuously along the veins, nowhere occurring in quantities as great as in the veins to the west. The cinnabar replaced graywacke fragments.

To the east the breccia zone has a southeasterly strike, but, as the trenches are largely sloughed, the geologic relations are obscure. Clarence Wren stated that very little cinnabar was found in the eastern part of the trench.

No cinnabar was found in the trenches transverse to the main breccia zone.

ORE EXPOSED BY THE ADITS

Two adits, at altitudes of 1,040 and 1,136 feet, explore the subsurface continuation of the breccia zone. The geologic relations in the adits and a cross section through the adits are shown on plate 8. The upper, or No. 1, adit intersects the fault zone about 50 feet vertically beneath the surface exposures in the main trench; the lower, or No. 2, adit intersects the zone at a point about 150 feet below surface exposures. A pronounced structural and lithologic break occurs across the fault zone.

In the upper adit, the cinnabar occurs as discrete small veins that branch from the main faults, as breccia fragments in or along massive white carbonate pods, and as disseminations in fractured graywacke (pl. 8). The cinnabar-bearing veins range in length from a few feet to at least 40 feet, and cinnabar in the veins ranges in thickness from less than an inch to as much as 3 inches. Most veins are less than 2 inches thick. Some are bordered by zones of brecciated graywacke; cinnabar is disseminated in the breccia. Disseminated ore is entirely confined to brecciated graywacke, or to interbedded graywacke and siltstone and is completely lacking where vein walls are composed of massive siltstone.

The most continuous vein is exposed in the southeast drift. This vein dips 70° NE. where it splits from the fault that the drift follows, but in the face of the small crosscut along the vein, the dip has flattened to 50° (pl. 8). Near the fault the vein contains as much as 2 inches of solid cinnabar, and the hanging wall of brecciated graywacke contains considerable amounts of disseminated cinnabar. In the face of the crosscut along the vein, the vein narrows to 2 inches of brecciated graywacke containing disseminated cinnabar.

Brecciated graywacke associated with a small vein trending north is intersected by the northwest drift of No. 1 adit. The vein dips

52°–70° W. and locally contains 1 inch of solid cinnabar. The brecciated graywacke on the east side of the vein locally contains an estimated 1–2 percent cinnabar in fractures and in replaced graywacke fragments. Several other small veinlets, all less than 1 inch in width, are exposed in the adit.

The lower (No. 2) adit exposed cinnabar only in the extreme eastern part of the northeast drift. Here cinnabar occurs in a distinct vein dipping 65° S. and as disseminations in brecciated graywacke, in part argillized, throughout the last 30 feet of the drift. The ore extends beyond the drift heading. The ore lies on the footwall of large barren calcite pods along the faults. Dark limonite is conspicuous in the fractured walls.

A grab sample of muck from the drift assayed 0.59 percent mercury, and a large grab sample from the dump, representing several cars of muck from the heading, assayed 1.09 percent mercury.

The distribution of cinnabar in the underground openings shows conclusively that massive graywacke wallrocks were distinctly more favorable sites for ore deposition than was the siltstone. Cinnabar is widespread in the upper adit, where most of the wallrocks are either graywacke or interbedded graywacke and siltstone. Most of the drifts in the lower adit followed faults whose walls are massive siltstone. Faulting in the siltstone gave wide zones of impervious gouge, along which solutions penetrated with difficulty. Where the east heading of the lower adit intersected massive graywacke, it penetrated ore. The massive graywacke was brittle during faulting, and it fractured to give abundant breccia and open spaces along which ore-bearing solutions penetrated freely.

The complexity of faults in the underground workings is notable. The zone of branching and interlacing faults is distinctly arcuate in configuration and reflects the tendency of the faults to follow the bedding around the nose of the plunging fold intersected by the fault.

Several ages of postmineralization movement along the fault zone are shown by striations and mullion structure on the massive calcite pods in the adits. The movement was consistently right lateral, and at two places striations show that earlier postmineralization faulting moved the hanging wall upward at an angle of 47° W. The latest displacement was similar in direction but was upward at an angle of 30°.

STRUCTURAL CONTROLS OF ORE DEPOSITION

The cinnabar ore at Red Top mine was deposited principally along open channels. The main channel was created where a regional fault, probably a bedding-plane fault, intersected a plunging fold and produced a complex breccia zone. Some ore was deposited by replacement of breccia fragments and of early dolomite in the main breccia zone. Much of this ore was broken and displaced by later movement and then sealed by calcite; the later fracturing and sealing of the ore with barren calcite reduced the grade of the early ore.

The best ore now uncovered is localized along distinct veins in relatively brittle graywacke or is disseminated in fractured brittle graywacke. The massive siltstone contains only isolated specks of cinnabar.

ORE GENESIS

The ore solutions at Red Top migrated upward from depth along the fault zone from an unknown source. The ore was deposited in an oxidizing environment where hematite and probably limonite coexisted in stable assemblage with cinnabar and dolomite or ankeritic dolomite. The carbonate and limonite may have been precipitated from circulating ground water that mixed with the ore solutions. The paucity of hydrothermal quartz at Red Top is noticeable as compared with that at the other cinnabar deposits of the Kuskokwim region.

The association of dickite with the ore indicates that ore deposition occurred below a maximum temperature of 305° C (Ewell and Insley, 1935). Right-lateral faulting having a large strike-slip component occurred after the deposition of much, if not all, of the barren calcite.

SUGGESTIONS FOR EXPLORATION

Future exploration at Red Top should be planned with the following factors in mind:

1. The best ore along the main breccia zone is found in veins that split from the main vein or are at intersections of cross faults with the main fault zone. New trenches, therefore, should be wide enough to expose the walls on both sides of the central breccia, as was done in the east-central part of the main trench.
2. The competency of the wallrocks seems to have been a major factor in localizing ore. The fractured graywacke is a distinctly more favorable site for ore deposition than is the siltstone, and hence exploration openings should be directed toward the intersection of massive graywacke with the main fault zone. The northeast heading of No. 2 adit is in ore in graywacke and should be extended as long as it remains in graywacke, even though the ore may not be continuous. The northwest heading of the No. 2 adit should enter predominately graywacke wallrocks on the north side of the fault if extended approximately 100–110 feet.
3. The large white calcite pods generally contain "drag ore" only and for the most part formed after mineralization. They do, however, indicate areas where abundant open spaces once existed. (Note the almost complete absence of carbonate pods in the

sheared siltstone exposed by No. 2 adit, pl. 8.) These open spaces presumably favored entrance of ore solutions as well as solutions that deposited the calcite.

4. Neither of the adits can be said with certainty to have passed through the fault zone. Ore shoots comparable to those exposed may exist along faults not yet exposed. If a crosscut is extended completely through the fault zone, however, it should be driven so as to intersect massive graywacke where overlain by massive siltstone. A small amount of additional trenching and detailed geologic mapping could outline the area where the massive graywacke that forms the entire hilltop at the mine (KCgg on the geologic map (pl. 8)) is intersected by the southernmost faults of the fault zone. This intersection area should be especially favorable for ore.

COMPARISON OF ALASKAN DEPOSITS WITH DEPOSITS ELSEWHERE IN THE UNITED STATES

The quicksilver deposits in southwestern Alaska are similar in many ways to deposits in the Western States that have been studied in detail and mined for extended periods of time. The Alaskan prospector and operator interested in quicksilver, therefore, should be able to gain valuable information from the large amount of published literature available. Becker (1888) gave one of the earlier descriptions of many of the quicksilver deposits of the Western United States. Several fundamental conclusions set forth by Becker still apply to most quicksilver deposits of the world and especially to those of the Western States. Some of these conclusions that are applicable to Alaskan deposits are listed below:

1. Quicksilver deposits are grouped throughout the world in areas of relatively recent deformation or volcanism.
2. The mineralogy of quicksilver ores is relatively simple; the ore consists of cinnabar or metacinnabar and, in some places, of native mercury. Stibnite and pyrite often accompany the cinnabar, as does arsenic in smaller amounts. Copper, zinc, and, more rarely, lead, silver, and gold are found in varying amounts in some deposits.
3. The chief gangue minerals accompanying cinnabar are silica and carbonates, and the proportion of the carbonate in the gangue is generally determined by the carbonate content of the adjacent wallrock. Barite, fluorite, and hydrocarbons are found in some cinnabar deposits.
4. Cinnabar most commonly fills open fractures, and more rarely it extensively replaces the wallrock. Thus, the prime requisite for

a lode quicksilver deposit is some type of porous zone in which hydrothermal solutions deposited mercury.

Although modifications have been made in Becker's ideas, these generalizations have been confirmed by many subsequent workers (Ross, 1942; Dickson and Tunell, 1955; Bailey and Phoenix, 1944) and are true of the Alaskan deposits.

Bailey and Phoenix (1944) studied 150 quicksilver deposits in Nevada and found that they could group the deposits into 8 types named by reference to the enclosing rocks in accordance with miner's usage (Bailey and Phoenix, 1944, p. 14–27). These types, some of which are identical with those of the Alaskan deposits, are as follows:

Name	*Host rock*	*Main characteristics*
Sulfurous	Tuff, granite	Low grade, abundant sulfur.
Opalite	Opalite formed from siliceous volcanic rocks.	Large tonnages, low grade.
Volcanic	Lava, agglomerates; generally andesitic.	Grade variable, abundant clay alteration, pyrite.
Diabase dike	Diabase	Rich ore localized by the structure in the dikes; shale or gouge traps common.
Interbedded sediments.	Sandstone, shale, limestone, chert.	Variable size and grade, localized by fractures; minor replacement.
Limestone	Limestone	Rich, erratic ore; replacement of limestone common.
Metamorphic	Metamorphic rock	In roof pendants; generally not important producers.
Granite	Any granitic rock	Metacinnabar very common; localized along faults or shears; high grade and small.

The Alaskan deposits for the most part represent a combination of the interbedded-sediment and diabase-dike types of Bailey and Phoenix, although the limestone and granite types are represented by the deposits at White Mountain and Kagati Lake, respectively. The Alaskan deposits, therefore, may be expected to be roughly comparable to similar deposits in Nevada in general ways. Bailey and Phoenix compiled the production figures for various types of mines in Nevada and arrived at the following generalities, which have been quoted from these authors.

At best it is difficult to estimate the potential worth of a quicksilver mine or ore body while it is still in the prospect or development stage. Because it has been possible to group quicksilver deposits into a few geologic types, some pertinent generalities on expectable yield and expectable grade of ore can be drawn. These generalities, however, must be applied with caution for they can only be based on averages, and some individual mines depart rather widely from these averages.

The ore bodies of the deposits of the limestone and basic-dike type have been the richest, but as they are localized in relatively small compact bodies, they are the most difficult to find. Ore bodies of this type probably will yield the greatest returns on investments if the profits are not expended in seeking for other ore bodies; certainly, their ores can be mined during periods of normal peacetime prices.

Deposits of the volcanic type in most cases are moderately large and continuous, and they contain a medium grade of ore. Therefore, ore can be blocked out in the advance of mining, with the result that it is generally possible to determine the most advantageous size of furnace and method of mining. Some of these deposits mined in the past contained ore that would yield a profit when the price of quicksilver was about $130 a flask; others contained ore of slightly lower grade.

Deposits of the opalite type are large and are cheaply mined, but the ores are nearly everywhere of low grade. While they can be mined on a large scale with good profit during the periods of high prices, most of them cannot be mined profitably during periods of low quicksilver prices.

Other types of deposits appear to show such wide variation that it is impractical to make any generalizations about them.

These generalities will probably be of use to Alaskan prospectors and operators as general guidelines, for the information accumulated to date on the Alaskan deposits indicates that most of the foregoing generalizations hold where applied to the Alaskan deposits.

ORE GENESIS

GENERAL

A full discussion of the ideas of the genesis of mercury deposits is beyond both the scope and usefulness of this report. Excellent summaries of current theory bearing on the transportation and deposition of cinnabar have been published in recent years, such as those by Dreyer (1940), Ross (1942), Krauskopf (1951), and Dickson and Tunell (1955). In general, the literature seems to favor the interpretation that cinnabar is transported in alkaline sodium sulfide solutions, although Krauskopf (1951, p. 521) concluded that transport as the volatile chloride or as mercury vapor is possible and D. E. White (oral commun., 1960) suggested that transportation as an organic complex may also be a possibility. Transportation of mercury as a colloidal dispersion or as a supersaturated solution of mercuric sulfide cannot be proven unreasonable, according to Krauskopf, and transportation as sulfomercuric acid, although seemingly unlikely, cannot be ruled out. Krauskopf further pointed out that cinnabar disassociates completely at temperatures well below 300° C in the presence of moving gases and offers this process as an explanation of the separation of mercury from other ores—that is, at temperatures at which other ores deposit, cinnabar is still disassociated and travels to regions of lower temperatures.

Although the chemical composition of the solutions that transport large amounts of mercury cannot categorically be stated to be alkaline solutions of sodium sulfide, deep-seated thermal waters probably contain H_2S; mixing of these waters with connate water may introduce sodium chloride, even if sodium chloride was not present originally. If these solutions are alkaline (high in OH^{-1}), they will contain both $Na^{\pm 1}$ and S^{-2} ions and therefore should be analagous to solutions of sodium sulfide. Hence, the assumption is not unreasonable that cinnabar is transported to the final point of deposition in such solutions, at least until it is shown that such solutions do not or cannot exist.

The factors leading to precipitation of cinnabar from an alkaline sulfide solution were reviewed most recently by Dickson and Tunell (1955), who made additional laboratory experiments involving the solubility of cinnabar in aqueous solutions of sodium sulfide and sodium hydroxide at temperatures of 25°, 50°, and 75°C. The main conclusions expressed by Dickson and Tunell in the system Na_2S–HgS–H_2O are as follows:

1. Solubility of cinnabar and metacinnabar decreases with increasing temperature to about 75°C. Metacinnabar is more soluble than cinnabar at all three temperatures, but the solubility of metacinnabar decreases with increasing temperature at a greater rate than the solubility of cinnabar. In the temperature range 100°–200°C, solutions of Na_2S can carry geologically significant amounts of cinnabar, although it should be pointed out that the solutions of Na_2S used in the laboratory are abnormally concentrated.
2. Dilution by water of a saturated solution of mercuric sulfide in sodium sulfide causes precipitation of cinnabar.
3. Isothermal evaporation of a saturated solution of cinnabar in sodium sulfide causes the solution to become unsaturated and thus capable of dissolving more cinnabar.
4. Removal of sulfur (by oxidation) from a saturated solution of cinnabar in sodium sulfide causes precipitation of cinnabar.

In the system Na_2S–HgS–Na_2O–H_2O at temperatures of 25° and 50° C, precipitation of cinnabar is brought about by (1) increasing temperature, (2) diluting with water, or (3) removing Na_2O, thus reducing the concentration of Na_2S. Increased solubility of cinnabar is brought about by (1) evaporating water, (2) cooling, or (3) increasing the concentration of Na_2S or Na_2O. It is inherent in the experiments with alkaline solutions, and expressly stated by most workers, that decreasing the alkalinity of a sodium sulfide solution by any method will cause rapid precipitation of cinnabar.

Of direct application to the problem of the genesis of the southwestern Alaska quicksilver deposits is the additional evidence given by Becker (1888, p. 430–434) that arsenic and antimony are readily soluble in solutions of sodium sulfide, as are small amounts of pyrite or marcasite, zinc, copper, and gold. Becker also demonstrated that rapid dilution of concentrated solutions of HgS in Na_2S precipitates black amorphous HgS that contains minute globules of native mercury. Dreyer (1940, p. 38), however, could not confirm Becker's results, but he did show that colloidal mercury is deposited. Thus, a method is available by which small amounts of native mercury can be derived from a cinnabar-bearing sodium sulfide solution, and the deposition of native mercury together with cinnabar is explainable by normal depositional factors applicable to hydrothermal solutions. However, it should be pointed out that no natural thermal waters equivalent to the alkaline sodium sulfide solutions used in laboratory experiments have been found to date in nature, although White (1957a) showed that many alkaline thermal springs contain NaCl and low concentrations of H_2S or sulfides.

The mineralogic and structural features of the cinnabar deposits of southwestern Alaska can be explained reasonably by assuming that the cinnabar was transported from an unknown source by hot alkaline sodium sulfide solutions. Deposition was probably caused principally by factors closely connected with mixing of ore solutions with ground water. The main factors were probably dilution, oxygenation of Na_2S solution by ground water, and increase in acidity of the ore solutions by mixture with acid water derived by oxidation of sulfur in hot springs or other near-surface systems or oxidation of sulfide minerals previously deposited or available in the bedded rocks—especially in the sulfide-bearing dikes.

ROLE OF THE DIKES

The idea of the genetic association of the quicksilver deposits of southwestern Alaska with altered dikes seems to have become firmly implanted among the miners and prospectors in the region, probably as a direct result of the following statement made by Smith (1917, p. 147):

> The mineralization by which the quicksilver was introduced clearly seems to have accompanied the intrusion of the dike rocks. The neighborhood of these intrusives is therefore the place to prospect for quicksilver lodes.

As a result of their study, Cady and others (1955, p. 104) concluded:

> The geologic relationships of the quicksilver deposits are remarkably similar throughout the region. The deposits consist of irregular bodies of cinnabar, commonly associated with the antimony mineral stibnite, in host rocks that comprise chiefly biotite basalt and adjacent graywacke and shale strata of the Kuskokwim group.

On p. 105 they also stated:

> The location and form of the quicksilver lodes are controlled chiefly by zones of fracture that have developed at the contacts between formations of con-

trasting competency. These are principally contacts between the biotite basalt sills, which have been altered to silica-carbonate rock, and adjoining less competent graywacke and shale.

During the present investigation, the continued preoccupation with dikes or sills was evidenced by statements of prospectors and others to the effect that "the dike rocks carry the mercury." Even geologists and mining engineers have seriously proposed that the cinnabar was derived directly from the dikes during the late stage of crystallization of the dikes. It is therefore pertinent to point out here the compelling evidence that the cinnabar deposits are not genetically related to the dikes that at times form the host rock of the deposits. The evidence is as follows:

1. Some of the known deposits are not associated with igneous rocks (White Mountain area), some are in granite not containing dikes (Kagati Lake), and at least one promising deposit (Red Top mine) is unrelated to the only dike exposed in the mine area.
2. The ore bodies everywhere show a much closer relation to faults or shear zones than to dikes, although the intersections of dikes and faults is a particularly favorable structure for deposits.
3. The ore is younger than the youngest of three types of dikes at one property (Rhyolite). Hence, one cannot sensibly assign a genetic association with any of the three types, which include such petrologically divergent types as diabase and rhyolite.
4. At Red Devil mine, the time between the emplacement of the dikes that localized the ore bodies and the introduction of cinnabar was so long that cumulative displacement of the dikes along premineralization cross-cutting faults is as much as 800 feet, and individual fault displacements are as much as 40 feet.
5. Most dikes observed in this study are bleached and altered and contain specks of iron sulfide; only a few contain cinnabar. The authors agree with Cady and others (1955, p. 107) that much of the alteration of the dikes took place before the introduction of the ore minerals and, in fact, may have been unrelated to actual ore deposition.

However, the fact that most of the deposits are closely associated with dikes must be explained. The writers have considered the following possible explanations:

1. The altered and silicified dikes were brittle, fractured readily, and thus provided the primary access channels for ore solutions.
2. The fractured dikes were more permeable than the enclosing rocks and provided greater amounts of ore solution or of ground water, which diluted the ore solutions and promoted deposition of cinnabar.

3. The dikes retained residual heat, which promoted the deposition of cinnabar by raising the temperature of the ore solutions.
4. The dikes or, more significant, the areas near the dikes provided a chemical environment more favorable for the precipitation of cinnabar than did the fractured graywackes along the faults.
5. The quicksilver was derived from the dikes by late-stage deuteric solutions.

Of these factors, 3 and 5 are refuted by the appreciable time span between emplacement of dikes and introduction of the ore. Furthermore, an attempt to genetically relate the ore in the Alaskan quicksilver deposits to dikes would require that the Alaskan deposits be considered as a separate entity from the circum-Pacific belt of quicksilver deposits of which they are a part. The assumption of a genetic association of the deposits with dikes leaves unexplained the deposits in limestone, dolomite, and graywacke. Factor 1 is probably valid if modified to the extent that all competent rocks that were shattered by faults are potential ore channels.

The writers favor factors 4 and 2 in explaining the localization of ore in the altered dikes. In this regard, the fractured dikes become a contributory factor to the localization of ore, rather than a necessary one, by providing physical or chemical conditions near the dikes that led to effective deposition of cinnabar near dikes along ore channels which may not have been confined to the dikes.

The pyrite found in all the dikes and the fact that the pyrite is lacking in the upper parts of the dikes where the dikes are intensely argillized suggest that acid sulfate water was generated near the dikes by weathering of pyrite. The abundant dickite in the ore veinlets suggests an acid environment (Grim, 1953, p. 384). These facts suggest to the authors that one function of the dikes in localizing ore was to direct acid sulfate waters of surface origin into the hydrothermal system near the dikes and thus cause precipitation of cinnabar from the ore solutions by (1) rapidly reducing the alkalinity of the solution, (2) diluting the solutions, and (3) removing sulfur (by oxidation) from the solutions. The fact that ore shoots are generally richer near dikes may reflect the rapid and complete precipitation of cinnabar by several factors; in contrast, only one, or possibly two, precipitating factors were at work in the formation of leaner deposits. In the deposits in limestone or graywacke, the prime cause of precipitation was dilution of ore solutions by ground water distinctly less acid than the sulfate waters near oxidizing dikes. The abundance of carbonate, including calcite, in many of the deposits and the iron sesquioxides ("limonite") closely intergrown with the ores are strong evidence of deposition in the ground-water zone, for the solubility of iron oxides (or hydroxides) and carbonate is extremely low in thermal waters

(Hem and Cropper, 1959; White, 1957a). Hence, the authors are in agreement with Thompson (1954, p. 196), who stated that hydrodynamics may be very important in the deposition of cinnabar ores. Close attention to the hydrodynamics of ground water in any particular area may give useful information in searching for localized ore shoots—for example, projection of a porous bed or breccia zone to its intersection with a hydrothermal conduit.

SIGNIFICANCE OF IRON OXIDES

In many of the deposits herein described, hydrous iron oxide (here called limonite) as well as hematite is closely associated with cinnabar. Part of the limonite is postmineralization and is the result of supergene weathering. Some limonite and hematite were deposited with the cinnabar, and some limonite predates the cinnabar. The problem of iron oxide minerals in deposits formed near the earth's surface was discussed by C. P. Ross (1942, p. 460–464), who stated:

> Obviously lodes formed as indicated above, in part under the influence of oxygenated water from the uppermost zones of circulation of water under ground, will have characteristic mineralogical features that ally them with parts of lodes of other kinds that have been altered after erosion has brought them into these upper zones. Under such conditions the conventional differences between supergene and hypogene processes and minerals become difficult to apply. The presence of oxides, even hydrous oxides, in a quicksilver deposit is not necessarily proof that supergene processes, in the ordinary sense, have been operative.

Thin sections of ore specimens from the Kuskokwim region show hydrous iron oxides (limonite) and hematite intimately mixed with the cinnabar ore. Several specimens are made up of brecciated graywacke fragments cut by veinlets of limonite, often containing specks of hematite. The fact that the limonite veinlets are cut off by carbonate veinlets that contain cinnabar shows that some of the limonite predates the ore. Some of the limonite veinlets contain cinnabar, and in many veinlets, a complete gradation seems to exist from brown limonite through deep-red-brown limonite to cinnabar. Some of the ores contain small fuzzy clots that in thin section are seen to be an intimate mixture of bleds of limonite and cinnabar. In such patches, the grain size of the cinnabar and limonite varies directly. This fact suggests that they were deposited simultaneously.

Some evidence, however, suggests that some limonite is supergene in origin. The amount of limonite in the Red Devil ores decreases with depth, although ore specimens from the 450-foot level contains some limonite. The 450-foot level has been beneath the water table since the ores were deposited, for the mine is well below the Kuskokwim River and the Kuskokwim is an antecedent stream. In some specimens of ores and wallrock from other deposits, the limonite rims pyrite grains, penetrates into the rock along late fractures cutting ores, and forms thin films around mineral grains. Such limonite is without question supergene in origin. The close association of hematite with cinnabar is more difficult to explain as the result of weathering, especially where the hematite occurs in the dark cinnabar.

The relations between some of the iron oxide and the ore and gangue minerals are most easily explained as a result of simultaneous deposition. Whether the iron was originally present in the ore-bearing solutions or whether it was brought into the hydrothermal system by ground water cannot be stated with certainty. The evidence indicates only that iron oxide and cinnabar were deposited simultaneously. The coexistence of hematite and cinnabar rather than pyrite and cinnabar restricts the assumed composition of the fluids depositing hematite and cinnabar, however, and it is instructive to see whether such fluids can be expected in hydrothermal systems.

The limiting conditions under which cinnabar and hematite can coexist in the presence of the sulfate ion, which would be present near the altering diabase dikes that contain pyrite or in oxidizing sulfur-bearing hydrothermal waters, were discussed in 1959 with Prof. Konrad B. Krauskopf at Stanford University. The writers are indebted to Dr. Krauskopf for suggesting the following chemical equations that enable us to investigate the chemical characteristics of hydrothermal systems in which the possible mineral combinations are cinnabar-pyrite, cinnabar-pyrrhotite, or cinnabar-hematite. Under standard conditions—which are a pressure of 1 atmosphere and a temperature of 25°C—the following equations are valid (data from Latimer, 1959, are used): [2]

[2] Abbreviations used, and their meanings, are as follows:
e^{-1}=electron
H^{+1}=hydrogen ion
$\Delta F_R°$=the standard free energy of reaction
a=activity
kcal=kilocalories
$E°$=electrical potential (voltage) of the reaction
V=volts
k=equilibrium constant
EH=oxidation potential under experimental conditions measured against the standard hydrogen electrode
R=gas constant
T=absolute temperature
n=number of electrons
F=the faraday
pH=negative logarithm of the hydrogen ion concentration (acidity)
ln=logarithm

$$4H_2O + HgS = Hg^{+2} + SO_4^{-2} + 8e^{-1} + 8H^{+1} \quad (1)$$

$\Delta F_R° = +100.47$ kcal per mole; $E_1° = 0.544V$

$$11H_2O + 2FeS = Fe_2O_3 + 2SO_4^{-2} + 18e^{-1} + 22H^{+1} \quad (2)$$

$\Delta F_R° = +138.45$ kcal per mole; $E_2° = 0.333V$

$$19H_2O + 2FeS_2 = Fe_2O_3 + 4SO_4^{-2} + 30e^{-1} + 38H^{+1} \quad (3)$$

$\Delta F_R° = +270.29$ kcal per mole; $E_3° = 0.392V$.

The equilibrium constants ($k_{1\ 2,3}$) of these reactions are:

$$k_1 = \frac{aHg^{+2} \cdot aSO_4^{-2} \cdot a^8H^+}{1},$$

$$k_2 = \frac{a^2SO_4^{-2} \cdot a^{22}H^+}{1},$$

and

$$k_3 = \frac{a^4SO_4^{-2} \cdot a^{38}H^+}{1}.$$

If values are assigned to the concentration of ions involved in the foregoing equations, the potentials of the reactions can be computed using the standard equation:

$$Eh = E° + \frac{RT}{nF} \ln K.$$

Assume that the concentrations of Hg^{+2} and SO_4^{-2} are 10^{-5} mole per liter, and express the H^{+1} concentration in terms of pH; the potentials of the three reactions are:

$$Eh_1 = 0.469V - 0.06pH,$$

$$Eh_2 = 0.293V - 0.073pH, \text{ and}$$

$$Eh_3 = 0.352V - 0.076pH.$$

As mercury can be transported as a chloride and as many minera: waters are high in chloride, the following equation is also considered

$$4H_2O + HgS + 4Cl^{-1} = HgCl_4^{-2} + SO_4^{-2} + 8e^{-1} + 8H^{+1}$$

$\Delta F_R° = +78.9$ kcal per mole; $E° = +0.428V$

$$K = \frac{aHgCl_4^{-2} \cdot aSO_4^{-2} \cdot a^8H^{+1}}{a^4Cl^-}$$

$Eh = 0.353V - 0.059pH$ (Cl^{-1} concentration of 1 mole per liter)

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Figure 11 is an Eh–pH diagram based on these four equations. The diagram demonstrates a considerable overlap of the stability fields of HgS and Fe_2O_3, if cinnabar is carried in aqueous solution containing SO_4^{-2} and free of chloride, and a reduced overlap in solutions containing 1 mole per liter of chloride ions.

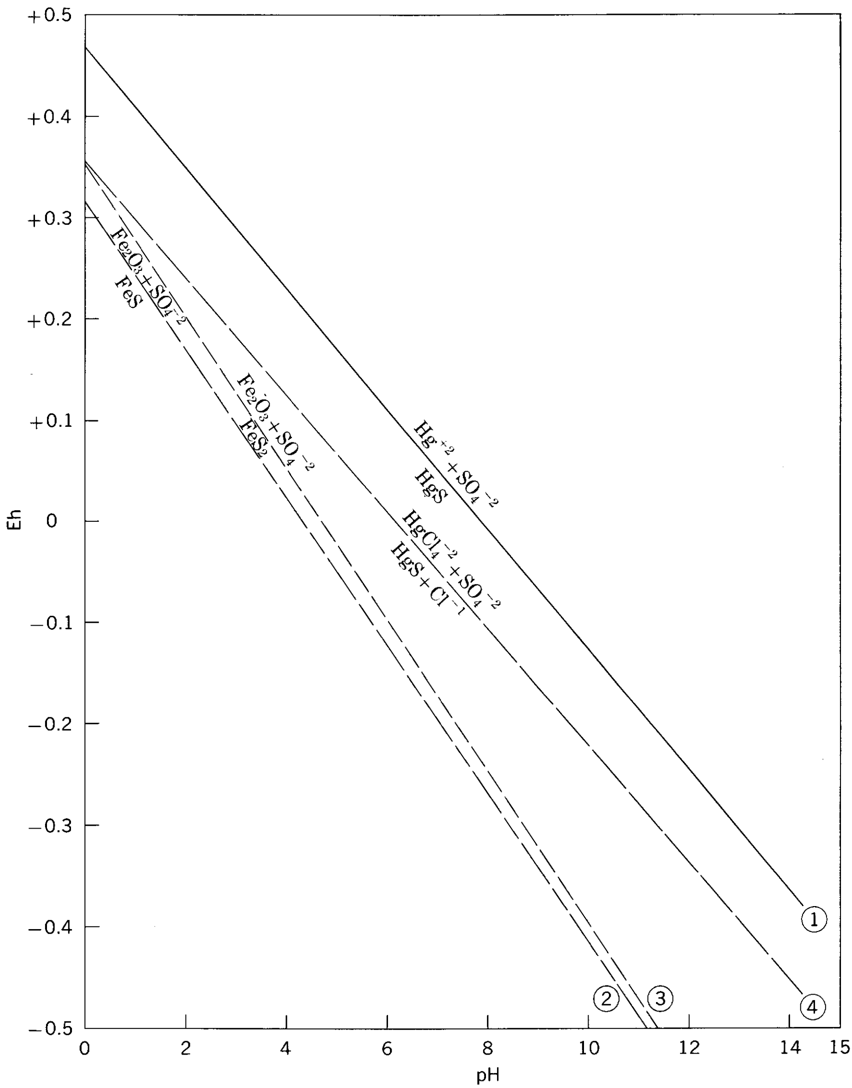

FIGURE 11.—Stability fields of cinnabar and hematite in terms of Eh and pH in solutions containing SO_4^{-2} or Cl^{-2} at 1 atmosphere pressure and 25°C temperature.

No thermodynamic data are available for calculations at higher temperatures and pressures; however, Dr. Krauskopf suggested (oral commun., 1962) that the assemblages would be stable at higher temperatures and pressures.

More elaborate diagrams could be constructed to show the effects of varying concentration of SO_4^{-2} and Hg^{+2} or to include equations expressing the stability of cinnabar in terms of pressures of sulfur. However, our intention here is to show only that cinnabar and hematite can coexist in hydrothermal solutions, as was observed in specimens of ores from the Alaskan deposits.

The fact that many surface and subsurface waters, including deep-well waters, contain SO_4^{-2} in concentrations equal to or greater than 10^{-5} molar (Hem, 1959, p. 64, 77, 103) indicates that admixture of ground water and ore solutions carrying mercury could cause simultaneous precipitation of cinnabar and hematite at depths considerably below the water table. In regard to the localization of ore near diabase dikes, the depth to which sulfate-bearing water derived by oxidation of pyrite in a dike would descend along fractures in the dike is unknown. However, Brown (1942) pointed out that waters from oxidizing sulfide deposits reach densities sufficiently high to enable them to penetrate below the water table, and Gilluly (1942, p. 302–303) showed that the pre-Recent weathering of the ore body at Ajo, Ariz., was " * * * controlled by local paths of deep ground water circulation." Hence, sulfate-bearing waters are not confined to the zone of vadose water, and hematite could be deposited well below the water table, as probably happened in some of the Alaskan quicksilver deposits.

The carbonates that form the gangue of many of the cinnabar veins could have come either from the hypogene ore-forming solutions or from meteoric waters that mixed with these solutions, but they more likely came from cold meteoric waters. Several workers (Ross, 1942, p. 452) pointed out that carbonate gangue in cinnabar deposits is common where the enclosing rocks contain notable amounts of carbonate. It is not certain, however, whether the carbonate is derived by leaching of the carbonate from wallrocks by hydrothermal solutions, with subsequent deposition from these solutions, or whether the carbonate is derived from meteoric waters that dissolved carbonate from the country rock and then mixed with hydrothermal waters. White (1957a, p. 1652) emphasized that the solubility of calcium carbonate in a thermal sodium chloride water is very low at 200°–300°C and that such hot thermal waters may come in contact with limestone without dissolving calcium carbonate. The calcium carbonate content becomes appreciable only after the solutions have cooled and have leached calcium from the wallrocks in the cooler environment.

The intimate relation of carbonate and hematite or limonite in some of the quicksilver deposits herein described suggests that both were deposited simultaneously. The large volumes of carbonate (predominantly calcite and minor early dolomite) with or near the cinnabar ores indicate that the hydrothermal solutions that deposited the ores or the solutions that mixed with the ore solutions probably contained notable concentrations of calcium carbonate in late stages and probably lesser amounts of magnesium carbonate in earlier stages. In view of the low solubility of calcium carbonate in hot water and its appreciable solubility in cold water, the carbonate in the cinnabar ores is most easily accounted for as having been carried into the hydrothermal system by admixture of meteoric water, which precipitated carbonate during heating. At the same time, the dilution of the hydrothermal solutions by the meteoric water caused precipitation of cinnabar. Any iron in solution in the meteoric waters would be precipitated both by heating and by the increase of pH, thus leading to the intimate mixture of limonite with the carbonate and ore, a feature common in the Alaskan ores. The low solubility of iron oxides and hydroxides in water having a pH of about 5 or more could be cited as evidence that the hydrothermal solutions, if they were alkaline sodium sulfide solutions, could not have contained significant amounts of iron to deposit with the cinnabar. However, the iron need not have been in solution, for it could have traveled as dispersed hydroxides. Nevertheless, the iron was more easily brought in from acid ground waters than transported in the hydrothermal solutions.

TRACE ELEMENTS IN THE ORES

Specimens of ore from several of the deposits were submitted to the laboratories of the U.S. Geological Survey for semiquantitative spectrographic analyses. The results are shown in table 1.

Most of the samples analyzed were relatively rich in cinnabar and weighed from a few ounces to half a pound. The analyses showed that small amounts of other metallic elements accompany the cinnabar, a fact previously pointed out by Ross (1942, p. 450–451), but that few of these are present in amounts significantly greater than their normal crustal abundance.

The spectrographic analyses should be interpreted in the light of the normal crustal abundance of the elements and the limits of detectability shown in the last two columns of the table, from which it can be seen that the reported presence or absence of some of the rarer elements is, at least in part, a function of the sensitivity of the detection method. For instance, the ores could contain appreciable cesium or rubidium, but their detection limits are so high as to preclude detection in the common spectrographic analyses.

The spectrographic analyses confirm the conclusion based on the study of thin sections and ore specimens that only very small amounts of other metallic elements are associated with the cinnabar and stibnite in the ores. The rock-forming elements (first nine listed in table 1) vary within limits explainable by fragments of unreplaced wallrocks. The titanium, which is relatively abundant, reflects the presence of leucoxene and probably rutile derived from ilmenite, sphene, and titaniferous magnetite in the dikes or graywacke. The strontium probably replaces calcium in calcite. The mode of occurrence of the vanadium is not known. The iron in the various samples is tied up in limonite, hematite, ankeritic dolomite, and possibly in magnetite. The silver in sample 278249 may reflect small amounts of unrecognized arquerite or another silver amalgam. No effort has been made to determine the geochemical association of the rarer elements, such as ytterbium and gallium, detected in trace amounts in some of the ores. The sodium, found in all specimens, varies in amount inversely with the mercury content and directly with the aluminum content, a fact suggesting that the ores contain unreplaced sodium-bearing feldspar.

The metal content of the black mud from the sulfur spring near White Mountain (Lab. No. 278242) is strikingly similar to that of the ores from the deposits, particularly to those from the Red Devil mine. The mud contains abnormal amounts of mercury and antimony along with trace amounts of the common metals cobalt, chromium, copper, and zinc. The spring may represent the surface exposure of a hydrothermal system that is depositing cinnabar at depth. D. E. White (oral commun. 1960) attached particular significance to the mercury in the mud, for it is difficult to explain as a result of wallrock contamination of the spring water by the common crustal rocks. He cautioned, however, that the mercury could be derived from mechanical disintegration of cinnabar in a deposit transected by the spring water. The mercury-bearing mud contains silicon, calcium, and sodium concentrations similar to those of the cinnabar ores. The iron in the mud again confirms the close association of iron with mercury and cinnabar.

TABLE 1.—*Semiquantitative spectrographic analyses,*

[Symbols used: 0, looked for but not found (see limits of detectability); M, major constituent (greater than
Nancy W. Conklin, spectrographic analyses; D. L. Skinner,

	White Mountain				Alice and Bessie mine (Parks property)	Red Top mine			Rhyolite prospect	Cinnabar Creek mine		Lucky Day prospect
	Peggy Barbara prospect	Mud from sulfur spring	North ore zone	South ore zone		Ore pile	Upper adit	Lower adit				
Lab. No	278241	278242	278243	278244	278245	278246	278247	278248	278249	278250	278251	278252
Si	0.07	M	0.7	0.03	0.7	1.5	0.03	7	7	M	M	3
Al	.07	3	.3	.07	.015	.3	.07	1.5	.15	0.15	0.7	.07
Fe	.15	1.5	.7	.07	.07	.7	.7	.7	1.5	.15	.7	.15
Mg	.7	.7	3	7	.03	.7	.15	3	.0015	.03	.015	<.001
Ca	M	1.5	3	M	1.5	1.5	.7	3	.003	.07	.07	<.002
Na	<.1	.7	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1	<.1
K	0	1.5	0	0	0	0	0	0	0	0	0	0
Ti	.007	.3	.015	.0015	.0007	.015	.0007	.03	.07	.015	.07	0
Mn	.007	.015	.015	.003	.003	.007	.003	.03	.003	.003	.007	.0007
Ag	0	0	0	0	0	0	0	0	.0015	0	0	0
As	0	0	0	0	.3	0	0	0	0	0	.3	0
B	0	D	0	0	0	0	0	0	0	D	D	0
Ba	.003	.07	.003	.0007	.03	.0015	.0007	.007	.07	.015	.03	.0007
Be	0	0	0	0	0	0	0	0	0	0	0	0
Cd	0	0	0	0	0	0	0	0	0	0	0	0
Co	0	.0007	0	0	0	0	0	0	0	0	0	0
Cr	.0007	.003	.0007	.0003	.0003	.0003	.0007	.003	.003	.0007	.0003	.0007
Cu	.003	.003	.0007	.0003	.007	.003	.007	.003	.007	.0015	.003	.003
Ga	0	D	0	0	0	0	0	0	D	0	0	0
Ge	0	0	0	0	0	0	0	0	0	D	D	0
Hg	6.9	.05	60.31	45.69	10.6	57.68	80.17	38.74	54.10	11.48	6.53	70.10
In	0	0	0	0	0	0	0	0	0	0	0	0
Ir	0	0	0	0	0	0	0	0	0	0	0	0
La	0	0	0	0	0	0	0	0	0	0	0	0
Li	0	0	0	0	-------	0	0	0	0	0	0	0
Lu	0	0	0	0	0	0	0	0	0	0	0	0
Mo	0	0	0	0	0	0	0	0	0	0	0	0
Nb	0	0	0	0	0	0	0	0	0	0	0	0
Nd	0	0	0	0	0	0	0	0	0	0	0	0
Ni	0	.0015	.0007	0	.0007	0	.0007	0	.0007	.0007	.0007	0
Os	0	0	0	0	0	0	0	0	0	0	0	0
Pb	0	D	.003	D	.003	0	0	0	D	0	D	0
Pd	0	0	0	0	0	0	0	0	0	0	0	0
Pr	0	0	0	0	0	0	0	0	0	0	0	0
Pt	0	0	0	0	0	0	0	0	0	0	0	0
Rb	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
Re	0	0	0	0	0	0	0	0	0	0	0	0
Sb	0	.07	0	0	M	.7	.015	.015	.03	>1	>1	.03
Sc	0	.0007	0	0	0	0	0	0	0	0	0	0
Sr	.3	.015	.03	.015	.007	.003	.015	.015	.007	.0007	.003	0
V	.015	.007	.003	.0015	0	.0015	.0015	.0015	.0015	D	.0015	0
Y	0	.0015	0	0	0	0	0	0	0	0	.0015	0
Yb	0	.00015	0	0	0	0	0	0	0	0	.00015	0
Zn	0	0	0	0	0	0	0	0	.07	0	0	.15
Zr	0	.015	0	0	0	0	.0015	.0015	0	0	.0015	0

Looked for in all samples and not found (detection limit and average crustal abundance, respectively, given within parentheses): P (0.2; 0.12), Au (0.002; 0.0000001), Bi (0.001; 0.00002), Ce (0.02; 0.00416), Dy (0.005; 0.000447), Er (0.005; 0.000247), Eu (0.05; 0.000106), Gd (0.00 5; 0.000636), Hf (0.01; 0.00045), Ho (0.01, 0.00015), In (0.001; 0.00001), Ir (0.01; 0.0000001), Lu (0.01; 0.000075), Nd (0.01; 0.00239), Os (0.01; ——), Pr *in percent, of quicksilver ores from southwestern Alaska*

10 percent); D, detected; <, less than percentage shown (standard detectabilities do not apply). Analysts: determination of Hg by Whitton Distillation method]

Lucky Day prospect—Continued	Willis property	Red Devil mine									Detection limit of the element	Average crustal abundance (percent; from Goldschmidt, 1954)
		450-ft level		300-ft level			Surface	Mary Jane stope above 200-ft level	200-ft level	Dolly shaft about 80 ft below collar		
278253	278254	278255	278256	278257	278258	278259	278260	278261	278262	278263		
M	M	M	M	M	M	M	7	M	M	3	0.002	27.72
0.3	0.7	0.15	7	1.5	3	7	.015	0.3	7	.03	.001	8.13
.3	.15	.7	3	.7	3	3	.015	.07	3	.07	.0008	5.00
.007	.003	.07	3	.3	1.5	3	.0015	3	3	.003	.0005	2.09
.03	.3	.3	.15	.3	.7	.3	<.002	.03	1.5	.7	.005	3.63
<.1	<.1	<.1	.3	.15	.3	.3	<.1	<.1	<.1	<.1	.05	2.83
0	0	0	3	.7	1.5	3	0	0	0	0	.7	2.59
.03	0	.07	.3	.15	.3	.3	.0015	.07	.3	.003	.0002	.44
.0015	.0015	.0003	.07	.03	.07	.07	0	.015	.15	.0015	.0002	.10
0	0	0	0	0	0	0	0	0 0	0		.0001	.000002
.7	.3	1.5	0	.7	0	0	.3	1.5	.7	3	.1	.0005
0	0	D	.015	.007	.015	.015	0	D	.007	0	.002	.0010
.003	.07	.007	.15	.07	.03	.15	.003	.15	.07	.003	.0002	.043
0	0	0	.0003	0	0	0	0	0	0	0	.0001	.0006
0	0	0	0	0	0	0	0	0	0	0	.005	.000018
.0007	.0007	D	.003	.0007	.0015	.003	0	.0007	.003	0	.0005	.0040
.003	.003	.003	.015	.003	.007	.015	.00015	.007	.07	.0003	.0001	.0200
.007	.015	.03	.015	.007	.007	.015	.0015	.003	.015	.015	.0001	.0070
0	0	0	0	.0015	D	.0003	.0007	0	0	D	.0002	.0015
0	0	0	0	.0015	0	0	0	0	0	0.001		.0007
35.87	34.53	0	0	5.16	0	0	30.31	20.97	0	32.15	-------	.00005
0	0	0	0	0	0	0	0	0	0	0	.001	.00001
0	0	0	0	0	0	0	0	0	0	0	.01	.0000001
0	0	0	.003	0	0	0	0	0	0	0	.002	.00183
0	-------	-------	.07	D	.07	.07	0	0	.07	-------	.02	.0065
0	0	0	0	0	0	0	0	0	0	0	.01	.000075
0	0	0	.0003	0	0	.0003	0	0	0	0	.0005	.00023
0	0	0	.0015	.0015	0	.0015	0	0	0	0	.001	.0020
0	0	0	0	0	0	0	0	0	0	0	.01	.00239
.003	.0007	.003	.015	.003	.003	.007	0	.003	.03	.003	.0003	.0100
0	0	0	0	0	0	0	0	0	0	0	.01	-------
.003	.0015	.015	.0015	0	D	.003	0	0	0	0	.001	.0016
0	0	0	.0015	0	0	0	0	0	0	0	.0003	.000001
0	0	0	0	0	0	0	0	0	0	0	.05	.000553
0	0	0	0	0	0	0	0	0	0	0	.003	.0000005
-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	10.	.0280
0	0	0	0	0	0	0	0	0	0	0	.005	.0000001
>1	M	M	.03	.07	0	0	M	M	.07	M	.01	.0001
0	0	0	.0015	.0007	.0007	.0015	0	0	.0015	0	.0005	.0005
.003	.003	.0007	.015	.015	.003	.007	0	.03	.07	.0015	.0002	.0150
.0015	.003	.0015	.03	.003	.007	.015	0	.0015	.015	0	.001	.0150
0	0	0	.003	.0015	.0015	.003	0	0	.0015	0	.001	.00281
0	0	0	.0003	.00015	.00015	.0003	0	0	.00015	0	.0005	.000266
.07	.07	0	0	0	0	0	0	0	0	0	.02	.0080
0	0	.0015	.015	.003	.007	.007	0	.003	.007	0	.001	.0220

(0.05; 0.000553), Pt (0.003; 0.0000005), Re (0.005; 0.0000001), Rh (0.005; 0.0000001), Ru (0.01; ——), Sn (0.001; 0.0040), Sm (0.01; 0.000647), Ta (0.02; 0.00021), Tb (0.1; 0.000091), Te (0.1; 0.00000018), Th (0.02; 0.00115), Tl (0.01; 0.00003), Tm (0.01; 0.00002), U (0.05; 0.0004), and W (0.01; 0.0001); not looked for; in all samples: Cs (2; 0.00032), F (——; 0.08), and Rb (10; 0.0280).

SUGGESTIONS FOR PROSPECTING

Many undiscovered cinnabar deposits without doubt remain in southwestern Alaska. The discovery of these deposits will continue to be hampered by the inaccessibility of the country and the generally thick cover of surficial deposits, tundra, and muskeg that obscure bedrock, as well as by the scarcity of experienced prospectors. Certain guide lines for prospecting may be cited here on the basis of information in the foregoing pages and may prove of value to the prospector not well acquainted with cinnabar deposits.

FAVORABLE STRUCTURES

Most of the known cinnabar deposits in southwestern Alaska occur in folded rocks in a belt almost parallel to the major arcuate fault systems trending northeastward through the area. These faults represent a tectonic zone that is still active (St. Amand, 1957, p. 1345). At least one mineral spring near one of these faults is still depositing mercury (White Mountain area). Elsewhere throughout the world, cinnabar deposits are spatially associated with the areas of Tertiary to Recent tectonism and volcanism (Becker, 1888, p. 51–52). Few deposits, however, have been found in major faults; most are localized by minor faults and brecciated zones near major faults (Bailey, 1959). Therefore, in prospecting, attention should be paid to fractured rocks near the main faults rather than to the main faults themselves.

The factors leading to the deposition of cinnabar from alkaline sulfide solutions are largely those that are dependent upon the changes that are most completely brought about by the mixing of ground water with hydrothermal solutions. Consequently, the localization of an ore body may be determined in large measure by the hydrodynamics of circulating ground water, which in turn is controlled in large part by porous zones such as fault breccias and permeable beds.

FAVORABLE COUNTRY ROCK

The most productive deposits known to date are in faulted and altered dikes that intrude the Gemuk and Kuskokwim Groups. Promising lodes, however, are found in graywacke and siltstone (Red Top mine) and in limestone. The deposits in granite (Kagati Lake) have not been explored sufficiently to evaluate their potential, although Bailey and Phoenix (1944) pointed out that in Nevada and California, deposits in granite tend to be small.

No deposits have been found to date in southwestern Alaska in the extrusive rocks of Tertiary and Quaternary age. Elsewhere in North America, cinnabar deposits have been found in Tertiary volcanic rocks.

As the volcanic rocks in southwestern Alaska are cut by faults older than the mercury mineralization, the volcanic rocks must be considered as possible host rocks.

RELATION OF ORE TO ALTERATION

The known cinnabar deposits of southwestern Alaska are associated with altered rocks differing in appearance from the enclosing rocks and hence are recognizable by the careful prospector. Although many altered dikes do not contain cinnabar, the deposits in dikes are associated with bleached dike rock converted to a mass of clay minerals, carbonate, and silica, which is stained deep reddish-brown by iron oxide. Hence, all such altered dike rock should be examined carefully, especially where the dikes are extensively altered to clay minerals.

The dolomite host rock of the cinnabar at White Mountain is distinctly different in appearance from the surrounding limestone. The dolomite is a gray-white rock containing innumerable minute voids in addition to the larger openings between breccia fragments. The dolomite is appreciably harder than the surrounding limestone, and hence simple hardness tests aid in its recognition. The dolomite will not effervesce with 0.5 normal hydrochloric acid, and this test, in conjunction with appearance and hardness, identifies it.

At the Red Top mine, coarsely crystalline white calcite in large amount was introduced into siltstone and graywacke near the ore channels. The sediments near the mine area are bleached and iron stained. Hence, other areas of staining and carbonatization should be examined carefully.

PROSPECTING METHODS

All the quicksilver deposits discussed in this report were found by tracing surface float or by using the gold pan; the gold pan must still be considered as the primary tool in prospecting for unknown deposits. Cinnabar is soft and friable but extremely resistant to chemical weathering, and it forms, therefore, distinct placers containing a dispersion halo of cinnabar fragments; these fragments are of pinhead size a mile or so from the lode, but they may be fairly large nuggets near the lode. Russel Schaeffer found all the prospects near Cinnabar Creek by use of the gold pan; he stated (oral commun., 1959) that, in his opinion, any outcropping cinnabar lode large enough to be of economic interest would yield a placer that could be traced to the source with the gold pan. Ed Hager, of the Cordero Mining Co., stated (oral commun., 1959) that cinnabar could be panned from any gravel bar in Chunitna Creek in the White Mountain area north of the granite. Stream gravels within a mile of the deposits contained notably richer placers. Joe Struver used the gold pan to trace float cinnabar to the lodes at Rhyolite.

Geochemical reconnaissance techniques have not yet been thoroughly tested by the Geological Survey to prove their usefulness in prospecting for mercury. Preliminary work using soil samples from near known mercury deposits in Alaska have disclosed sharp anomalies of mercury, arsenic, and antimony (R. M. Chapman, oral commun., 1960), and samples taken by Ward and Bailey (1958) demonstrated that soil and rock samples near known mercury deposits in California and Nevada could be used to find the mercury deposits. Sainsbury (1957) demonstrated that stream sediments could be used to detect antimony deposits. Therefore, geochemical prospecting by use of stream sediments and soil samples may be useful in the exploration for quicksilver in Alaska because of the close association of antimony and mercury in most of the quicksilver deposits of southwestern Alaska. Further work will probably show that mercury can be detected with equal facility in stream sediments. At present, however, conventional methods of prospecting are best used in the search for new deposits, perhaps in conjunction with analyses of stream sediments as a broad reconnaissance method.

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INDEX

[Italic page numbers indicate major references]

S

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