Geology of the Red Devil Quicksilver Mine, Alaska

By E. M. MacKEVETT, Jr., *and* H. C. BERG

CONTRIBUTIONS TO ECONOMIC GEOLOGY

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A description of the geology and ore deposits of Alaska's largest quicksilver mine

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By E. M. MacKevett, Jr., and H. C. Berg

ABSTRACT

The Red Devil mine, which has produced about 20,000 flasks of mercury, is Alaska's largest mercury producer. The mine is in the Central Kuskokwim region about 250 miles northwest of Anchorage in a thick sequence of graywackes and argillaceous rocks that are cut by a few altered dikes and are locally mantled by surficial deposits. Most of the Red Devil ore has formed along and near intersections between the altered dikes and northwestward-trending faults that largely are parallel to the bedding of the sedimentary rocks. The many discrete ore bodies that are thus controlled are crudely prismatic and commonly plunge about 40° S. The ore, which was formed mainly by processes of open space filling, consists of cinnabar that generally is associated with abundant stibnite in a quartz-rich gangue. Less common constituents are realgar, orpiment, calcite, clay minerals, and secondary antimony minerals.

INTRODUCTION

The known quicksilver deposits of Alaska are almost entirely confined to southwestern Alaska and are mainly in the area drained by the Kuskokwim River. This report, which describes the Red Devil mine, is one of two related reports on the quicksilver deposits of southwestern Alaska.

The Red Devil mine, Alaska's leading quicksilver producer, is in the Central Kuskokwim region about 250 miles N. 78° W. of Anchorage and 6 miles northwest of Sleetmute (fig. 1). The mine is near the southwest bank of the Kuskokwim River, and its surface altitudes range from 260 to about 570 feet. Access to the mine is principally by airplane. Northern Consolidated Airlines operates scheduled flights to Red Devil, and besides serving as a freight, passenger, and mail carrier, it transports the mine's output of quicksilver to Anchorage. Local transportation consists of small airplanes, riverboats in the summer, and dog teams during the winter. During the summer the mining company operates a power barge between Red Devil and Bethel for transshipping fuel from seagoing vessels to the mine.

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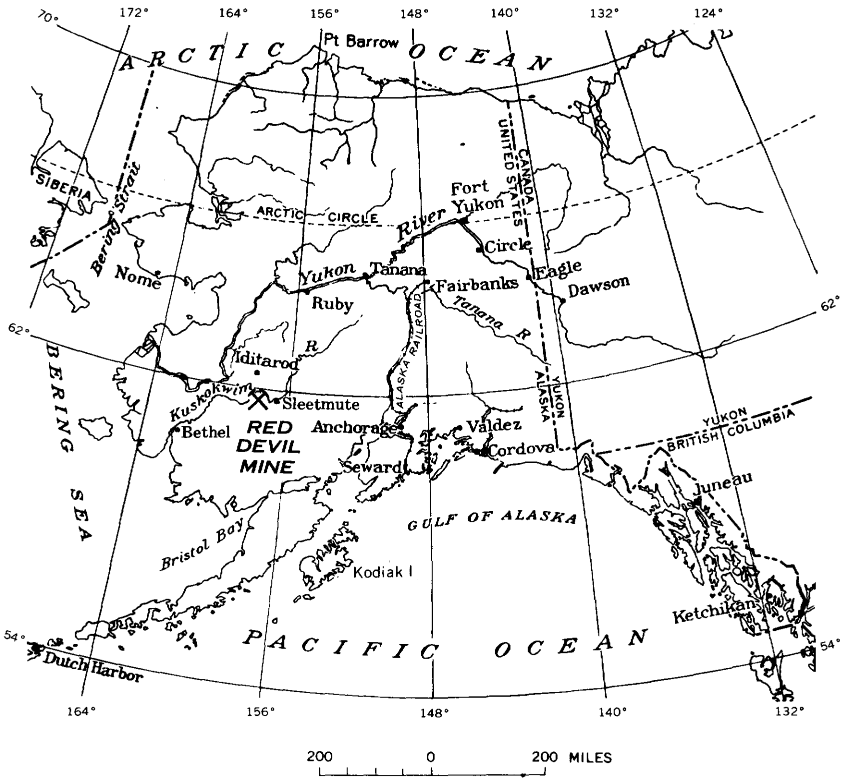

FIGURE 1.—Index map of Alaska showing the location of the Red Devil mine.

This report is largely an outgrowth of work done under the Defense Minerals Exploration Administration (DMEA) program and is based chiefly on 5 weeks of field investigation during the summer of 1958.

A U.S. Geological Survey party under the direction of W. M. Cady studied the Red Devil deposits in conjunction with its investigation of the geology of the Central Kuskokwim region between 1941 and 1948 (Cady and others, 1955). B. S. Webber and associates of the U.S. Bureau of Mines have also examined and reported (1947) on the Red Devil deposits. Studies involving geochemical prospecting have been undertaken at Red Devil by L. M. Anthony of the University of Alaska, and by a U.S. Geological Survey party headed by R. M. Chapman.

This report is intended to supplement and update earlier geologic descriptions of the Red Devil mine and to provide additional data on the size, shape, and structural control of the deposits, based largely on mapping of workings that were excavated after the earlier geologic investigations. Fieldwork consisted of mapping the surface with a plane table and alidade at scales of 1 inch to 100 feet and 1 inch to 20 feet, and mapping most of the accessible underground workings by Brunton and tape methods at a scale of 1 inch to 20 feet.

Extensive laboratory studies were not made as the rocks and minerals of the deposits have been adequately described by Cady and others (1955). However, a few thin sections were studied, and several minerals and rocks analyzed with an X-ray diffractometer, and X-ray spectrometer, or by colorimetric and semiquantitative spectrographic methods.

Our work was aided by the helpful cooperation of many people associated with the mine, particularly R. F. Lyman, the mine manager, and G. W. Herreid, the former mine geologist. Mr. Herreid also graciously provided his geologic maps of workings that were driven during the latter part of 1958. Discussions with J. D. Murphy, a former manager and geologist at Red Devil, and with colleagues on the U.S. Geological Survey, particularly E. H. Bailey and C. L. Sainsbury, were also beneficial.

HISTORY, PRODUCTION, AND RESERVES

The Red Devil claims were staked by Hans Halverson in 1933, and the mine was operated seasonally between 1939 and 1946 (Cady and others, 1955, p. 109). After several years of dormancy the mine was reactivated by the DeCoursey Mountain Mining Co. in the fall of 1952 aided by a loan provided by DMEA. It has been operated more or less continually since then. During the spring of 1959 the DeCoursey Mountain Mining Co. changed its name to Alaska Mines and Minerals, Inc.

The mine produced about 20,000 flasks of mercury. Between 1939 and 1946 the Red Devil mine produced approximately 3,000 flasks of mercury (Cady and others, 1955, p. 109). From 1952 through 1959 Alaska produced 17,019 flasks of mercury (U.S. Bur. Mines, 1960, v. 3, p. 88), practically all of which came from the Red Devil mine. The only other Alaskan production between 1952 and 1959 came from a small mine operated by one man. The mercury is recovered at the Red Devil mine by treating ore in a modified Herreshoff furnace.

According to R. F. Lyman (written communication, 1960) the known reserves are adequate to sustain mining for almost 2 years at the current production level. Additional reserves can be inferred from the probable downward continuation of many of the known ore bodies, and the geologic probability of finding new ore bodies.

WORKINGS

The Red Devil mine is worked by underground mining methods although some exploration consisted of surface trenching and hydraulic sluicing of overburden (fig. 2). The underground workings are fairly extensive and consist of a total of about 9,600 feet of shafts, adits, crosscuts, drifts, raises, and winzes with workings on five main levels (pls. 1, 4, 5, 6). A large part of the 200 level and most of the shallower workings were dug during the early period of mining, and the rest of the workings have been excavated since 1952.

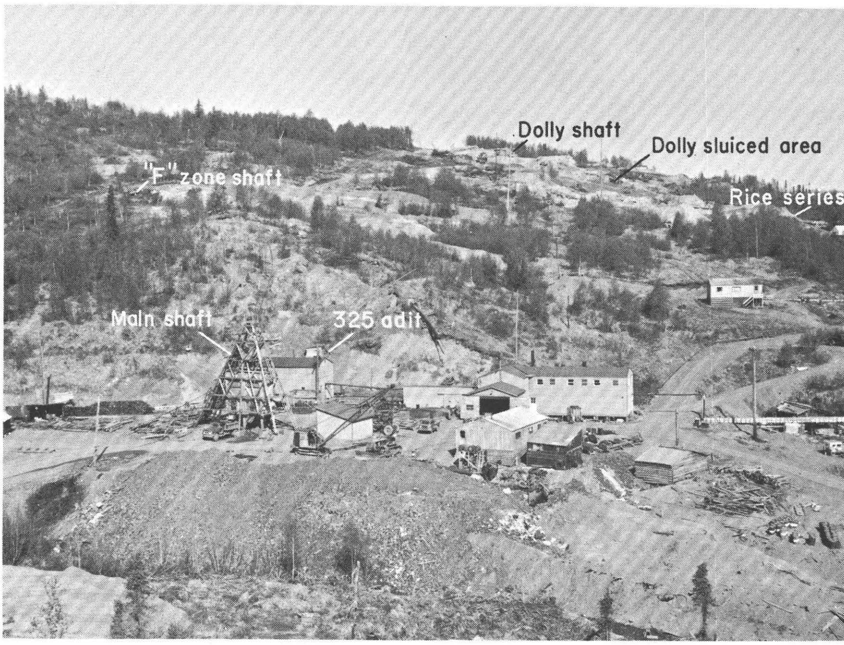

FIGURE 2.—View toward northwest of the Red Devil mine area showing the main surface workings.

The most extensive workings are near the main shaft which has a slope length of 507 feet and extends to a depth of 143 feet on an average incline of 63°35′. Five main levels of lateral workings connect with the main shaft. Newer workings in the vicinity of the Dolly shaft are also fairly extensive, and during 1958 underground work was in progress in both areas. Surface exposures of ore in the area of the Rice series of ore bodies have so far been explored by shallow trenches and pits. The workings near the Dolly shaft are connected by the Dolly raise with the 300 level workings that extend from the main shaft (pl. 4). Most of the ore bodies have been mined by stoping between levels; the largest and most numerous stopes are in the eastern part of the mine between the 300 and the 73 levels. In places the levels are connected by winzes and raises.

The older workings consist of the 325 adit and its associated workings, which total about 1,000 feet of level workings; the inaccessible 311 adit, which is about 120 feet long; and the levels and inclined workings, including most of the 200 level, near the upper parts of the main shaft. Many of the old shallow workings are caved and inaccessible. Among these workings are two shafts that extended to the 325 adit level, and several stopes that reached the surface.

The discovery of the Dolly series of ore bodies in the early summer of 1957 resulted in sinking the Dolly shaft, the collar of which is 1,082 feet N. 43½° W. of the main shaft, and subsequent excavation of the adjacent crosscuts, stopes, and the Dolly raise.

Many of the workings require timber, particularly where they penetrate fractured and contorted shale and argillite along and near faults. In addition to the adverse effects of the fractured rocks, intermittent freezing and thawing promote instability in the near-surface workings although permafrost is apparently absent in the mine area.

GEOLOGY

The central Kuskokwim region is near the center of a still active mobile belt of mountain building and volcanic activity that developed during the late Mesozoic (Cady and others, 1955, p. 18). The regional geology is dominated by a thick sequence of folded sedimentary rocks of Cretaceous age known as the Kuskokwim group, which in places is overlain by Tertiary volcanic rocks and locally is cut by plutonic and hypabyssal rocks.

The prevalent lithologic types at the mine are graywackes and argillaceous rocks of the Kuskokwim group (Cady and others, 1955, p. 35–45) that form a thick flysch-type sequence. These rocks are cut by a few altered dikes and are locally overlain by surficial deposits of loess and alluvium (pl. 2). Surface exposures of bedrock at the mine are largely confined to road cuts, stripped areas, and trenches. Surface exposures of the Rice series (pl. 3) were mapped in detail because they illustrate the surface aspects of the structure of the dikes, the faulting that offsets the dikes, and the alteration associated with the ore, as well as the distribution of the ore bodies in relation to the dikes and faults.

KUSKOKWIM GROUP

The Kuskokwim group is a very thick sequence of interbedded graywacke and argillaceous rocks (Cady and others, 1955, p. 35–41).

About 1,300 feet of well-bedded strata consisting of nearly equal amounts of graywacke and very fine grained argillaceous rocks are exposed at the mine. The graywacke beds, which commonly are 2 or 3 feet thick, range in thickness from half a foot to about 20 feet. The graywacke is a medium- or dark-gray rock that weathers brown and is fine grained and well indurated. Its fine-grained character precludes satisfactory megascopic identification of its minerals and textures. Descriptions by Cady and others (1955, p. 37, 38) of similar graywackes from throughout the central Kuskokwim region indicate that many of them are lithic graywackes which contain a variety of detrital rock fragments despite their prevailing fine-grained textures.

Well-developed sole markings that probably include both groove-cast and load-cast lineations (Crowell, 1955, p. 1358) are characteristic of many of the thicker graywacke beds. These markings are abundantly exposed in the mine workings and, when adjacent to faults, are referred to by the miners as knobby hanging walls.

Microscopic examination reveals that the graywacke is a poorly sorted rock that is composed of subrounded to angular lithic fragments and mineral grains that range from less than 0.001 to 0.5 mm in average diameter. The larger and more abundant minerals consist of quartz, muscovite, pyrite, plagioclase, and calcite. These minerals and the lithic fragments, which were principally derived from slate, schist, and volcanic rocks, are surrounded by very fine grained assemblages of quartz, calcite, plagioclase, muscovite, clay minerals, epidote, and chlorite. Calcite is the dominant cementing material, and it also forms a few veinlets. Some of the quartz grains have serrated boundaries.

The results of a semiquantitative spectrographic analysis of graywacke from the 300 level (58AMK–14) are shown in table 1.

The very fine grained argillaceous rocks are dark gray or black and weather brown. Most of these rocks that are exposed underground are argillites, but some of their surface and near-surface counterparts are shales. Discrete argillaceous beds are commonly a few inches thick, but locally these beds have a cumulative thickness of 20 or 30 feet without intervening graywacke. Commonly the argillaceous rocks are well indurated. Some of them are fissile, and many tend to fracture subconchoidally. The argillites are flecked with fine crystals of muscovite, the only megascopically visible mineral.

Thin-section study showed that these argillaceous rocks are similar to the graywacke in composition. They differ from the graywacke in texture in that they are finer grained and contain fewer lithic fragments. A typical argillite from the mine consists of subangular grains of quartz, epidote, muscovite, and pyrite that are less than

0.03 mm in average diameter, associated with clots and lamellar aggregates of very fine-grained clay minerals and mica.

The results of semiquantitative spectrographic analyses of an argillite from the 450 level (58AMK–7) and an argillite from the 300 level (58AMK–23) are shown in table 1.

Although no fossils were found at the mine, the Cretaceous age and dominantly marine origin of the Kuskokwim group are substantiated by paleontologic data cited by Cady and others (1955, p. 45, 46).

ALTERED DIKES

Three hydrothermally altered dikes are exposed at the Red Devil mine. These dikes strike N. 50°–75° E. and dip 40°–65° SE. The main dike is exposed at the surface southeast of the "F" zone shaft (pl. 2) and ore bodies in and near it are intersected by the underground workings in the vicinity of the main shaft (pl. 4). The northernmost dike can be traced on the surface from near the Dolly shaft to the Rice series (pl. 2), and its underground extension has been cut in the northwest end of the 300 level (pl. 4). The southernmost dike is known only from a few surface exposures.

The dikes range from 1 foot to about 14 feet in thickness. The main dike has a few pluglike and sill-like offshoots and a few small branching dikes that lack continuity.

In underground exposures the dikes are light gray. At the surface the dikes are masked by pervasive hydrous iron oxides and are difficult to distinguish from similarly weathered graywacke.

Generally the dikes are hard, but in some of the wet, higher mine workings they are soft, cohesive masses, a product that Cady and others (1955, p. 107) attributed to the solution of the constituent carbonates and the resulting relative increase in clay minerals and sericite.

Microscopic examination reveals that the dikes consist entirely of fine-grained and very fine-grained masses of calcite, chalcedony, limonite, and sericite, and subordinate amounts of quartz, hematite, and clay minerals. The porphyritic textures of the dikes are manifested by small relict phenocrysts, now largely replaced by calcite in a very fine grained groundmass. A few veinlets composed of calcite and minor amounts of quartz cut the dikes. C. L. Sainsbury (oral communication, 1960) has noted relict diabasic textures in thin sections of dikes from the Parks and Willis deposits, respectively 2⅔ and 4⅓ miles northwest of Red Devil. The relationships of these dikes to ore deposits are similar to those at Red Devil.

Cady and others (1955, p. 106) call the altered dikes silica-carbonate rock and believe that they represent hydrothermally altered quartz basalt dikes.

The results of semiquantitative spectrographic analysis of an altered dike from the 200 level (58AMK–38) are shown in table 1.

The results of an X-ray analysis of an altered dike (58AMK–1) are shown in table 2.

SURFICIAL DEPOSITS

The surficial deposits at the mine are loess and alluvium. The alluvium consists of fluvial deposits associated with the Kuskokwim River and Red Devil Creek and slope wash.

Loess, which mantles much of the bedrock (pl. 2), commonly rests on rocky soil formed by the weathering of bedrock, but locally it overlies the older river gravels. The loess deposits range from a few inches to about 30 feet in thickness and commonly lack bedding. They are buff colored and friable and are well exposed in some of the exploration trenches.

Microscopic examination of the granular loess in immersion oils reveals that the loess consists chiefly of subangular grains between 0.01 and 0.05 mm in diameter with extremes in grain size of 0.003 and 1.0 mm. In order of decreasing abundance the constituents of the loess are: quartz, plagioclase, lithic fragments consisting largely of schist and slate, muscovite, biotite, chlorite, hornblende, hypersthene, and minor amounts of magnetite or ilmenite, zoisite, epidote, zircon, garnet, K-feldspar(?), hydrous iron oxides, and clay minerals.

Cady and others (1955, p. 60) term the loess deposits silt and believe that they are of Wisconsin age.

The fluvial deposits include gravel, sand, and silt that have been deposited on the flood plains of the Kuskokwim River. The oldest of these deposits is locally overlain by the loess, but most of the fluvial deposits postdate the loess, and some of them were probably formed during the past few years. In some places exposures of the fluvial deposits are as much as 20 feet thick. Most of the deposits are well bedded. The pebbles of the river gravels are mainly graywacke. They are commonly flat and have an imbricate structure. The sands and silts are medium or dark gray. The fluvial deposits probably range in age from Pleistocene to Recent.

Minor quantities of recently deposited alluvium, including slope wash, are exposed on the lower slopes of some of the hills, in the valley of Red Devil Creek, and along the Kuskokwim River (pl. 2).

STRUCTURE

The Red Devil mine is on the southwest limb of the Sleetmute anticline, a northwestward-trending fold that has been traced by Cady and others (1955, pl. 3) for about 7 miles. The Sleetmute anticline deviates from the prevailing northeastward-trending structures of the central Kuskokwim region (Cady and others, 1955, pl. 1). The bedding in the Kuskokwim group at the mine strikes N. 10°–60° W., but its dominant strikes are N. 30°–45° W. The prevalent dips of these beds are 45°–60° SW. The few steeper, and, in places, overturned beds are attributed to surface creep or to the drag effect of faulting.

The dominant faults at the mine strike northwestward and commonly are parallel to the bedding. They are well exposed in both the underground and the surface workings (pls. 2, 4, 5, 6, 7) and are particularly well developed and numerous in the argillaceous rocks. They are characterized by grooved and slickensided surfaces that are locally curved, by minor gouge and breccia, and by contorted and plicated agrillite throughout zones as much as 10 feet thick. A few of these northwestward-striking faults transect the bedding and in places are vertical or dip steeply southwest or northeast (pls. 5 and 6).

Some of the faults, like those exposed in the northwest drift of the 300 level (pl. 5), are traceable for several hundred feet, but discrete faults are generally difficult to trace for long distances because of their myriad constituent fractures and the lack of critical exposures. Many of the faults appear to be en echelon. Some of the faults shown on the generalized block diagram (pl. 4) probably are not continuous, but they graphically represent the combined effects of numerous individual fractures.

The major component of movement on the northwest-striking faults was right lateral, as indicated by the offset dikes (pls. 2, 4, 5, 6, and 7). Individual right-lateral displacements on these faults range from a few inches to about 40 feet, and their cumulative right-lateral displacement is several hundred feet. The major grooves and striae on the fault surfaces commonly rake between 0° and 20° NW., but some rake as steeply as 50° NW., and a few have gentle southeast rakes. Steep, fine slickensides that rake nearly 90° are superposed on some of the grooved fault surfaces. These probably indicate minor dip-slip movement caused by gravitational adjustments after the main period of faulting.

Transverse faults are uncommon at the mine. Two faults that cut the prevalent northwestward-trending faults are exposed in the underground workings. One of these, which is exposed in the Dolly raise (pls. 4 and 7), strikes N. 70° W. and dips 70° NE. It apparently had a dominantly right-lateral component of movement. The other transverse fault, which is shown on plate 4, is in the B–1 stope below the 300 level (pl. 1). It strikes N. 70° W. and dips 75° SW., and its apparent major movement was left lateral. A few minor northeastward-trending faults that are cut by the northwestward-trending faults are exposed for short distances in some of the underground workings.

A steep fault that strikes N. 33° E. is exposed in the Dolly sluiced area (pl. 2), but the nature of its movement and its relationship to the other faults could not be determined.

Joints are best developed in the thicker graywacke beds. Most of them strike northeast and dip steeply southeast, but they were not studied in detail during the present investigation. Many of the joints have attitudes that are roughly parallel to those of the dikes, and conceivably the dikes may have been injected along similar joints.

The chronological sequence of structural events probably was as follows: (a) folding of the sedimentary rocks forming the Sleetmute anticline and the probable concomitant development of steep, northeastward-striking tensional joints; (b) the intrusion of dikes into a few of these joints; (c) the development of steep, northwestward-trending faults that offset the dikes right laterally; and (d) minor dip-slip movement on some of the northwestward-trending faults caused by gravitational adjustments.

ORE DEPOSITS

Ore at the Red Devil mine forms numerous discrete bodies that are mainly localized along and near intersections between the northeastward-trending altered dikes and the many northwestward-trending faults. This structural control was first recognized by J. D. Murphy, former manager and resident geologist at the mine. Most of the known ore bodies are associated with the main altered dike, and they have been extensively mined in the region southeast of the main shaft (pl. 1). The Dolly series and its southeastward continuation, the Rice series (pls. 2, 3, and 4), consist of at least 12 ore bodies along and near the northernmost altered dike exposed in the mine area. The ore bodies are crudely prismatic and range from a few inches to about 2 feet in thickness and from 1 foot to 30 feet in strike length; they are elongated in the plunge direction for several hundred feet. Although a few of the ore bodies diminish in size or pinch out with increasing depth, most of them persist to depths beyond the limits of exploration. The longest known ore bodies, those of the Dolly series, extend from the surface at least to the 450 level where they were intersected in 1960 without any indication of bottoming. Thus their known vertical and longitudinal extents are about 633 and 906 feet. Some of the deposits are characterized by variations in size and in tenor and by local pinching and swelling. The ore bodies and their controlling dike-fault intersections commonly plunge about 40° S.

These intersections occur throughout a zone that is at least 600 feet wide, 1,500 feet long, and 600 feet deep, and constitute the most important structural control at the mine, even though some of them are barren.

Cady and others (1955, p. 109) believe that a flexure in the sedimentary strata may have influenced the localization of ore. Other minor structural features and slight changes in lithology also may have promoted ore deposition.

Some of the Red Devil ore is exceptionally high grade and contains as much as 30 percent mercury, but most of the ore contains between 2 and 5 percent mercury. Generally the richer and larger sulfide masses formed in and near the dikes. These rich ore bodies commonly grade laterally along the northwestward-trending faults into zones successively characterized by networks of (a) closely spaced cinnabar-bearing veinlets and (b) widely spaced veinlets that form protore containing less than 1 percent mercury, and distally into a peripheral zone of barren veinlets and clay alteration.

The dominant process of ore formation was open-space filling, although some of the rich, massive ore bodies were probably formed partly by replacement. Cinnabar and stibnite have locally replaced parts of the altered dikes. The high-grade ore typically consists of masses of intimately associated cinnabar and stibnite. Much of the ore consists of closely spaced intricate networks of veinlets, breccia cemented by vein minerals, and cinnabar-bearing incrustations. Some of the veinlets contain numerous vugs.

MINERALOGY

Cinnabar, the only mineral that has been exploited in the deposits, is associated with abundant stibnite; some realgar, orpiment, and secondary antimony minerals; and minor amounts of iron minerals, in a quartz, carbonate, and clay gangue. The probable paragenetic relationships, which were generally determinable megascopically, from oldest to youngest are: carbonate minerals_1—quartz_1—(arsenic minerals)—stibnite—cinnabar—quartz_2—(carbonate minerals_2)—clay minerals. Arsenic minerals and second-stage carbonate minerals (carbonate minerals_2) are in parentheses because their positions in the paragenetic sequence are doubtful. This sequence was established megascopically by the relationships in incrustations and veinlets; the veinlets commonly contain abundant quartz adjacent to their walls, an intermediate zone of stibnite, and a central zone of cinnabar. When carbonate minerals are present they commonly antedate the quartz and lie closest to the veinlet walls, but late-stage carbonate minerals occur in the central parts of a few veinlets. Clay minerals locally occupy the central parts of the veinlets and appear to postdate the ore deposition.

The cinnabar occurs in well-formed crystals, commonly rhombohedral penetration twins; in irregular masses; and in minor quantities as powdery "paint" along fracture surfaces. The cinnabar paint is probably of supergene origin. Generally the cinnabar encrusts, cuts, or is perched upon quartz or stibnite. Less commonly cinnabar crystals are supported by carbonate minerals or wallrock.

Stibnite is abundant in most of the deposits. In form it ranges from massive-appearing varieties to fine needlelike crystals, many of which are curved. Generally it encrusts quartz, but some lodes consist almost entirely of massive stibnite, as much as 1 foot thick, in contact with wallrock. Some of the most spectacular mineral specimens from the mine consist of crystals of stibnite and cinnabar encrusting quartz. Where stibnite is exposed to weathering, its surfaces are coated with minor amounts of yellowish-brown secondary antimony minerals or tarnished to bluish-purple hues.

Realgar and orpiment are minor constituents of a few of the ore bodies, notably the one opened by the E–C winze (pl. 1) below the 300 level. All analyses of the ore revealed minor amounts of arsenic (tables 1, 2) even though no arsenic minerals were found in most samples. The realgar and orpiment, where megascopically distinguishable, generally occur with stibnite and cinnabar.

Most of the quartz is early-stage quartz which antedates ore deposition. It consists of comb-structured white quartz aggregates whose terminal crystal faces are well exposed in vugs in the veinlets. Late-stage quartz is represented by a few euhedral crystals of clear quartz as much as 5 mm long that are perched upon cinnabar or stibnite. These crystals contain liquid inclusions and, uncommonly, inclusions of cinnabar and (or) stibnite, which substantiates their postore age of formation. Both types of quartz have the external symmetry of alpha quartz.

The early-stage carbonate minerals are adjacent to the walls of some of the veinlets and in a few veinlets form the dominant gangue mineral. The late-stage carbonate minerals occur as sparsely distributed thin tabular crystals that are perched on quartz or line vugs. Most of the carbonates are probably calcite, but other carbonates and impure varieties of calcite may be present in minor amounts. The high strontium content of a sample of altered gouge that contains carbonate veinlets (table 2, 58AMK–13) is probably attributable to a strontium-bearing carbonate.

Clay minerals occupy the central parts of some of the ore-bearing veinlets, but they are more conspicuous in the barren veinlets away from the ore bodies. Dickite is probably the dominant clay mineral and is the only one that has been identified from the mine. It forms pale-green or white masses in some of the veinlets and fractures. Locally the dickite masses have polished, glassy surfaces that have been produced by late-stage faulting. Part of an X-ray diffractometer pattern of pale-green dickite from the 300 level is shown in figure 3.

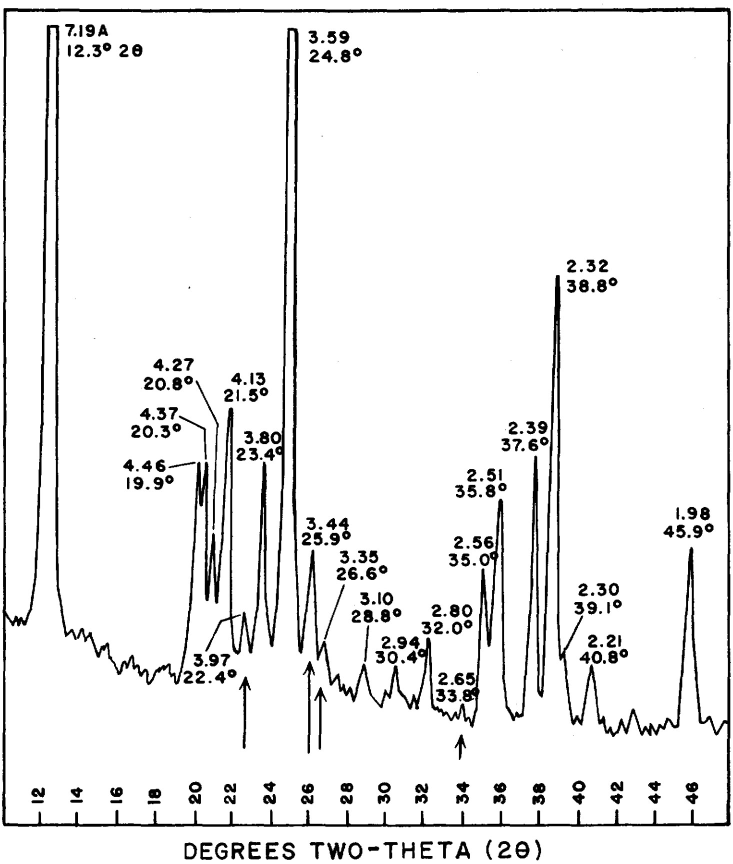

FIGURE 3.—Part of an X-ray diffractometer pattern of dickite from the Red Devil mine. Arrows indicate diagnostic dickite peaks, as distinguished from kaolinite peaks. Upper number is d-spacing in angstrom units (A); lower number is two-theta (2θ) angle. Ni-filtered Cu radiation; 45 KV, 15 MA.

WALLROCK ALTERATION

The alteration of the primary minerals of the dikes to chalcedony, calcite, sericite, and clay minerals was probably accomplished by deuteric processes prior to the offsetting of the dikes by the northwestward-trending faults. Deuteric solutions locally produced similar alteration effects in the graywackes and argillaceous rocks near the dikes. The postfaulting alteration that occurred late in the ore-forming hydrothermal activity resulted in the formation of dickite. The dickite is commonest along most of the northwestward-trending faults near the ore bodies and diminishes laterally away from them.

Alteration that accompanies weathering is a widespread surface and near-surface phenomenon at the mine. It is largely indicated by hydrous iron oxides that have pervaded the bedrock near the surface and in the upper mine workings.

COMPOSITION

The composition of the ore is shown by the semiquantitative spectographic analyses of samples of ore that are listed in table 1 and by the X-ray spectrometer analyses of eight samples of stibnite-rich ore shown in table 2.

AGE AND PROBABLE GENESIS

The Red Devil mercury deposits are probably late Miocene or early Pliocene in age, which is the age inferred by Cady and others (1955, p. 107) for all of the mercury deposits in the Central Kuskokwim region. The chronological evidence cited by Cady and others (1955, p. 107) is that mercury-antimony veins intersect stocks of probable Oligocene or Miocene age at localities near the Central Kuskokwim region (Mertie, 1937, p. 248; Brooks, 1916, p. 49), and that the deposits are intersected by the Sleetmute upland surface, which probably started to evolve in Pliocene time.

The deposits are probably largely hydrothermal in origin. Solutions which probably had deuteric affinities attacked the dikes and small parts of the adjacent sedimentary rocks and subsequently formed their typical alteration products. This activity was followed by the development of northwest-trending faults, some of which tapped the deep-seated sources of the ore-forming solutions. The solutions ascended some of the northwestward-trending faults and formed ore deposits at favorable loci under suitable temperature and pressure conditions. Dickite was deposited during the waning stages of ore formation. Conceivably the components represented by the deuteric alteration products and by the ore deposits could have been transported by hot, slightly alkaline solutions, but dickite is generally believed to have formed in an acid environment.

Table 1.—*Semiquantitative spectrographic analyses and colorimetric selenium analyses of ores and rocks from the Red Devil mine*

[Semiquantitative spectrographic analyses by Nancy W. Conklin, U.S. Geol. Survey; selenium analyzed by colorimetric methods by G. T. Burrow, U.S. Geol. Survey. These analyses were made for 69 elements. Only elements that were detected in at least one sample are listed. Values are reported to the nearest number in the series 7, 5, 3, 1.5, 0.7, 0.3, 0.15, in percent. These numbers represent midpoints of group data on a geometric scale; ——, not detected; M, major constituent greater than 10 percent; d, barely detectable and concentration uncertain]

Sample	Name and location	Al	As	B	Ba	Be	Ca	Co	Cr	Cu	Fe	Ga	Ge	Hg	K	La	Li
58AMK-4	Stibnite-rich ore, 450 level	0.15	1.5	d	0.007	------	0.3	d	0.003	0.03	0.07	------	------	<1	------	------	------
7	Argillite, 450 level	7	------	0.015	.15	0.0003	.15	0.003	.015	.015	3.0	------	------	<1	3	0.0003	0.07
13	Ore, 300 level	1.5	.7	.007	.07	------	.3	.0007	.003	.007	.7	0.0015	0.0015	>5	.7	------	d
14	Graywacke, 300 level	3	------	.015	.03	------	.7	.0015	.007	.007	3.0	d	------	<1	1.5	------	.07
23	Argillite, 300 level	7	------	.015	.15	------	.3	.003	.015	.015	3.0	.0003	------	<1	3	------	.07
30	Ore, Rice series at surface	.015	.3	------	.003	------	.002	------	.00015	.0015	.015	.0007	------	>5	------	------	------
38	Altered dike, 200 level	7	.7	.007	.07	------	1.5	.003	.07	.015	3.0	------	------	<1	------	------	.07
42	Stibnite-rich ore, Mary Jane stope above 200 level	.3	1.5	d	.15	------	.03	.0007	.007	.003	.07	------	------	>5	------	------	------
50	Ore, Dolly shaft	.03	.3	------	.003	------	.7	------	.0003	.015	.07	d	------	>5	------	------	------

Sample	Name and location	Mg	Mn	Mo	Na	Nb	Ni	Pb	Sb	Sc	Si	Sr	Ti	V	Y	Yb	Zr	Se (ppm)
58AMK-4	Stibnite-rich ore, 450 level	0.07	0.003	------	0.1	------	0.0003	0.015	M	------	M	0.0007	0.07	0.0015	------	------	0.0015	15
7	Argillite, 450 level	3	.07	0.0003	.3	0.0015	.015	.0015	0.03	0.0015	M	.015	.3	.03	0.003	0.0003	.015	2
13	Ore, 300 level	.3	.03	------	.15	.0015	.003	------	.07	.0007	M	.015	.15	.003	.0015	.00015	.003	0.5
14	Graywacke, 300 level	1.5	.07	------	.3	------	.003	d	------	.0007	M	.003	.3	.007	.0015	.00015	.007	.5
23	Argillite, 300 level	3	.07	.0003	.3	.0015	.007	.003	------	.0015	M	.007	.3	.015	.003	.0003	.007	1
30	Ore, Rice series at surface	.0015	------	------	.1	------	------	------	M	------	7	------	.0015	------	------	------	------	1
38	Altered dike, 200 level	3	.15	------	.1	------	.03	------	.07	.0015	M	.07	.3	.015	.0015	.00015	.007	.5
42	Stibnite-rich ore, Mary Jane stope above 200 level	.3	.015	------	.1	------	.003	------	M	------	M	.03	.07	.0015	------	------	.003	3
50	Ore, Dolly shaft	.003	.0015	------	.1	------	.003	------	M	------	3	.0015	.003	------	------	------	------	.5

TABLE 2.—*X-ray spectrometer analyses of stibnite-rich ore and altered rocks from the Red Devil mine*

[The relative quantities of the elements that were found are indicated as follows: A, major constituent; B, moderate constitutent; C, minor constituent; T, trace or very minor constituent; --, not detected]

Sample	Type	As	Fe	Hg	Mn	Sb	Sr	Zn
58AMK-1	Altered dike	C	A	----	C	----	C	T
4	Stibnite-rich ore	C	B	C	----	A	----	----
8	do	T	C	B	----	A	----	----
13	Altered gouge with carbonate veinlets.	T	A	----	T	----	A	C
15	Stibnite-rich ore	C	C	C	----	A	T	----
22	do	C	C	B	----	A	T	----
30	do	C	T	B	----	A	----	----
32	do	C	C	C	----	A	----	----
34	do	C	T	C	----	A	----	----
36	do	C	T	B	----	A	----	----

The localization of ore near the dikes is probably largely a physical phenomenon resulting from well-developed fractures with abundant open spaces that formed at intersections between dikes and faults. This fracturing was facilitated by the competence of the chalcedony-rich dikes and by the large angles of intersection between the dikes and the faults. Conversely the poor development of open spaces in the sedimentary rocks is attributed mainly to the localization of most of the bedding-plane faults in incompetent argillaceous rocks. Replacement of small parts of the dikes by ore minerals may indicate local chemical influences that rendered the dikes more susceptible to replacement than the other rocks.

Although a hydrothermal origin is indicated by most features of the deposits, such as the cockscomb structure and local symmetrical banding in some of the veinlets and the presence of liquid inclusions, the possibility of some ore deposition from gaseous or colloidal phases cannot be precluded.

REFERENCES

Brooks, A. H., 1916, Antimony deposits of Alaska: U.S. Geol. Survey Bull. 649, 67 p.

Cady, W. M., Wallace, R. E., Hoare, J. M., and Webber, E. J., 1955, The Central Kuskokwim region, Alaska: U.S. Geol. Survey Prof. Paper 268, 132 p.

Crowell, J. C., 1955, Directional-current structure from the Prealpine Flysch, Switzerland: Geol. Soc. America Bull., v. 66, p. 1351–1384.

Mertie, J. B., 1937, The Yukon-Tanana region, Alaska: U.S. Geol. Survey Bull. 872, 276 p.

U.S. Bureau of Mines, 1960, Minerals Yearbook, 1959: U.S. Bur. Mines, v. 3, 1134 p.

Webber, B. S., Bjorklund, S. C., Rutledge, F. A., Thomas, B. K., and Wright, W. S., 1947, Mercury deposits of southwestern Alaska: U.S. Bur. Mines Rept. Inv. 4065, 57 p.

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