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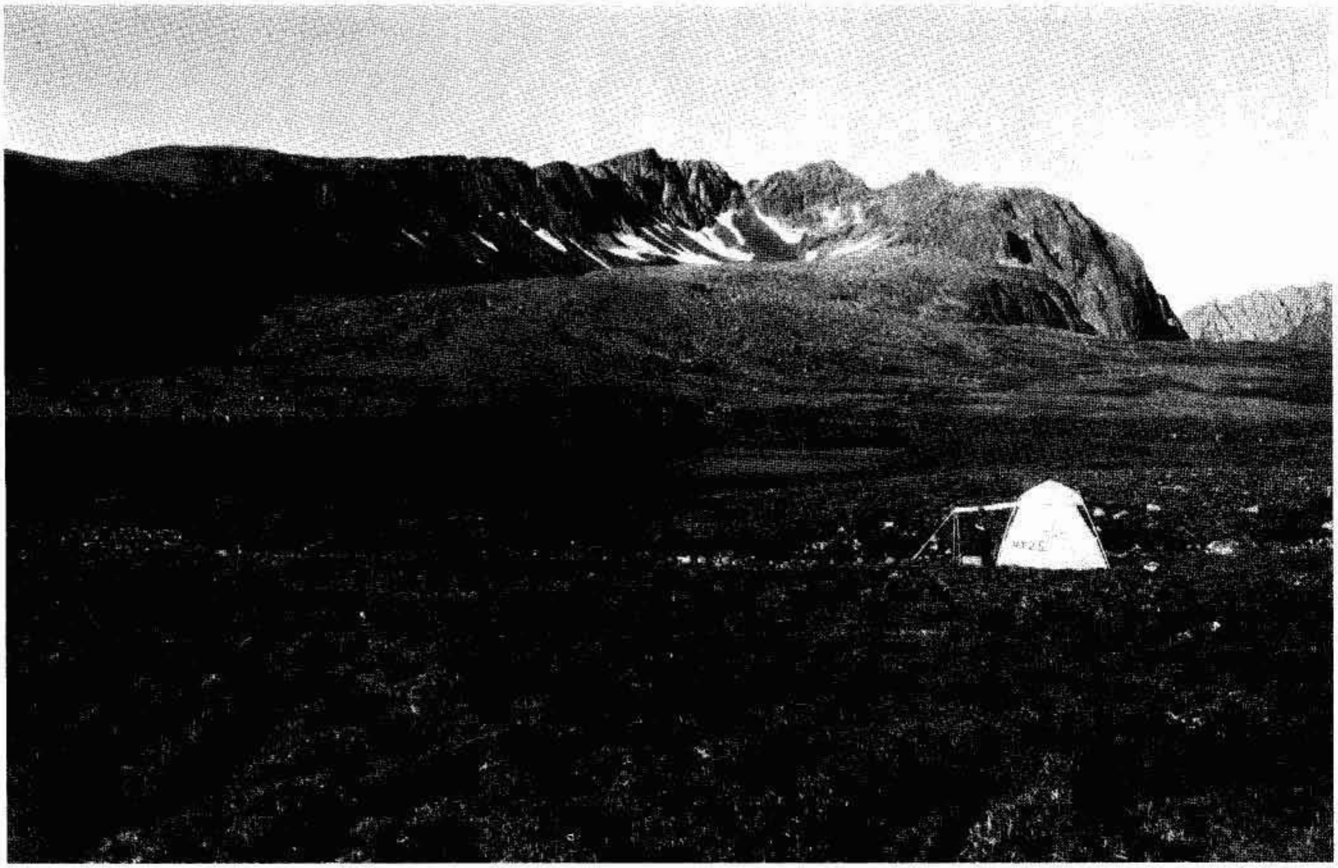


Classic tundra tussocks in southwestern Alaska.

Mineral Resource Assessment, Bendeleben and Solomon Quadrangles, Western Alaska

Bruce M. Gamble

A multidisciplinary mineral resource assessment of the Bendeleben and Solomon quadrangles, western Alaska, has identified 13 permissible mineral deposit types. These include deposit types that are currently known to exist and those that are speculative based on available data. Thirty-five tracts (shown on three poster session maps) are favorable for the following mineral deposit types:

- Map 1: Tin vein, greisen, skarn, and replacement; iron-(copper), tungsten, and lead-zinc skarn; polymetallic replacement and vein; and molybdenum stockwork.
- Map 2: Volcanogenic massive sulfide and sediment-hosted exhalative zinc-lead.
- Map 3: Low-sulfide gold-quartz veins.

Gold placers account for the majority of metallic mineral production from these quadrangles; approximately 2 million ounces of gold were produced between 1898 and 1985. From 1903 to 1907, about 27,000 ounces of gold were obtained from low-sulfide gold-quartz veins at the Big Hurrah mine. Small amounts of silver-rich galena ore were mined from the Omilak mine (polymetallic replacement?) and the Independence mine (polymetallic vein).

Deposit types that occur in the quadrangles but have not produced ore are sedimentary exhalative zinc-lead, iron-(copper) skarn, molybdenum stockwork, and polymetallic tin veins.

Concealed tin deposits are possible around the Oonatut Granite Complex—the easternmost of the tin granites on the Seward Peninsula. A small, prominent aeromagnetic high above a buried portion of the granite may be related to a concealed tin skarn or a tin replacement deposit. Aeromagnetic data also indicate the potential for additional iron-(copper) skarn mineralization. Concealed polymetallic vein, replacement, and lead-zinc skarn deposits may be present near several plutons. Molybdenum stockwork mineralization associated with the Windy Creek pluton could represent the outer portions of an ore deposit.

The Hannum-Harrys Creek deposit is the only example of a sedimentary exhalative zinc-lead deposit in these two quadrangles; however, several similar occurrences are in the Nome quadrangle to the west, and there is potential for additional deposits of this type in the Bendeleben and Solomon quadrangles. Volcanogenic massive sulfide deposits have not been found in this area; however, favorable host rocks and anomalous stream sediment geochemistry indicate that there is some potential for Besshi-type deposits.

Low-sulfide gold-quartz veins may represent the best hope for future mineral production in these quadrangles. Most of the veins, with the exception of those at the Big Hurrah mine, are too narrow (mostly <10 cm) and discontinuous to have warranted much interest in the past. However, higher gold prices and other factors have contributed to increased exploration in the area. Most of the low-sulfide gold-quartz veins examined on the Seward Peninsula occur in a mixed unit of interlayered quartz-graphite schist, pure and impure marbles, and lesser pelitic and chlorite-albite schist. Some occur in a unit composed of chlorite-albite and mafic volcanic schists that overlies the mixed unit.

The reality of the rain forest in southeastern Alaska. (Note the notorious Devil's Club plant at left center.)

Multiple Sources for Gold in the Juneau Gold Belt, Alaska

Rainer J. Newberry and David A. Brew

Vein gold deposits of the Juneau gold belt vary in host rock, mineralogy, metamorphic setting, metal ratios, and source of the gold. Geological, geochemical, and isotopic studies indicate there are at least two major sources of the gold: remobilized from preexisting low-grade gold deposits and exotic, or introduced. In remobilized deposits there are two subsources: remobilized plutonic-hosted deposits and remobilized volcanogenic deposits.

Remobilized plutonic-hosted gold deposits are north of Berners Bay (for example, Kensington, Jualin) and on eastern Douglas Island (Treadwell group). Major-element analyses of the least-altered rocks and trace-element analyses of altered rocks indicate that the host plutonic rocks have distinctive alkalic chemistry and range from monzodiorite to monzonite and quartz monzonite. The altered and least-altered host rocks and the deposits are probably of Late Cretaceous age, and all have experienced Late Cretaceous, lowest grade greenschist facies metamorphism. Orebodies are massive quartz-ferroan dolomite-pyrite "main-stage" veins and breccias that have moderately wide (<100 m) carbonate alteration envelopes; gold-bearing "pre-main-stage" quartz-K-feldspar-pyrite-magnetite$\pm$biotite-chlorite-chalcopyrite-molybdenite veinlets and veins occur in deeper exposures of both systems. The main-stage gold-quartz-carbonate veins are characterized mineralogically by: (1) relatively high oxidation and sulfidization state assemblages, such as hematite-rutile-bornite-pyrite; (2) the presence of telluride minerals; (3) high Au:Ag (2:1–20:1); (4) high Cu and Mo content; and (5) low As, Sb, Pb, and Zn abundances. Sulfur isotope ratios vary from $+1.2$ to -3.8 per mil, compatible with a plutonic-hydrothermal sulfur source. Lead isotope ratios are compatible with a Mesozoic, subduction-derived lead source.

Remobilized volcanogenic deposits are represented by the Alaska Treasure mine on southeastern Douglas Island and the Fremming-Valentine deposits north of Berners Bay. Host rocks are Lower Cretaceous bimodal(?) volcanics of the Gravina overlap assemblage that have been overprinted by Late Cretaceous lower greenschist facies metamorphism. The gold veins are postmetamorphic quartz-ferroan dolomite-albite-pyrite-galena veins that have very narrow (<1 m) alteration envelopes. They occur near massive and semi-massive volcanogenic pyrite-sphalerite-chalcopyrite-galena deposits in quartz-dolomite gangue. The veins have gold abundances about three times higher than the nearby deposits and are characterized by: (1) low Au:Ag (1:2–1:20); (2) low Te, Mo, As, and Sb content; and (3) high Pb, Zn, and Cu abundances. Vein sulfur isotope ratios are similar to massive sulfide ratios: both vary from +2 to +4.3 per mil and are similar to ratios for Mesozoic volcanogenic massive sulfide deposits. Lead isotopic ratios are compatible with a Mesozoic, subduction-derived lead source.

"Exotic" gold deposits are veins and vein swarms for which there is no evidence of a preexisting gold concentration in the country rocks. The Alaska-Juneau (A–J) group, east of Juneau, is the largest deposit of this type, and the Eagle River and Sumdum deposits are smaller. All are hosted by metamorphic rocks of late Paleozoic to early Mesozoic age and postdate Late Cretaceous-earliest Tertiary metamorphism. The A–J vein swarm is enclosed in a ≥0.5-km-wide biotite-chlorite-ankerite alteration envelope. All of these deposits have (1) variably high As, Sb, Bi, W, Pb, and Zn; (2) low Mo, Cu, and Te; (3) highly variable Au:Ag (10:1–1:100); and (4) low oxidation and low sulfidization state mineral assemblages, such as pyrrhotite-arsenopyrite. Sulfur isotope ratios for these deposits are very light, −12 to −18 per mil, suggesting a sedimentary sulfur source. Lead isotope ratios are very radiogenic, indicating lead derivation from a sedimentary source and an appreciable residence time.

Metallogenesis of Lode Mineral Deposits of "Mainland" Alaska

Warren J. Nokleberg, Thomas K. Bundtzen, Donald J. Grybeck, and Thomas E. Smith

For "mainland" Alaska, west of 141° W. longitude, regional metallogenetic patterns are delineated by classification of metalliferous lode mineral deposits, according to recently developed mineral deposit models and bedrock geologic and tectonic setting. In each region, the origin and modification of many of these lode mineral deposits can be related to specific sedimentary, magmatic, metamorphic, and (or) deformational events.

Major belts of middle Paleozoic sedimentary exhalative zinc-lead-silver, bedded barite, and kuroko volcanogenic massive sulfide deposits occur in the Brooks Range and in the Alaska Range. In the northwestern Brooks Range is a belt of Mississippian and Pennsylvanian sedimentary exhalative zinc-lead-silver and bedded barite deposits that probably formed during late Paleozoic rifting. Belts of Devonian and Mississippian kuroko volcanogenic massive sulfide and associated Kipushi copper-lead-zinc (carbonate-hosted copper) deposits occur in the southern Brooks Range and in the eastern Alaska Range and probably formed during middle Paleozoic continental margin volcanism. A major belt of Devonian and Mississippian granitic-magmatism-related deposits occurs in the southern and eastern Brooks Range. These deposits consist of suites of polymetallic vein, Sb-Au vein, porphyry Cu and Mo, and Cu-Pb-Zn and Sn skarn deposits.

Major belts of Jurassic, Cretaceous, and early Tertiary granitic-magmatism-related deposits occur throughout the State. On the Seward Peninsula is an extensive suite of tin vein, skarn, and greisen; polymetallic vein; porphyry molybdenum; and felsic plutonic uranium deposits. In southwestern and west-central Alaska are suites of Sb-Au vein, polymetallic and epithermal vein, porphyry Mo and Cu, Cu and Fe skarn, and felsic plutonic U deposits. In east-central Alaska are suites of polymetallic vein, Sb-Au vein, porphyry Cu-Mo, felsic plutonic U, and Sn greisen and vein deposits. On the Aleutian Islands and the southwestern Alaska Peninsula are extensive suites of early Tertiary epithermal, polymetallic vein, and porphyry copper-molybdenum deposits. Farther northeast in the Aleutian-Alaskan Range batholith, the Alaska Range, and the Wrangell Mountains are belts of Jurassic, Cretaceous, and (or) early Tertiary Cu-Zn-Au-Ag and Fe skarn, polymetallic and Sb-Au vein, Sn greisen and vein, and porphyry Cu-Au and Cu-Mo deposits. These granitic-magmatism-related deposits are related mainly to a succession of Jurassic through early Tertiary subductions.

A suite of moderate-size podiform chromite deposits that has local platinum group element occurrences and serpentinite-hosted asbestos deposits occurs around the margins of the Yukon-Koyukuk basin in west- and east-central Alaska. These deposits are hosted in thin discontinuous thrust sheets of late Paleozoic and early Mesozoic ophiolites that were probably thrust onto continental margin rocks in the Jurassic and (or) Cretaceous. A lesser suite of podiform chromite and related platinum group element occurrences in ultramafic rocks is exposed along the Border

Ranges fault system in southern Alaska. These deposits probably formed at the base of an island arc.

Major belts of gold and copper-silver quartz vein deposits occur in low-grade, regionally metamorphosed sedimentary and volcanic rocks in several regions and are related to metamorphism that accompanied accretion or subduction. These metamorphic deposits occur on the Seward Peninsula and in the southern Brooks Range in Jurassic and (or) Cretaceous rocks; in east-central Alaska, the Alaska Range, and the Wrangell Mountains in mid-Cretaceous rocks; and in southern Alaska in early Tertiary rocks. Extensive basaltic copper deposits, which, in part, may be related to mid-Cretaceous regional metamorphism, occur in the Kennecott district in eastern southern Alaska.

An extensive suite of Besshi and Cyprus massive sulfide deposits occurs in the Prince William Sound region in coastal southern Alaska. These deposits are related mostly to mafic rocks interbedded with Upper Cretaceous and lower Tertiary flysch and probably formed during late Mesozoic and early Cenozoic sea-floor spreading.

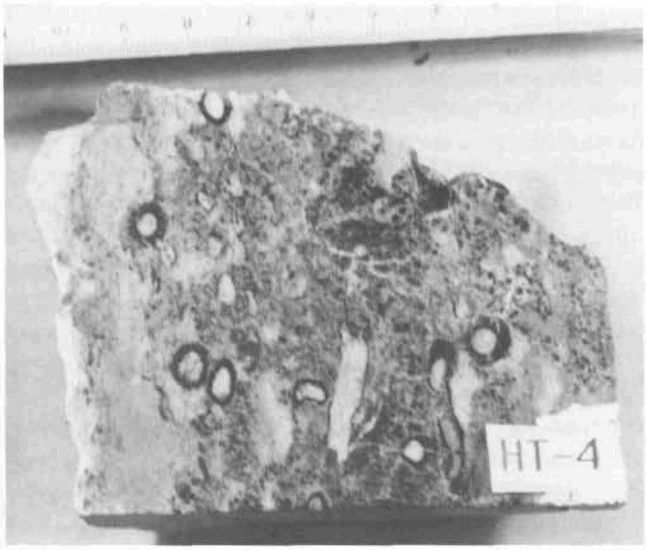
Reconstruction of Primary Features and Isotopic Evidence for Multiple Sulfur Sources at the Red Dog Zinc-Lead-Silver Deposit, Noatak District, Alaska

Jeanine M. Schmidt and Robert A. Zierenberg

The giant Red Dog sediment-hosted sulfide deposit (77 million metric tonne, 17.1 percent zinc, 5.0 percent lead, 82.0 g/metric tonne silver) consists of at least three, and probably five thrust panels of ore, each folded during and after thrusting. The three most important panels are the Hilltop deposit and the upper and lower ore plates of the Main deposit. Core logging (at 1:120, on 60-m spacings) in the Main deposit has enabled a partial reconstruction of the orebody prior to its deformation in the Cretaceous Brooks Range fold- and thrust-belt orogeny. The first thrust emplaced the entire deposit, Mississippian footwall, and Permian to Cretaceous hanging-wall rocks over Cretaceous sedimentary rocks. There was a minimum of 2 km displacement, but more likely tens of kilometers displacement. A second thrust, having <500 m northeasterly displacement, stacked the upper ore plate over the lower. A 200 by <300 m area in the upper plate having apparently upside-down zonation (silicified barite to mineralized barite to barren barite to baritic shale downward) may be the overturned limb of a drag fold associated with this second thrust. The two ore plates of the Main deposit and their bounding thrusts were then broadly folded beneath the third thrust, which emplaced footwall rocks and the Hilltop part of the deposit above the upper ore plate.

Massive (70–100 percent) and semi-massive (30–70 percent) sulfides and lower grade (0–30 percent) siliceous ores are texturally heterogenous and interfinger on scales of <40 m vertically and <300 m laterally. Unlike most shale-hosted deposits, pyritic massive sulfide ores are uncommon and small (<10×<100 m). Vein and disseminated sulfides occur in footwall rocks wherever they are preserved below the Main deposit. Silicification of both shale and massive barite is common, and silicification fronts between ore and host shales are locally steep. Burrows of vent-specific infauna, probably worms, increase in frequency upward in the upper ore plate and to the northwest in the deposit, but discrete vent sites have not yet been identified. Clastic ores of fine sand to conglomerate are rare, spatially restricted, but locally thick (40 m); their

Diamond drill in the Noatak camp near the Red Dog deposit, Alaska Brooks Range.[Schmidt and Zierenberg abstract]



Worm tubes and pellitoids in massive barite from the Red Dog zinc-lead-silver shale-hosted massive sulfide deposit. These Mississippian-age trace fossils are evidence for some of the oldest known hydrothermal vent specific fauna. [Schmidt and Zierenberg abstract]

distribution indicates local sea floor relief during ore deposition. Mineralization at Red Dog occurred prior to lithification of Carboniferous siliceous black shale host rocks, but Red Dog differs from standard models of sedimentary exhalative deposits in that much of the mineralization occurred below the seawater-sediment interface. Diagenetic growth of minerals in unlithified sediment and progressive replacement of sediment and previously deposited ore minerals are well documented in the Main deposit.

Massive barite locally formed an upper cap to the deposit and was partially replaced from below by hydrothermal sphalerite, galena, and silica. Although Red Dog is hosted by black, organic carbon-rich rocks indicative of anoxic conditions of deposition, the sulfur source for the massive barite has $\delta^{34}S$ values of 16 to 19 per mil, near those of normal mid-Carboniferous seawater sulfate. Disseminated, diagenetic barite precipitated in unlithified shale at the margins of the Red Dog deposit has $\delta^{34}S$ values up to 50 per mil; these values suggest formation from residual pore water sulfate modified by open-system sulfate reduction. In contrast, other zinc-lead massive sulfide deposits of similar age in the district lack barite and have $\delta^{34}S$ values indicative of total reduction of seawater sulfate to sulfide.

Sphalerite and galena in the Red Dog Main deposit generally have $\delta^{34}S$ values of -5 to 5 per mil. Sphalerite that replaces massive barite is isotopically similar to both massive sulfide and sphalerite in footwall veins and reflects a uniform $\delta^{34}S$ value of the hydrothermal fluid. Therefore, replacement of barite proceeded by dissolution and reprecipitation and did not involve direct reduction of barite sulfate to sulfide. The reduced (hydrothermal) sulfur probably formed by water-rock interaction in clastic rocks below the mineralized horizon and was transported to the site of sulfide deposition by the metal-bearing ore fluid. Pyrite is a minor component of the massive ore and formed from isotopically distinct fluids before the majority of zinc-lead mineralization. Paragenetically early disseminated and nodular diagenetic pyrite in the distal portions of the deposit formed by biogenic reduction of pore-water sulfate having $\delta^{34}S$ values as low as -40 per mil, but this source of reduced sulfur was not quantitatively important in the formation of the ore deposit. Pyrite enriched in $\delta^{34}S$ (8–18 per mil) occurs in massive ore, in pyritic silicified shale, and in paragenetically late pyrite veins and probably formed by partial reduction of seawater sulfate.

Mineral Resource Assessment of the White Mountains National Recreation Area, East-Central Alaska

Florence R. Weber, Thomas D. Light, Richard B. McCammon, and C. Dean Rinehart

The U.S. Geological Survey, the Alaska Division of Geological and Geophysical Surveys, and the U.S. Bureau of Mines conducted multidisciplinary interagency investigations to evaluate the potential for undiscovered mineral resources in the White Mountains National Recreation Area (WMNRA), east-central Alaska. Research by the U.S. Geological Survey focused on geologic mapping, reconnaissance geochemical and geophysical surveys, and the synthesis of all published information on mineral deposits in the western three-fourths of the WMNRA. The results of these studies are critical to land-use planning decisions by the U.S. Bureau of Land Management.

Table 1. Estimated number of undiscovered mineral resource deposits in the western three-fourths of the WMNRA [Weber and others abstract]

Deposit type	Number of undiscovered deposits	Probability in percent
Placer gold	1 or more	50
	2 or more	25
	3 or more	5
Polymetallic veins	1 or more	50
Tin greisen	1 or more	10
U/Th/REE	1 or more	10
Lode gold	1 or more	10
Sedimentary exhalative lead-zinc	1 or more	10
Tungsten skarn	1 or more	5

The White Mountains National Recreation Area is a part of the Yukon-Tanana Upland. This terrane consists primarily of quartzitic, pelitic, and calcic metasedimentary rocks and lesser metamorphosed mafic and felsic igneous rocks that have been intruded by Mesozoic and Cenozoic granitic rocks and minor amounts of intermediate and mafic rocks. The disruptive structures in the area are major thrust faults and strike-slip faults that are splays of the Tintina fault zone.

We have made probabilistic estimates for the number of undiscovered deposits that occur within the western three-fourths of the WMNRA (table 1). Placer gold, the only commodity in the area that has been produced in significant amounts, ranks highest in probability. It has been recovered from Nome Creek and its tributaries since the turn of the century. The cumulative production to date is estimated to be 29,000 oz.

By using the estimates, we have also estimated the mean undiscovered mineral resource endowment in the area studied for Au, Ag, Pb, Sn, Th, W, Zn, rare-earth oxides, and high-calcium limestone. We do not expect significant undiscovered resources of chromium, asbestos, nickel, or diamonds even though occurrences of these commodities have been reported in or near the study area. The recent report on the occurrence of platinum in gold samples in the nearby Tolovana mining district suggests platinum may be a potential metallic resource.

Geology and Mineral Resources of the Port Moller Region, Western Alaska Peninsula, Aleutian Arc

Frederic H. Wilson, Willis H. White, and Robert L. Detterman

Geologic mapping of the Port Moller, Stepovak Bay, and Simeonof Island quadrangles was begun under the auspices of the Alaska Mineral Resource Assessment Program (AMRAP) in 1983. Two important mineral deposits are located in the Port Moller quadrangle; the Pyramid prospect is the largest copper porphyry system in the Aleutian Arc, and the Apollo Mine is the only gold mine to reach production status in the Aleutian Arc.

Geologic studies have shown a number of differences between the Port Moller region and other portions of the Alaska Peninsula. (1) In the Port Moller region, faulting is more prevalent than folding in contrast to elsewhere on the Alaska Peninsula. (2) Mesozoic rocks typical of the Alaska Peninsula are allochthonous and have been thrust from the southeast; rocks of the Port Moller region are autochthonous and have minor thrusting from the northwest. (3) Products of late Tertiary and Quaternary volcanism are more widespread. (4) A terrane boundary juxtaposes the Alaska Peninsula and Chugach tectonostratigraphic terranes. Throughout the south-central portion of the Port Moller quadrangle, late Miocene volcanic rocks are widespread; these rocks are uncommon elsewhere on the Peninsula, presumably due to erosion. South of these rocks on Popof, Unga, and Korovin Islands are extensive exposures of Oligocene volcanic rocks of the Meshik magmatic arc.

We found that the Pyramid prospect is part of a northeast-trending belt of three shallow plutons and has associated hydrothermal alteration typical of porphyry copper systems on the mainland north of Unga Island. We also found a number of other shallow plutons that have similar alteration zones in the Port Moller region; the Kawisgag (Ivanof) prospect is the best known. The Apollo mine, on southeast Unga Island, produced from an epithermal gold vein system localized along a northeast-trending fracture system. Production was 3.3 million grams of gold; the bulk was produced between 1894 and 1906.

Both Popof and southeastern Unga Islands are composed dominantly of volcanic rocks of the Popof volcanic

View looking east of the Stillwater mining companies' platinum operation, Stillwater River Valley, Mont. This is the Nation's only operating platinum deposit.

rocks, a local name informally used for rocks correlated with the Meshik Formation, and sedimentary rocks of the Stepovak Formation. Radiometric dating of the volcanic rocks yields ages of approximately 35 to 30 Ma. On the basis of fossil determinations, the sedimentary rocks are of Oligocene age. Hydrothermal alteration and mineralization is more common in the Popof volcanic rocks of Unga and Popof Islands than in the otherwise similar Meshik volcanic rocks on the mainland. The major difference between the areas may be the presence of Alaska Peninsula terrane rocks beneath the volcanic rocks on the mainland and possible Chugach terrane rocks beneath the volcanic rocks on Unga and Popof Islands. Magma passing through the compositionally and structurally different basement rocks in the two areas should yield hydrothermal fluids of different compositions, which may explain the more abundant mineralization on Unga and Popof Islands.

On the basis of historical records, industry reports to the Aleut Corporation, geologic mapping, and geochemical sampling, 117 mines, prospects, and occurrences have been catalogued in the Port Moller region. Epithermal gold vein systems and porphyry copper-type systems dominate; however, polymetallic vein and disseminated gold occurrences have also been found. In addition to U.S. Geological Survey geologic mapping and geochemical studies, large-scale industry exploration sampling and drilling programs and detailed USGS studies of hydrothermal systems in the area are helping to characterize and model mineralized areas in the region.