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Maps showing the resource assessment of the Port Moller, Stepovak Bay, and Simeonof Island quadrangles, Alaska Peninsula

By Frederic H. Wilson, Willis H. White,
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with a section on

Geology of the Pyramid porphyry copper deposit, Alaska Peninsula Alaska
By W.H. White, J.S. Christie, M.R. Wolfhard, and F.H. Wilson

and a section on

Description of the Shumagin epithermal gold vein deposit

By W.H. White and L.D. Queen

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Maps showing the resource assessment of the Port Moller, Stepovak Bay, and Simeonof Island quadrangles, Alaska Peninsula

By Frederic H. Wilson, Willis H. White, Robert L. Detterman, and James E. Case

INTRODUCTION

We conducted a mineral resource assessment of the Port Moller, Stepovak Bay, and Simeonof Island 1° by 2° 1:250,000-scale quadrangles, Alaska Peninsula ("Port Moller study area") as part of the Alaska Mineral Resource Assessment Program (AMRAP) of the U.S. Geological Survey (USGS). This assessment is mandated by Section 1010 of the Alaska National Interest Lands Conservation Act (ANILCA) of 1980. This assessment is based primarily on reconnaissance geologic mapping; however, we also use geochemical data obtained from rock, stream-sediment, and heavy-mineral concentrate samples, analysis of specially enhanced Landsat imagery, limited geophysical (gravity and scintillometer) data, and exploration reports made available to us by the Aleut Corporation.

The geologic mapping phase of the AMRAP assessment of the Port Moller study area on the Alaska Peninsula began with a short reconnaissance field season in 1982. Primary mapping was completed between 1983 to 1986 and a short follow-up season was conducted in 1988. Geologic observations were made by helicopter-aided foot-traverses and at spot localities. Coverage of areas between surface observations was made using helicopter overflights, vertical aerial photography, and enhanced and extensively processed Landsat imagery (York and others, 1985; Wilson and York, 1985). A new geologic map of the study area is in preparation (Wilson and others, in press) and the assessment is strongly based on that map. Helicopter-supported field investigations were conducted from a base in Sand Point in 1982, 1984-1986, and 1988 and from Port Moller in 1984 and 1985. In addition, field work in 1983 and 1984 was also conducted from the U.S. Geological Survey Research Vessel *Don J. Miller II*.

Individual project responsibilities were as follows: F.H. Wilson, geochronology, stratigraphy of igneous rocks, mineral resource evaluation, and remote sensing; R.L. Detterman, stratigraphy and depositional environments of sedimentary rocks; J.W. Miller, paleontology and stratigraphy; J.E. Case, geophysical interpretation and stratigraphy; and J.G. Frisken and S.E. Church, stream-sediment and heavy mineral concentrate geochemistry and evaluation. Additionally, F.R. Weber contributed significantly to mapping of Quaternary geologic units. Louie Marincovich contributed many Tertiary megafauna determinations and valuable paleoenvironment data, and W.H. White and B.M. Gamble aided in mineral deposit studies. M.E. Yount did detailed mapping of Ukolnoi and Wosnesenski Islands assisted by R.L. Detterman and D.C. Gosse. J.E. York provided much of the skill and "know-how" to the remote sensing study. L.M. Angeloni, G.D. DuBois, M.A. Pernokas, and Stephanie Zurinski (Gajewski) provided able office and field assistance.

INTRODUCTION (Geologic base)

Geologic mapping of the Port Moller, Stepovak Bay, and Simeonof Island 1° by 2° (1:250,000 scale) quadrangles on the Alaska Peninsula was conducted as part of the AMRAP. The mapping of Burk (1965), Kennedy and Waldron (1955), and Moore (1974) provided an excellent base for the AMRAP mapping. The geology on this map incorporates both Moore's (1974) map of the Outer Shumagin Islands and Kennedy and Waldron's (1955) map of the Pavlof Volcano area with minor additions. However, significant changes were made to Burk's (1965) pioneering work.

The geologic data on this map was compiled on 1:63,360-scale topographic maps and digitized using an extensively modified edition of GSMAP version 3.0 (Selner and others, 1986). This digital data was then transferred to ARC/INFO[1] for editing and compilation into a 1:250,000-scale geologic map (Environmental Systems Research Institute, 1987; Wilson, 1989b). The digitized geology was then generalized for this map and composited with a nondigital mosaic of the 1:250,000-scale topographic base maps.

Assistance to the authors in preparing the geologic map was provided by R.L. Detterman for Cenozoic and Mesozoic stratigraphy, J.W. Miller for Mesozoic paleontology and stratigraphy, and J.E. Case for geophysical interpretation and stratigraphy. F.R. Weber contributed significantly to the mapping of Quaternary geologic units. Louie Marincovich, Jr., contributed many Tertiary megafauna determinations and valuable paleoenvironment data.

GEOLOGY OF THE PORT MOLLER STUDY AREA

GEOLOGY

The rocks in the map area record Late Jurassic to Holocene sedimentary and igneous activity along an episodically active convergent plate margin. Late Jurassic deposition of arkosic sandstone and siltstone (Jn) in a shallow-water shelf environment was followed by Early Cretaceous deposition of fine-grained siltstone and shale (Kst) in a similar environment. These sedimentary rocks were derived from a gradually eroding source terrane composed in part of the Alaska-Aleutian Range batholith (Reed and Lanphere, 1973). The record of the Late Jurassic to Early Cretaceous sedimentary regime culminated with deposition of a high-energy calcarenite unit (Khe) dominated by *Inoceramus* prisms, suggesting virtual elimination of the contribution of quartzose clastic debris from the source terrane. Mid-Cretaceous (Aptian to Santonian) rocks are missing, presumably eroded from the map area. This mid-Cretaceous interval is missing over much of the Alaska Peninsula, and its widespread absence suggests uplift and erosion of the entire terrane during a part of Aptian to Santonian time. A short-lived but vigorous marine transgression in the map area in Late Cretaceous time deposited fluvial to deep-marine clastic strata

1 Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Geological Survey.

(Kc, Kh) on the Alaska Peninsula and deep-sea fan and abyssal-plain turbidites (Ks) in the Outer Shumagin Islands. A brief regression in early Tertiary time and granodiorite plutonism (Tg) in the Outer Shumagin Islands was followed by deposition of fluvial and continental clastic strata (Tt) on the mainland and in the inner Shumagin Islands. This was followed by deposition of transgressive marine clastic strata (Ts) and an areally extensive outpouring of andesitic, dacitic, and basaltic volcanic and volcaniclastic rocks (Tm, Tp) in the northern and central parts of the map area during late Eocene and early Oligocene time. These volcanic and volcaniclastic rocks have been included in the Meshik arc as defined by Wilson (1985). Late Miocene time was marked by another brief transgression (Tbl) and by initiation of repetitive thrusting from the southeast, followed by renewed volcanism and plutonism (Tv, Ti), which initiated the modern Aleutian magmatic arc. Subsequent rapid uplift and erosion has exposed the roots of late Miocene and Pliocene and earlier volcanic centers. Outcrop patterns of late Miocene to Holocene volcanic and intrusive rocks indicate that the axis of the Aleutian magmatic arc has migrated in a northwestward direction from the Pacific coast.

Hydrothermal alteration and sulfide mineralization has accompanied magmatic activity at most igneous centers. Four clusters of Holocene volcanic edifices, including the Pavlof group, the most active volcanic center in the continental United States, lie partly or wholly in the map area. There were four reported eruptions of Pavlof Volcano during the course of this project (1982 to 1987) in addition to the 1983 eruption of Mt. Veniaminof (Yount and others, 1985), which lies on the northern border of the map area.

Complex interaction between glacial advances, volcanic activity, and sea-level variation has resulted in a rich Quaternary history for the map area (F.R. Weber and F.H. Wilson, unpublished data, 1993).

STRUCTURE

Thrusting from the southeast is an important component of the structural style in the Port Moller area. Structures are aligned subparallel to the general northeast to southwest trend of the Alaska Peninsula and are dominated by a zone of northeast- to southwest-trending high-angle reverse faults (Wilson and others, 1985a). This zone goes from the vicinity of Tolstoi Peak in the southwest to Mitrofania Bay in the northeast. Northwest of this zone, the major structures are a series of ramped, northwestward-directed thrust faults that carry Mesozoic rocks of the Chignik subterrane of the Alaska Peninsula terrane (Wilson and others, 1985b) and early Cenozoic rocks over late Miocene rocks. Southeast of the zone of high-angle reverse faults, the only exposed Mesozoic rocks lie in the Outer Shumagin Islands and are part of the Chugach terrane (Plafker and others, 1977). Early Cenozoic rocks southeast of the fault zone are the same lithologically as early Cenozoic rocks northwest of it; however, the Bear Lake Formation (Tbl) is not known to exist southeast of the fault zone. Wilson and others (1985a) suggested that this fault zone may represent projection through the overlying younger rocks of the buried boundary between the Chugach and Alaska Peninsula terranes.

The Mesozoic rocks of the Outer Shumagin Islands are characterized structurally by tight, generally northeast-trending folds. Dips in these rocks tend to be steep, rarely less than 35 degrees, and overturned beds are locally common, for example, on the north end of Nagai Island. This is in marked contrast to the Mesozoic rocks of the mainland part of the map area. Moore (1974) indicated that the rocks of the Shumagin Formation are pervasively faulted; however, he was able to trace individual faults "*** only along topographic lineaments or at the contact between the Shumagin Formation and the intrusive granodiorite."

In the area of Staniukovich Mountain, the allochthonous Mesozoic rocks of the Chignik subterrane are cut by numerous normal faults resulting in chaotic structures, whereas west of Pinnacle Peak, normal faulting has minor influence in the Mesozoic rocks. Northeast of Left Head on Port Moller, an inferred normal fault trends northeast to southwest and runs from Left Head to the headwaters of the Milky River, offsetting volcanic rocks as young as Pleistocene in age.

Folds in much of the map area are mainly related to faults. Dips are relatively uniform within a fault block except close to the bounding faults, where it is common for bedding to roll over in the direction of faulting. In the eastern part of the map area, a gradual transition is made to folds that have northeastward-aligned axes, and faulting becomes less dominant. Also in the eastern part of the map area, thrusting is replaced by these northeastward-aligned folds.

DATA COMPONENTS OF THE RESOURCE ASSESSMENT

GEOCHEMISTRY

Rock sampling

Sampling of rocks for geochemical analysis was conducted in conjunction with geologic mapping (Angeloni and others, 1985; Wilson and others, 1987). Additional samples were also collected during stream-sediment sampling (Arbogast and others, 1987). In total, more than 2,700 rock samples were collected and analyzed for this study. We attempted to obtain a detailed sampling of all rock types and units; however, samples collected from areas of exposed rock alteration tend to be over-represented. The samples collected are primarily single grab samples though a few composite samples were collected. A large proportion of the rock samples collected during stream-sediment sampling were stream cobbles or float; however, these represent less than 10 percent of the total data set.

Few samples were collected in the northwestern part of the study area because this lowland area is mantled by unconsolidated Quaternary deposits. Also, essentially no samples were collected around the Pavlof group of volcanoes. Finally, few samples were collected in the Outer Shumagin Islands due to weather and limited access.

Stream-sediment and heavy-mineral-concentrate sampling

Stream-sediment samples were collected at 787 sites in the study area (Arbogast and others, 1987) during the 1983 to 1985 field seasons. At 768 of those sites, heavy-mineral concentrate samples were also collected by panning at the site. In 1984, replicate heavy-mineral concentrate samples were collected at 161 sites; these replicates were used for gold analyses. Stream-sediment samples were collected from active alluvium in first- and second-order streams shown on 1:63,360-scale topographic maps. Arbogast and others (1987) indicated that "each sample was composited from several localities within an area ***" that may extend over as much as 60 m of stream length. Heavy-mineral concentrate samples, also composites, were screened through a 2-mm (10 mesh) screen and then panned until most lower density and clay-sized material were removed. Prior to analysis, stream-sediment samples were passed through a 0.17-mm (80 mesh) sieve, only the finer fraction was analyzed. Heavy-mineral concentrate samples were passed through a 0.6-mm (30 mesh) sieve, then separated in bromoform to remove all material of less than 2.85 g/cm^3 density. The resulting concentrate was separated into three magnetic fractions, the least magnetic of which was split for spectrographic and mineralogical analysis.

Analysis of geochemical samples

The rock, stream-sediment, and heavy-mineral-concentrate samples were analyzed for 31 elements using a semiquantitative direct-current arc emission spectrographic method (Grimes and Marranzino, 1968) and for additional elements by atomic absorption or instrumental methods (see Arbogast and others, 1987; Angeloni and others, 1985; and Wilson and others, 1987). The nonmagnetic heavy-mineral-concentrate samples were also examined under a binocular microscope to determine mineralogies present; however, 19 samples were too small for a mineralogical split and were not examined. Frisken and Arbogast (1992a) report the chemical and mineralogical data from the nonmagnetic heavy-mineral concentrate samples for selected elements and minerals.

Statistical analysis

Statistical analysis of the rock, stream-sediment, and heavy-mineral-concentrate sample analytical data helped to determine thresholds for anomalous concentrations. Thresholds were chosen approximating the 90th percentile for moderately anomalous samples and 98th percentile for highly anomalous samples. In addition, the 10th percentile was used to delineate anomalously low concentrations. Maps were plotted combining the rock, stream-sediment, and heavy-mineral-concentrate data for single elements to help locate anomalous areas.

In addition, two derivative maps were created, integrating the rock type and rock geochemical data with porphyry copper type and epithermal gold vein mineral deposit models. The porphyry-type model used is a composite of the porphyry model described by Cox (1986a) and the characteristics of the Pyramid porphyry copper deposit (section A). The epithermal gold vein model was developed by W.H. White based on studies of the Shumagin deposit (White and Queen, 1989; section B this report, and unpublished data). These derivative maps used thresholds calculated for rock-type groups, rather than the thresholds derived from the overall data set as used for other maps. The techniques used to produce the map fitting data to the porphyry model proved to be moderately successful in delineating areas of potential for porphyry mineralization. The map plotted using the epithermal gold vein model also used the geologic map in a digital format to help delineate areas of potential for gold mineralization. However, this modeling was less successful than the porphyry modeling largely because the sample data was too widely spaced to allow delineation of areas that have potential for these small deposits.

Stream-sediment and heavy-mineral-concentrate analytical data was processed using R-mode factor analysis with Varimax rotation (Frisken, 1992). A five-factor model explaining 71 percent of the total variance of the data set was selected by Frisken (1992) for the stream-sediment samples. Of the five factors, only the fourth (SSF-4), accounting for 8 percent of the variance, appears to be directly related to mineralization. This factor has high positive loadings for copper, lead, and boron. Drainage basins that have high scores for this factor also tend to be anomalous in copper, molybdenum, silver, lead, and zinc and sometimes boron, tin, or arsenic. Silver, arsenic, molybdenum, tin, and zinc were not included in the calculations because of their very low detection ratios (equal to the number of unqualified values divided by the total number of samples analyzed for a given element). This factor corresponds weakly to element associations expected for porphyry copper and polymetallic vein mineral deposit models (Cox, 1986a; Cox, 1986b).

Six factors were chosen for the heavy-mineral-concentrate data; these also explain 71 percent of the variance in the data set (Frisken, 1992). Frisken (1992) chose to include some highly censored or qualified data in the factor analysis for the heavy-mineral-concentrate data set. He states that inclusion of this qualified data "*** caused virtually no change in the other variable interrelationships. At the same time, their inclusion provides a quick means for identifying correlations within the upper ends of their distributions." Two of the factors from the heavy-mineral-concentrate data appear related to mineralization; factor 1 (PCF-1) explains 22 percent of the variance, and factor 5 (PCF-5) explains 6 percent of the data-set variance. Factor 1 (PCF-1) is highly loaded on iron, cobalt, nickel, and copper and has a lesser loading on zinc, lead, barium, and molybdenum. Factor 5 (PCF-5) has a high positive loading on silver and lead and a lesser loading on tin and zinc. The heavy-mineral-concentrate factors best correspond to the element association reflecting the polymetallic vein model (Cox, 1986b) and to a lesser extent the porphyry copper mineral deposit model (Cox, 1986a).

GRAVITY SURVEY AND ANOMALY MAP

Measurements of the gravity field were made by R.L. Morin during 1984 in conjunction with stream-sediment sampling in the study area. These measurements, combined with other data collected by D.F Barnes and R.L. Morin and by the Alaska Division of Geological and Geophysical Surveys, have been compiled into a draft contour map of the simple Bouguer anomaly data by D.F. Barnes and R.L. Morin (written commun., 1987). The available data are not terrain corrected; interpretive problems in use of such data were discussed by Case and others (1981) for the Chignik and Sutwik Island quadrangles to the north and also apply in this area.

The gravity anomaly map (fig. 1) is characterized by a north-northwest-sloping gravity field, ranging from high values of +75 to +100 mGal near the Pacific Ocean coast to lower than 0 mGal on the Bering Sea coast. Prominent features on this general trend are very large gravity lows over the Pavlof group of volcanoes and southwest of Unga Strait, high gravity values over the Inner Shumagin Islands, and a northeast-trending series of gravity highs that diagonally cross the Port Moller quadrangle. Most of this part of the Alaska Peninsula has strongly positive simple Bouguer and isostatic anomalies, which suggests oceanic crust (see also Barnes and others, 1994).

A zone of steepened gravity gradient trends east-northeast across the northern part of the Port Moller quadrangle. Contours defining the gradient bifurcate near Mt. Dana, and a west-trending splay continues west of Mt. Dana. This zone is a continuation of the major northeast-trending zone of steepened gravity gradient discussed by Case and others (1981) for the Chignik and Sutwik Island quadrangles to the north.

Patterns of gravity anomalies in the Port Moller area roughly correspond to geologic features known from other studies. The large gravity low of 20 to 25 mGal at the Pavlof group of volcanoes is similar to that reported for Mt. Veniaminof (Case and others, 1981) north of the map area. A small gravity low of about 10 mGal is also apparent at Mt. Dana, a much smaller Quaternary volcanic center; however, terrain correction may minimize or eliminate both of these lows. In contrast to these volcanic centers, the volcanoes of the Stepovak Bay area (Wilson, 1989) lie on part of the series of gravity highs trending east-northeast across the map area. The map shows a low at the southwesternmost of the volcanic centers produced as a result of the algorithm used by the contouring program; only a few gravity stations on its perimeter suggest it may be real, however.

The major zone of steepened regional gravity gradient and an area of gravity highs immediately south of this zone generally correspond to areas of Mesozoic sedimentary rocks of the Alaska Peninsula terrane. The main area of gravity highs corresponds to the outcrop area of allochthonous Mesozoic rocks through the central part of the map area (see Wilson and others, in press). The bifurcation of the zone of steepened regional gravity gradient near Mt. Dana is at a break in the geologic trend of the Mesozoic rocks. The northwest continuation of the zone of steepened gravity gradient and gravity highs lies over the Black Hill region, an area of autochthonous(?) Mesozoic rocks. Barnes (1977) showed that this part of the trend continues offshore into Bristol Bay to the limit of the gravity data. The southwest extension of the trend is interrupted by the gravity lows spatially associated with the Pavlof group of volcanoes; however, sparse data in the study area and in the Cold Bay and False Pass quadrangles to the southwest (Barnes, 1977) may indicate a continuation of this zone of steepened gradient. Although no Mesozoic rocks of the Alaska Peninsula terrane are known to crop out southwest of Pavlof Bay, they may be present at depth.

The large gravity low of 15 to 20 mGal southwest of Unga Strait corresponds to the informally named Unga basin. Structurally, the strata surrounding this gravity low dip into the basin. The Unga Formation (unit Tu, sheet 1; Detterman and others, in press) is the dominant geologic unit surrounding the basin and its outcrop area is limited to the region of the basin and southwest. As much as 2.5 km of strata of relatively low density may underlie the basin if the mean density contrast is -0.2 g/cm^3. Such a contrast might exist if the rocks adjacent to the basin have a mean density of 2.6 g/cm^3 and those in the basin have a density of 2.4 g/cm^3, producing a relative negative anomaly of about 20 mGals.

North of the Unga basin, a large gravity high follows the trend of a zone of high-angle reverse faults (Wilson and others, 1985a). This fault zone is thought to be localized on the terrane boundary between the Alaska Peninsula and Chugach tectonostratigraphic terranes and may be a projection of the Border Ranges fault through the younger overlap sequence. Fisher and von Huene (1984) described a large gravity anomaly along 400 km of the Border Ranges fault northeast of this area. The gravity high we describe here may correspond to and extend that shown by Fisher and von Huene (1984).

The gravity high described above merges with another area of higher gravity anomalies that lie in the Inner Shumagin Islands. These highs may be "artifacts" of the low-density rocks of the Unga basin rather than truly high-density rocks. Here, mildly altered intermediate to mafic volcanic rocks of dominantly Eocene to Oligocene age crop out. Areas of similar, though less altered volcanic rocks elsewhere in the map area and in the Chignik and Sutwik Island quadrangles to the north (Case and others, 1981) also are associated with moderate gravity highs.

LANDSAT ENHANCEMENT AND ANALYSIS

Landsat multi-spectral scanner (MSS) scenes covering the study area were digitally processed to produce color anomaly or alteration images to assist in our resource assessment (Wilson and York, 1985; York and others, 1985). Landsat imagery can be used to delineate areas of surface alteration through processing techniques that emphasize the spectral characteristics unique to these areas. For this study, areas classified as primarily rock and soil were first separated from areas of vegetation, snow, and water using a digital image of Landsat land cover classes that was prepared for another study in this area (J.E. York, unpublished data, 1984).

The rationale behind this study was that many mineralized systems on the Alaska Peninsula display color anomalies due to hydrothermal alteration. These color anomalies tend to display shades of red and yellow due to iron staining and leaching. Given that these color anomalies commonly cover large areas and are distinctive, detection of them through remote sensing techniques was a natural approach. Success in this approach in other areas (Podwysocki and others, 1983) led to our attempt to apply it in this area.

A number of image processing techniques were tried to delineate areas of known alteration. These included contrast stretching, band ratioing, classification based on spectral brightness, and principal component transformation. Podwysocki and others (1983) used a band ratioing technique to enhance Landsat MSS images to detect surface alteration. However, our (York, Wilson, and B.M. Gamble) attempt to duplicate the approach of Podwysocki and others (1983) was largely unsuccessful. Later discussions with M.H. Podwysocki (oral commun., 1985) suggested that the vegetation and humid environmental conditions of our study area versus the unvegetated and arid conditions of their study area may account for the limited success we had using band ratioing techniques. Further work by M.H. Podwysocki (various oral communs., 1985 to 1988) using band ratioing and Landsat Thematic Mapper (TM) images has had great success at actually distinguishing types of alteration; however, TM imagery is not available for the Port Moller study area. Therefore, the best delineation of surface alteration for our study area was produced through the use of a principal component transformation of MSS images and empirically selected threshold values for the selection of pixels. The third and fourth principal components were most useful for detecting surface alteration whereas the first principal component was useful to approximate topography. We found that by maximizing the third principal component and minimizing the fourth principal component we produced an image that best displayed surface alteration. Field checking of the digitally selected areas showed good correspondence with areas of surface alteration. All areas of previously known surface alteration were visible on the images except where the area was in shadow. Our field checking showed that the most important characteristic of the targeted areas was the presence of iron staining, which is an important indicator for the most common form of surface alteration on the Alaska Peninsula. Many previously unknown areas of surface alteration were also found; knowledge of these new areas guided detailed field examinations and geochemical sampling.

A few limitations apply to the use of this technique for this resource assessment; in spite of these, the images proved to be of significant aid in the resource assessment. The limitations are (1) the surface alteration must be exposed, though some vegetation cover does not significantly affect selection of an area, (2) shadowed areas tend to be masked and therefore not selected, (3) the surface alteration should cover at least one acre to be recognized as a single picture element (pixel) though intensely altered areas that are smaller may be selected if they are sufficiently distinct from surrounding pixels, and (4) not all areas of surface alteration are mineralized and not all mineralized areas have the type of surface alteration we were able to delineate.

MINERAL OCCURRENCES

Mines, prospects, and mineral occurrences at 116 localities in the study area were described by Wilson and others (1988). These localities are widely scattered over the study area (see fig. 2) and indicate a generally high potential for metallic mineralization throughout the area. In evaluating mineral potential we have attempted to apply a number of mineral deposit models (see below) to the occurrence at each locality. However, many of these occurrence descriptions are based on sparse data and as a result are very general. It is therefore difficult to apply specific mineral deposit models to each occurrence.

MINING AND EXPLORATION HISTORY

Mining and mineral exploration in the Port Moller study area dates at least to the Russian period of Alaska history. According to Dilliplane (1990; see also Atwood, 1911, p. 19), coal mined on Unga Island was shipped to Sitka in the 1840's. In 1852, Peter Doroshin examined coal occurrences on Unga Island (Golder, 1916). Later, in 1889, development of the Herendeen Bay Coal Field began from a mine site at Mine Harbor (Dall, 1896, p. 806). In 1890, at least 200 to 300 tons of coal was shipped after which the mine was abandoned. Later development work at the mine site in 1898 and after 1904 did not result in production (Atwood, 1911) as no market for the coal was found (Atwood, 1911). U.S. Bureau of Mines (USBM) data indicate a total production of 904 metric tons from the mine at Mine Harbor (James Coldwell, USBM, oral commun., 1990). However, the first reported actual mining in the study area during the American period was in 1882 when coal was mined at Coal Harbor on Unga Island (Atwood, 1911). Two cargoes totalling about 700 tons were shipped to San Francisco in 1883 from Coal Harbor; other coal mined was used locally or to supply small steamers used in seal hunting. At the time of Atwood's visit in 1908 (Atwood, 1911), one mine was in operation on a shipping basis; it is not known how long this mine may have continued in operation past 1908.

Following discovery in 1884 by George C. King (Alaska Apollo Gold Mines Ltd., written commun., 1987), gold production began at the Alaska-Apollo Consolidated Mine on Unga Island in 1891. Total production was about 500,000 tons of ore between 1891 and 1904 and during the summer of 1908 (Atwood, 1911; see also Wilson and others, 1988, p. 8). During same period and continuing until about 1915, the neighboring Sitka Mine also produced about 15,000 tons of ore (Wilson and others, 1988, p. 7). The nearby King Mine also produced a small amount of gold during the period (Martin, 1905). Across Popof Strait from Unga Island, a beach placer on Popof Island near the present-day airport produced an estimated 500 to 600 ounces of gold in 1904 and 1905. Intermittent production has continued from this placer deposit in the years since (Wilson and others, 1988, p. 11; Bill Ellis, Battle Mountain Exploration Co., oral commun., 1988).

After the Alaska-Apollo Consolidated Mine shut down prior to World War I, little further mining or exploration work is recorded for the Port Moller region until the 1970's. Sporadic reports in the annual USGS Mineral Resources in Alaska Bulletin through the 1920's (see Wilson and others, 1988 for full references) record minor activity at the Popof Island beach placer. F.R. Brown, former general manager of mining operations at the Alaska-Apollo Consolidated Mine reexamined and reevaluated the Alaska-Apollo properties between 1922 and 1935; his report eventually became an Alaska Territorial Department of Mines report (Brown, 1947).

During and immediately after World War II the USGS and USBM conducted brief investigations in the Port Moller region. The Herendeen Bay Coal Field was re-examined and estimates of probable and inferred reserves were made (Gates, 1944). Webber and others (1946) examined many of the prospects and mining properties on Unga and Popof Islands in the course of reconnaissance investigations on the Alaska Peninsula and the Aleutian Islands.

In the 1970's exploration activity in the Port Moller area saw a major resurgence, in part because of the creation of the various Alaska Native Claims Settlement Act (ANCSA) Native corporations. A joint venture by The Aleut Corporation and the Quintana and Duval Corporations was designed to assist The Aleut Corporation in the evaluation of lands set aside for selection under ANCSA (Christie, 1974). Aerial reconnaissance to locate color anomalies was followed by on-the-ground geological study and limited geochemical evaluation of these color anomalies. The focus was on porphyry copper deposits, recognizing that some porphyry deposits may also contain significant amounts of molybdenum and gold. A total of 92 color anomalies were located and examined on Aleut Corporation lands, including the study area, but also encompassing the rest of the Alaska Peninsula to the southwest and the Aleutian Islands, during the summer of 1974. This joint venture resulted in the drilling and discovery of the Pyramid porphyry copper deposit (see Wilson and others, 1988, p. 12) and the drilling of the Zachary Bay porphyry copper prospect (see Wilson and others, 1988, p. 50).

Resource Associates of Alaska in the early and middle 1980's conducted additional regional reconnaissance evaluation through geologic mapping and extensive geochemical sampling of The Aleut Corporation lands and located a number of mineral occurrences of economic interest. Their emphasis was on gold-related mineralization. Their work led to further evaluation by Teton Exploration Drilling on Unga Island in 1982 through 1985 and by Freeport Exploration Company at Mt. Dana in 1984. Site specific geophysical surveys, detailed geochemical sampling, and mapping was used by these companies to evaluate numerous areas of mineral potential. In 1988 and 1989, Battle Mountain Exploration Co. undertook regional exploration, including geologic mapping and geochemical sampling, for gold over a large part of The Aleut Corporation lands and did extensive exploration drilling and geochemical sampling at the old Herman Lode (named "Centennial" by Battle Mountain) on Popof Island (see Wilson and others, 1988, p. 5). Each of the studies mentioned above benefitted from and built upon previous work, well-documented in the extensive files of The Aleut Corporation.

Renewed exploration and development activity at the Alaska-Apollo Mine beginning in the 1980's resulted in the blocking out of reserves at the Alaska-Apollo and Sitka Mines and a major discovery at the turn of the 20th century Shumagin prospect (see section B and White and Queen, 1989).

DEFINITION OF MINERAL RESOURCE TRACTS

As part of the process of preparing this resource assessment, we divided the Port Moller study area into a series of land parcels that we called sub-tracts. Each sub-tract was defined using geologic, geochemical, and geophysical criteria, based on a particular mineral deposit model, as described below. The mineral deposit models used were selected on the basis of their applicability to the study area and the availability of sufficient data to properly classify sub-tracts within the study area. Additional applicable mineral deposit models were considered; however, for reasons discussed below, sub-tracts were not defined for these other models. By definition then, the mineral resource appraisal is not exhaustive and only represents a snapshot of available information at this time.

The geologic setting and geochemical and geophysical evidence for each sub-tract is listed in table 1. Mineral occurrences or deposits known to be located within the sub-tract are also listed in table 1. An assessment was made of each sub-tract. After definition and evaluation of each sub-tract, we combined these into tracts. Tracts (table 2) are defined as sub-tracts assembled by region; they combine areas of similar geology permissive for one or more mineral deposit models. Appraisal of each tract was made for each of the mineral deposit models represented by sub-tracts within the tract. All sub-tracts within a tract defined on the basis of a common deposit model were considered together in the tract.

Within each sub-tract an estimate was made of undiscovered mineral deposits at the 10-, 50-, and 90-percent confidence levels. In addition, the level of mineral potential and the certainty of the assessment was made using the criteria outlined in appendix A of this report.

Two additional factors we considered are that the definition of a sub-tract for a given mineral deposit model meant that at least one undiscovered mineral deposit at the 10-percent confidence level must be attributed to the sub-tract. Secondly, definition of a porphyry copper sub-tract in any given area meant that we automatically defined a polymetallic vein sub-tract in the same area. The basis for the first of these factors is that if, in our estimation, there were criteria that suggested any particular mineral deposit type sufficient to define a sub-tract, then there had to be at least one undiscovered mineral deposit at our lowest confidence level. The second factor was based on the fact that many of the criteria appropriate to define a porphyry copper type sub-tract are also sufficient to define a polymetallic vein sub-tract and as the models are closely related genetically we added the polymetallic vein sub-tract. In combining sub-tracts into tracts, we did not consider the estimated probabilities for undiscovered mineral deposits to be additive; hence, the estimated number of undiscovered mineral deposits within a tract may be less than the number of sub-tracts that might contain mineral deposits of that type within the tract.

Finally, although presently available data do not suggest undiscovered mineral deposits for areas not included within defined sub-tracts, these areas are not precluded from having undiscovered mineral deposits.

MINERAL RESOURCE ASSESSMENT

MINERAL DEPOSIT MODELS

Mineral deposit models appropriate for the geologic setting of our study area were adapted from Cox and Singer (1986) and are used to define the suites of elements characteristic of each deposit type. Based on the known mineral occurrences, the nature of the rock units, and types of geochemical anomalies, three mineral deposit models are most appropriate for the Port Moller study area. These are the porphyry copper, epithermal gold, and polymetallic vein models. Two mineral deposits in the study area, the Pyramid porphyry copper deposit (section A) and the Shumagin epithermal gold vein deposit (Queen, 1988; White and Queen, 1989; and section B, this report) were used as type examples for the mineral resource assessment. The characteristics of these deposits also help us "fine-tune" the mineral deposit models to the Port Moller study area.

Porphyry copper model

The porphyry copper model we used is derived from a combination of the characteristics of the porphyry copper model outlined by Cox (1986a) and the Pyramid porphyry copper deposit (section A), in the Port Moller 1:250,000-scale quadrangle.

Pyramid porphyry copper deposit

The Pyramid porphyry copper deposit is on the southwest flank of Pyramid Mountain, about 6 km northwest of Balboa Bay, in the central part of the Port Moller 1:250,000-scale quadrangle. The deposit is centered on a quartz diorite stock approximately 6 m.y. old (Armstrong and others, 1976; Wilson, and others, 1994) emplaced in, and contact metamorphosing, fine-grained sedimentary rocks of the Tolstoi Formation (section A, fig. 2). Quartz-feldspar porphyry dikes and breccia pipes within and outside the stock were emplaced late during, and locally after, the main period of copper mineralization. Initial mapping of the deposit in 1975 by Quintana Minerals and Duval Corporations identified a 1.29-km^2 altered and mineralized zone (see section A, fig. A2 and A3). Drilling of 19 short, vertical core holes totaling 1695.6 m (5,563 ft) was completed in 1976. A supergene-enriched chalcocite blanket as much as 90 m thick (300 ft) has estimated reserves of 126,000,000 tons (114,000,000 tonnes) averaging 0.403 percent copper and 0.025 percent molybdenum (see section A).

Three hydrothermal alteration zones are recognized in the deposit: 1) biotite, 2) quartz-sericite-andalusite, and 3) chlorite (section A). The biotite zone is characterized by the alteration of primary mafic minerals to secondary biotite and magnetite; primary plagioclase remains fresh. The biotite zone, the innermost of the three, is entirely within the stock and forms the core around which the copper deposit and other alteration zones are distributed. Surrounding the biotite core and extending from the stock into the adjacent hornfels is the quartz-sericite-andalusite zone, which is characterized by the absence of mafic minerals, an abundance of pyrite, and the alteration of plagioclase to sericite and local andalusite. The orebody is found within the inner part of this zone. The chlorite zone is the outermost zone and it encircles, but does not overlap the quartz-sericite-andalusite zone. The chlorite zone is characterized in pre-alteration dike rocks by the development of chlorite, magnetite, trace epidote, and calcite after hornblende; chlorite and epidote after biotite; and minor sericite, epidote, and calcite after plagioclase. Sandstone of the hosting Tolstoi Formation shows the development of chlorite in the matrix and partial alteration of plagioclase to sericite. The intensity of this alteration decreases with distance from the pluton and hydrothermal system. The outer boundary of the chlorite zone is undetermined.

A geochemical signature for the porphyry copper model can be defined using a number of elements. In the "ore" zone of the Pyramid deposit, manganese, strontium, and zinc are depleted relative to typical intrusive rocks and sandstone in the Port Moller region, whereas copper, molybdenum, gold, and silver are enriched. Zinc is enriched in rocks 1.6-4.8 km (1-3 mi) from the center of the mineralizing system which suggests the presence of an outer zinc halo. There is insufficient lead data to arrive at clear conclusions regarding its distribution; available data reveals few samples yielding analytical results above background.

Definition of porphyry copper type sub-tracts

In defining sub-tracts permissive for porphyry copper type deposits, areas of any type of bedrock within 2 to 5 km of small felsic stocks or inferred buried stocks were selected. In the Port Moller study area, where dated, these stocks tend to be latest Miocene or Pliocene in age. However, age is not considered a significant factor in defining a sub-tract. For example, in sub-tract G (sheet 1) the geochemical anomalies and alteration may be related to an early to middle Miocene intrusion, whereas in sub-tract E (sheet 1) alteration and mineralization are associated with igneous rocks as young as Quaternary in age. Geochemical anomaly patterns corresponding to the geochemical signature described above were also used to help define sub-tracts. The recognition of hydrothermal alteration suggestive of porphyry mineralization, either during field mapping or derived from enhanced Landsat images also helped define sub-tracts. However, none of these indicators are in themselves definitive with respect to porphyry mineralization.

Epithermal gold vein model

The combined characteristics of the Creede epithermal gold model (Mosier and others, 1986b), the adularia-sericite model of Heald and others (1987), the Hot Springs gold-silver (Berger, 1986), the Sado-type gold model (Mosier and others, 1986a), and the gold deposits of Unga Island in the study area were used to create an epithermal gold model. The Shumagin deposit (White and Queen, 1989) and, secondarily, the Alaska-Apollo deposit are most useful in defining this model. We realized in the application of the deposit models to the Unga and Popof Islands and the mainland parts of the study area, that the model of necessity varied. The mineral occurrences and known deposits of Unga and Popof Islands tend to be most similar to the various adularia-sericite models (Heald and others, 1987; Mosier and others, 1986b), whereas on the mainland the Hot Springs model of Berger (1986) may be a closer approximation. We presumed, on the basis of the data at hand that the range of models from adularia-sericite to Hot Springs represented different levels of the same type of hydrothermal systems. Given that the epithermal gold vein model used in this report is a composite of a number of models, there is no grade and tonnage curve available for our model. One might consider using the grade and tonnage curves for the Creede epithermal gold model (Mosier and others, 1986b, 1986c); however, base-metal concentrations in the mineral occurrences of the study area are far below what would be expected if the Creede model were directly applicable. As few deposits in the study area have estimated grades and tonnages, it is not possible to construct a grade and tonnage curve. The Alaska-Apollo and Shumagin deposits, contain about 540,000 tons ((t), 490,000 tonnes(T)) at 8.9 g/t gold and 270,000 tons (245,000 T) at 16.8 g/t gold and 68 g/t silver, respectively. Other deposits in the area have the following estimated tonnages and grades: Centennial, 4.54 million t, 1.37 g/t Au; Amethyst, 27,000 t, 7.8 g/t Au, 27.4 g/t Ag; Sitka, 127,000 t, unknown grade, but thought to be similar to Alaska-Apollo.

Shumagin deposit

The Shumagin gold deposit is located at the head of Baralof Bay on Unga Island. The Shumagin gold deposit is a fault-controlled, epithermal, volcanic-hosted quartz vein occurrence. Two fault breccia units, at least four individual veins, and two vein systems are present within the Shumagin gold deposit. A fuller description of the Shumagin deposits is given in section B, as this deposit is important to understanding the model we used to guide our mineral resource assessment of epithermal gold veins.

The deposit is developed within the Aquila-Shumagin Fault Zone which strikes northeast across the entire island. The Aquila-Shumagin Fault Zone strikes N. 60°E. and dips 80-85° SE. The surface trace of the fault zone is marked by outcrops of silica-cemented, clast-supported fault breccia and matrix-supported quartz breccia veins having an average width of about 12 m. Although sense of movement in the fault zone is uncertain, faults having similar trends in the vicinity of the Aquila-Shumagin Fault Zone are up on the southeast, suggesting high-angle reverse displacement (J.R. Riehle, USGS, written commun., 1988). The southeast wall is crystal lithic tuff, whereas the northwest wall is andesite. The fault zone is offset laterally as much as 15 m by northwest-trending cross faults having either left- or right-lateral displacements. The Aquila-Shumagin Fault Zone apparently developed in two stages, the first consisting of possible incipient movement recorded by a pyrite-rich cataclasite; the second and principal movement reflected in the development of a clast-supported fault breccia. Subsequent emplacement of veins included the gold-rich hydrothermal event recorded by the Union vein; a hydrothermal breccia event that produced the matrix-supported quartz breccia vein and deposited minor sulfides; minor gold-bearing events indicated by the Greenbaum and the Lucky Friday veins; a late event that produced the vuggy watercourse vein system and also deposited minor sulfides; and a carbonate-depositing event indicated by the cross-cutting carbonate vein system. The absence of enargite, and the presence of sericite alteration, presumed adularia, probable rhodonite, and chlorite suggest that the Shumagin deposit is an adularia-sericite type hydrothermal system as defined by Heald and others (1987).

During the period 1983 to 1987, Alaska Apollo Gold Mines Ltd. explored the Shumagin deposit with 2,825 m (9,269 ft) of core drilling (Queen, 1988) and established an estimated reserve of 245,106 T (270,000 short tons) grading 16.8 g/t Au and 68 g/t Ag (Mining Journal, 1987).

Alaska-Apollo deposit

The Alaska-Apollo deposit (Atwood, 1911; see also Wilson and others, 1988, p. 8) was located at the head of Delarof Bay on southeastern Unga Island. The deposit occurred in three parallel calcite-bearing open-growth quartz veins striking N. 20° E., and dipping steeply south that were generally less than 18 m (60 ft) apart. Ore came mostly from two shoots, the largest of which was about 250 m (800 ft) long and 2.5 to 5 m (8 to 16 ft) wide by 150 m (500 ft) down dip. Ore consisted of free gold, pyrite, galena, sphalerite, chalcopyrite, and native copper (Webber and others, 1946). Various estimates in the literature suggest that production was about 500,000 tons of ore valued at $3,000,000. Assuming that 90 percent of the ore value was derived from gold and that the average gold price was $20.67 per ounce during production, then roughly 130,000 oz. gold were recovered from ore grading about 8.9 g/t gold.

Sitka deposit

The Sitka deposit (Wilson and others, 1988, p. 7) was mined in conjunction with the Alaska-Apollo Mine until about 1915 and had further development work done in the 1920's and 1980's. The deposit was found in a 3-m-(10 ft) wide zone of sulfide-bearing open-growth quartz veins that contained as much as 5 percent chalcopyrite, galena, and lesser sphalerite (Webber and others, 1946, p. 21). The veins parallel a shear zone that strikes east-west and dips 65 to 80° S., cross-cutting the main N. 20° E.-trending Apollo Fault Zone. It is the only one of the Unga Island deposits mined that contained significant lead and zinc. The estimated production was about 15,000 tons; however, the grade of the ore is unknown. On the basis of a drilling program in the 1980's, remaining reserves of 140,000 tons of gold and silver ore at an unreported grade have been reported (Alaska Construction and Oil, 1984). According to Webber and others (1946), milling losses were high and therefore, not all of the ore produced was milled. The ore minerals were concentrated at the base of inward-penetrating quartz crystals in individual veins.

Definition of Epithermal Gold Vein Sub-tracts

The definition of sub-tracts permissive for epithermal gold vein deposits is based primarily on geology. The most promising areas occur in the andesitic to dacitic volcanic terranes of the Popof volcanic rocks unit; however, the Meshik Volcanics and other areas of volcanic rocks locally have promising areas. Unique in the study area is a rhyolite(?) dome on the south flank of Mount Dana volcano (sub-tract AJ). This dome and nearby ash-flow tuffs contain numerous geochemical anomalies that suggest potential for epithermal gold vein mineralization. This occurrence was examined in detail by geologists of Freeport Exploration Company in 1984.

We are generally unable to define sub-tracts from our reconnaissance-level geochemical sampling because of the limited areal extent and subdued nature of geochemical anomalies for epithermal gold vein deposits. However, the available geochemical data do provide further support for the geologically permissive areas. Available geophysical data do not contribute to sub-tract definition; however, analysis of Landsat imagery does indicate some areas of alteration that may be related to epithermal gold vein mineralization.

Polymetallic vein model

We used the polymetallic vein model outlined by Cox (1986b) for this resource assessment. Briefly, these deposits occur in a near-surface environment associated with felsic hypabyssal intrusions. Typical character of the deposits is quartz-carbonate veins containing gold and silver associated with base-metal sulfides. In the Port Moller region, high-silica andesite, dacite, and rare rhyolite plugs, domes, dikes, and sills are commonly associated with hydrothermal alteration and mineralization. All are of Tertiary or Quaternary age and, except in the Shumagin Islands, are restricted in age to the late Tertiary and early Quaternary. Numerous small veins are present on the periphery of known porphyry occurrences and in the vicinity of shallow plutons, such as at American Bay and Moss Cape. However, few of these occurrences have been studied. We have also included in this category polymetallic replacement deposits (Morris, 1986) because of the few cases where carbonate rocks (Herendeen Formation) occur associated with polymetallic geochemical assemblages. All of these occurrences can also be classified using the polymetallic vein model.

The geochemical signature of these deposits is characterized by anomalous concentrations of zinc, copper, lead, arsenic, gold, silver, manganese, and barium. Cox (1986b) describes these anomalies as zoned outward from copper-gold to zinc-lead-silver to manganese at the periphery. According to the grade and tonnage model of Bliss and Cox (1986), typical tonnages range from 290 T (90 percent of deposits this size or larger) to 200,000 T (10 percent this size or larger) for base-metal polymetallic veins. However, Bliss and Cox (1986) do not present grade and tonnage data for gold-silver polymetallic veins because they had inadequate data. Gamble and others (not dated, p. 53) also point to problems with the grade and tonnage model because "deposits" considered in the model in many cases actually represent multiple ore bodies; hence it is difficult to evaluate individual ore bodies because of the skewing upward of the tonnage curves. Bliss and Cox (1986) indicate other problems with this particular model such as the likelihood that zinc values are underestimated and point out that one mining district contributed nearly 60 percent of the deposit data.

Mud Bay prospect

Possibly the best example of a polymetallic vein system in the study area is the Mud Bay prospect (Wilson and others, 1988, p. 88). Located south of Mud Bay, thin-bedded siltstone and sandstone of the Stepovak Formation is cut by a swarm of propylitically altered andesite(?) dikes. Best exposed along the nose of a ridge, the sedimentary rocks contain numerous dark manganese(?)-stained beds and quartz-carbonate veins containing masses of galena. Anomalous metals include zinc, copper, lead, arsenic, silver, manganese, bismuth, cadmium, and antimony. The occurrence also appears to be anomalously depleted in barium.

Other mineral deposit models considered

Porphyry copper-gold

We considered the porphyry copper-gold model of Cox (1986c); however, few porphyry copper systems in this study area have sufficient data to be evaluated with respect to the porphyry copper-gold model. Those that do have sufficient data typically do not have sufficient gold to warrant classification by this mineral deposit model. Therefore, we used the more general porphyry copper model described above.

Hot-spring mercury

The hot-spring mercury model (Rytuba, 1986) has potential applicability to the Port Moller study area. However, the reconnaissance nature of most of our mapping and sampling typically do not allow us to distinguish individual occurrences from epithermal gold vein occurrences. The occurrence of cinnabar in multiple heavy-mineral concentrates from Dolgoi and Popof Islands and the west flank of Mt. Dana suggests that some sites are appropriately considered for hot-spring mercury deposits. In particular, the samples at Mt. Dana were collected downstream of apparent hot-spring "tufa" deposits.

Placer gold-PGE and iron-titanium

The Port Moller study area is clearly enriched in gold compared to other areas of the Alaska Peninsula (see Church and others, 1989; Cox and others, 1981). However, extensive glaciation, including the actual over-riding of much of the mainland by glaciers derived from the continental shelf to the south has scoured surficial deposits from much of the southern part of the mainland and offshore islands. Deposits derived from these glaciers, together with contributions from late Quaternary (including Holocene) volcanic eruptions now make up much of the Nushagak-Bristol Bay Lowland physiographic province as defined by Wahrhaftig (1965). At a number of localities on the Alaska Peninsula, including the Port Moller study area, Berryhill (1963) sampled beach sands along the Bering Sea coast for iron, titanium, and gold. Typically, little or no gold was detected and iron-titanium concentrations were at uneconomic levels.

The placer gold deposit located on beaches of Popof Island south of the Sand Point airport has a long history of low-level production. Martin (1905) reported production as early as 1904; intermittent production continues to the present day. Gold for this deposit is derived from erosion of the nearby mineralized basalt and andesite. Other reported placer occurrences are associated with the Alaska-Apollo and Sitka Mines near Delarof Bay (Wilson and others, 1988, p. 16) and on the northwest side of Popof Island (Wilson and others, 1988, p. 14). All of these occurrences are beach placers.

Stream-sediment and heavy-mineral-concentrate sampling conducted as part of the Port Moller resource assessment (Frisken and Arbogast, 1992a, 1992b; Frisken and Kelley, 1992; Frisken, 1992) has shown the presence of gold detectable in panned concentrates in many localities in the study area. However, these occurrences tend to be localized around known lode gold prospects and mineral occurrences. Southeast Unga Island and southwest Popof Island have the reported beach placers mentioned above. The potential size of alluvial deposits in the Shumagin Islands is small because of extensive glaciation and scouring. The area around Mt. Dana is of potential interest for placer gold for a number of the reasons. Exploration of the Canoe Bay prospect (Wilson and others, 1988, p. 49) demonstrated the presence of significant, though probably uneconomic gold, associated with a rhyolite(?) dome. In addition, Holocene pyroclastic deposits derived from Mt. Dana have gold detectable by panning (Bill Ellis, Battle Mountain Exploration

Co., oral commun., 1990). These pyroclastic deposits, including airfall material, are dispersed as far as 25 km (more than 15 miles) to the northwest of Mt. Dana. The contribution of gold from these pyroclastic deposits to alluvial sediments is difficult to quantify; however in the immediate vicinity of Mt. Dana and the Canoe Bay prospect, the two gold sources may combine to produce small placer deposits.

Another area of placer potential, on the basis of our geochemical sampling, occurs in the drainages of the Beaver and Canoe Bay Rivers and Four Bear Creek. Three components may contribute to the observed presence of gold in these drainages. In the upper part of the Beaver River drainage, a poorly exposed porphyry-copper occurrence may be the dominant source of gold in that drainage. The other drainages drain another possible porphyry-type occurrence. A second source of gold in all the drainages is airfall pyroclastic debris from Mt. Dana, and in the Beaver River drainage a third source may be glacial drift derived, in part, from Unga Island. Due to extensive glaciation, some masking of potential gold occurrences may be expected (except the above mentioned lower Beaver River); this would also serve to lower the potential for placer deposits.

Gold has been panned from a number of the streams that drain the Ivanof porphyry prospect (Wilson and others, 1988, p. 92); however, because of the shortness and steepness of the drainages, this area is not favorable for significant placer deposit formation. Numerous other gold occurrences have been described by Frisken (1992), most are not favorable for the development of placer deposits.

Porphyry copper skarn-related deposits

Porphyry copper skarn-related deposits, as described by Cox (1986d) are unlikely in the Port Moller study area. Only one geologic unit of the region, the Herendeen Formation (Detterman and others, in press), has a significant component of carbonate-bearing rocks. This unit does not crop out in any of the areas having potential for porphyry-type mineralization.

Sandstone uranium

The sandstone uranium model of Turner-Peterson and Hodges (1986) has potential applicability in the Port Moller study area. The host-rock environment for this type of deposit is present in the Naknek, Tolstoi, and, to a lesser extent, Unga Formations (Detterman and others, in press). However, contemporaneous felsic volcanism or eroding felsic plutons, the source rocks for the uranium, are not present locally. It is therefore considered unlikely that deposits of this type are present in the study area.

Sandstone-hosted lead-zinc

Briskey (1986) describes a sandstone-hosted lead-zinc deposit model. As in the sandstone uranium model above, the Naknek Formation provides a good host environment for this deposit type. However, the tectonic setting of "Deep weathering and regional peneplanation during stable tectonic conditions, accompanied by marine platform or piedmont sedimentation ***" and sialic basement is not matched by the Alaska Peninsula. Nonetheless, a number of unexplained zinc anomalies occur in Mesozoic sedimentary rocks of the Staniukovich Mountain vicinity and the mountains between the Kametolook River and Red Bluff Creek in the Stepovak Bay quadrangle. Igneous rocks generally do not occur in these two areas and therefore this model may be used as a tentative explanation for the zinc anomalies; however, lead anomalies are generally not present in these areas.

METALLIC MINERAL RESOURCES

We used a statistical convolution program written by D.A. Singer (written commun., 1993) to aggregate the undiscovered mineral deposit estimates (table 2) for each tract for each mineral deposit type. Output from this program (table 3) predicts the number of undiscovered mineral deposits in the study area at each confidence level. This calculated data is then used to further calculate the expected number of mineral deposits in the study area for each deposit type. We prefer a more conservative approach, made on the basis of our permissive geological, geochemical, and geophysical characteristics outlined in table 1, and the distribution of known mineral occurrences (see Wilson and others, 1988); thus our non-statistical estimate would have yielded somewhat lower numbers for each deposit type in the Port Moller study area than those shown in table 3. In addition to the data presented in table 3 we also estimate that at the 10-percent confidence level, in the specific sub-tracts shown in table 2, there may be the following undiscovered mineral deposits: 1 sandstone lead-zinc deposit and 1 sandstone uranium deposit.

As discussed above, the epithermal gold vein mineral deposit model we used is a composite of a number of published models. This precludes the usage of published model-specific grade and tonnage curves as directly related to the Port Moller study area.

Singer and others (1986) have published grade and tonnage curves applicable to porphyry copper deposits; available data for Alaskan porphyry copper deposits suggest that Alaskan deposits are smaller and lower grade than deposits elsewhere. The median-size deposit on the published grade and tonnage curves is 140,000,000 T at 0.54 percent copper. Grade and tonnage curves considered more appropriate for British Columbian (Canada) and Alaskan porphyry copper deposits (W.D. Menzie, written commun., 1993) suggest a median size of 100,000,000 T and a copper grade of about 0.4 percent. By comparison, the Pyramid deposit, largest known porphyry copper occurrence in the study area, has reserves of approximately 114,000,000 T at 0.403 percent copper.

Discussion

The five tracts (table 2) considered to be most prospective for epithermal gold, porphyry copper, and polymetallic vein deposits are the Mt. Dana (tract 2), Cape Aliaksin to Mud Bay (tract 4), American Bay to Mount Veniaminof (tract 6), Humpback Bay to Kupreanof Peninsula (tract 7), and the Inner Shumagin Islands (tract 11) tracts.

The Mt. Dana tract (tract 2, table 2), is characterized by late Tertiary(?) to Holocene felsic volcanic rocks, local felsic domes, and an abundance of hydrothermal alteration. Elevated gold concentrations in rocks; copper in stream sediments and heavy mineral concentrates; and silver, lead, zinc, and molybdenum concentrations in all three sample media suggest the presence of gold and copper mineralization.

The tract extending from Cape Aliaksin to Mud Bay (tract 4) contains highly altered volcanic and hypabyssal rocks that show extensive silicification, abundant quartz veining, and between Balboa and San Diego Bays, the largest area of hydrothermal alteration in the study area. In addition, a number of small hypabyssal porphyry plugs are aligned along a northeast to southwest trend, and anomalous copper in all sample media in the vicinity of these plugs indicate moderate copper potential. The Pyramid porphyry copper deposit lies within this tract and is associated with the most southwestern of the exposed plugs. Southwest of the Pyramid system, multiple geochemical anomalies in rocks suggest another plug that is not yet exposed by erosion; unfortunately no geophysical data is available to support this inference. Available data from the area between Balboa and San Diego Bays (sub-tract AF) allow us to predict the existence of at least one undiscovered epithermal gold deposit at a 90 percent confidence level for this sub-tract.

The American Bay to Mount Veniaminof tract (tract 6), has a complex assemblage of most of the geologic units of the study area locally overprinted by hydrothermal alteration. Highly anomalous multi-element anomalies in rocks, stream sediments, and heavy mineral concentrates suggest epithermal gold, polymetallic vein, and copper porphyry type mineral deposits may be present in the tract. Little data are available to suggest the location of undiscovered mineral deposits; this is the primary reason that few of these deposits are thought to be present at a 50 percent confidence or greater. However, there is abundant evidence within the tract to suggest mineralization.

The tract extending from Humpback Bay to the Kupreanof Peninsula (tract 7) consists of early Tertiary volcanic and Late Cretaceous and early Tertiary sedimentary rocks intruded by a number of small hypabyssal plugs and dike swarms. Many multi-element geochemical anomalies occur throughout the tract and a number of minerals of economic interest have been found in the heavy mineral concentrates (see table 1; sub-tracts A, B, K, L, and M). Some of the small plugs have local, spatially associated, hydrothermal alteration, which suggests porphyry copper deposits. One of these, the Ivanof or Kawisgag prospect (sub-tract A) has been examined a number of times by industry geologists (see SB001, Wilson and others, 1988).

The Inner Shumagin Islands tract (tract 11) consists of early Tertiary rocks of the informally defined Popof volcanic rocks that are locally interbedded with volcaniclastic sedimentary rocks equivalent to the Stepovak Formation and overlain on the northwest by volcaniclastic and volcanogenic rocks of the Unga Formation. On Unga and Popof Islands, the tract is characterized by numerous alteration zones, through-going faults, and highly anomalous gold, silver, and arsenic in rocks and stream concentrates. The only known gold deposits in the study area, the Alaska-Apollo Consolidated Mine and the Shumagin prospect are on Unga Island. We predict, at a 90-percent confidence level, that at least one undiscovered epithermal gold deposit exists in tract 11. Sub-tract G, within tract 11, contains the Zachary porphyry prospect (Wilson and others, 1988; PM048); geochemical anomalies, sericitic, propylitic, and phyllic alteration associated with a quartz diorite intrusion, and industry drilling data suggest potential for undiscovered copper.

It is with much less confidence that we can predict the existence of mineral deposits conforming to other deposit models. Undiscovered polymetallic vein, hot-spring mercury and placer gold-PGE (Yeend, 1986) are all likely to be present in the study area; however, sampling and mapping were not sufficiently detailed to allow definitive predictions for polymetallic vein and hot-spring mercury deposits. Permissive geology and the presence of cinnabar in heavy mineral concentrates of the Mt. Dana (tract 2), Pavlof Islands (tract 10), and Inner Shumagin Islands (tract 11) tracts suggest hot-spring mercury deposits. Any placer deposits that might exist would tend to be small because of the lack of time for them develop since glaciation and short length of most streams. The only known placer deposit in the area is a beach placer that has been intermittently mined since the early 1900's. It is expected that beach placers will have the greatest potential for small subeconomic deposits. Areas permissive for placer iron-titanium, porphyry copper skarn-related deposits, sandstone uranium, and sandstone-hosted lead-zinc deposits all occur within the study area; however, there is little data to actually suggest these types of deposits.

NONMETALLIC MINERAL RESOURCES

The economic potential for sand, gravel, and riprap deposits were not considered during this AMRAP study. Nevertheless, a brief statement can be made concerning these resources. At present, local needs for sand, gravel, and riprap are being met by readily available supplies. Extensive glaciation has deposited vast quantities of sand and gravel on the north and northwest side of the study area in low-lying wetlands. The same glaciation has stripped the south and southeast parts of the study area to bedrock. Subsequent erosion in this stripped area has produced small pockets of sand and gravel in stream valleys and beach deposits in sheltered areas. Holocene volcanic eruptions have resulted in the deposition of large quantities of volcanic debris and ash, resulting in the alluviation of Port Moller, the unnamed stream valley at the head of Stepovak Bay, and the Kametolook River near Perryville. In other areas along the Pacific Ocean, the rugged, fjord-like coast is eroding headward, generally leaving narrow boulder beaches. Near the community of Sand Point, an andesitic volcanic plug of Oligocene age is being quarried for riprap and gravel for harbor construction and road maintenance.

ENERGY RESOURCES

Petroleum

The Port Moller study area contains the sites of five exploratory drill holes (table 4), most of which were drilled in the 1960's and 1970's. None were successful in the discovery of producible hydrocarbon reserves but data from these wells are useful in the evaluation of adjacent areas. Drilling in the Port Moller study area demonstrated the difficulty of successful hydrocarbon exploration in an active tectonic environment. Three of the five wells proved to be poorly sited; the Canoe Bay well drilled through as many as seven repeated sections of the Late Cretaceous Hoodoo Formation (R.L.

Detterman, written commun., 1989). The Hoodoo No. 1 well was drilled along a fault plane, providing little useful data and requiring the drilling of the Hoodoo No. 2 well. In the Big River well, drilling had to be stopped early because bottom hole temperatures soared to more than 200°C (400°F), no doubt due in part to its close proximity to Kupreanof Volcano. The David River well, northwest of the Canoe Bay well, also encountered repeated stratigraphic sections (see cross section, Wilson and others, in press), opening the possibility for structural traps if hydrocarbon accumulations have developed. The Port Moller study area lies between the offshore North Aleutian basin (Bering Sea-Bristol Bay) and the Shumagin planning area (Horowitz and others, 1989; Shumagin, Sanak, and Unimak Basins; North Pacific Ocean). To date little exploration has been conducted in these offshore areas, largely because of the many legal issues affecting offshore lease sales.

An environmental impact statement (EIS) was prepared by the Minerals Management Service (1985) for the proposed North Aleutian Basin lease sale. In this EIS, the conditional resources of the North Aleutian Basin ranged from a low of 62 million barrels (MMbbls) of oil and 0.39 trillion cubic feet (tcf) of gas and a high of 759 MMbbls oil and 4.38 tcf gas; the mean estimate ranged from 254 to 279 MMbbls oil and 1.76 to 2.10 tcf gas depending on the area considered and at no better than a 20 percent certainty (see Addendum, Minerals Management Service, 1985). To date, no estimates of potential hydrocarbon reserves are available for the Shumagin planning area.

Coal resources

The first mining in the region was for coal from the Stepovak Formation on Unga Island; at nearly the same time coal was also mined from the Chignik Formation at Herendeen Bay. The early mining history of the Port Moller region suggests that coal resources are an important part of the mineral resource base of the region. Although our more complete mapping of the distribution of geologic units and structure limits some of the more speculative ideas (Conwell and Triplehorn, 1978) on the extent of rocks that have the potential for coal deposits in the study area; the area of potential for coal deposits remains large. However, our mapping suggests that at best, the resource that exists is a subsistence level resource. By this, we mean that coal collected from outcrops may be used for local heating purposes. Coal resources that exist in the study area are essentially restricted to four geologic units, the Late Cretaceous Chignik Formation, the early Tertiary Tolstoi and Stepovak Formations, and the late Tertiary Unga Formation. Areas of highest potential for coal deposits (coal resource tracts, fig. 3) are restricted to parts of the outcrop area of these rock units.

Unga Island Coal Field

Edgar and others (1982) briefly described two small coal fields in the Port Moller study area. One of these, the Unga Island Coal Field, was the source of the coal mined at Coal Harbor starting in the 1840's. The coal mined from the Unga Island field was lignite and probably came from the Stepovak Formation. At nearby White Bluff, the lower part of the exposed section contains good quality coal in the Stepovak Formation; the upper part of the exposed section also contains thin and generally poor-quality coal beds in the Unga Formation. Lyle and others (1979) gave a lithologic description of the White Bluff section and assigned its rocks to the Unga Formation; however, more recent USGS (R.L. Detterman and F.H. Wilson, unpublished data, 1983-1990) and industry (Virgil Wiggins, written commun., 1989) paleontological and geochronologic data suggest a revised stratigraphic correlation for the section that places the rocks of the lower part of the section in the Stepovak Formation. Atwood's (1911) and Stone's (1905, p. 167-168) descriptions of the Unga Island Coal Field, although brief, are the best available in the literature. A description and discussion of the Unga Island Coal Field by Dall (1896) presented a slightly different perspective than these later reports. The analyses of the coal from Unga reported by Dall (1896, p. 810) and Atwood (1911, p. 105) indicate that though relatively easy to obtain, this coal is of comparatively low quality compared to coal at other nearby coal fields at Herendeen Bay and Chignik Bay (north of the study area). We unsuccessfully attempted to examine the Unga Island mine site; thick brush and uncertainty as to the actual location prevented this. In spite of this, on the basis of Atwood's (1911) report and our observations of the White Bluff exposures, we agree with Atwood's conclusion that this coal is best suited for local subsistence use.

Herendeen Bay Coal Field

The Herendeen Bay Coal Field described by Edgar and others (1982) has, at various times, been believed to represent an important component of the mineral resource base on the Alaska Peninsula. This belief has continued as recently as the 1990's, as witnessed by a study begun in 1989 by the U.S. Army Corp. of Engineers on mineral-development-related port sites in Alaska.

The Herendeen Bay Coal Field is located in rocks of the Chignik Formation. In the vicinity of Herendeen Bay, the Chignik Formation and other Mesozoic and early Tertiary rocks form the upper plate of a nearly horizontal thrust fault. The rocks in this thrust sheet are cut by numerous normal faults, resulting in almost chaotically jumbled kilometer-sized blocks. Prospecting and mining in the Herendeen Bay field lasted almost 25 years starting in 1880; mining apparently ceased at some time before 1895 when a fault that offset the coal beds in the "Johnson tunnel" of the 1890 mine at Mine Harbor on Herendeen Bay, was reached and further prospecting was not able to locate the extension of the coal.

The coal ranges from lignite to bituminous; the thicker seams are apparently bituminous. Sections measured by Atwood (1911, p. 98) show individual coal seams as thick as 84" (2.1 m) and an aggregate thickness of 28'4" (8.64 m) in a section 161'3" (49.15 m) thick. However, in the mine at Mine Harbor, the thickest coal was 60" (1.5 m) thick and the aggregate was 76" (1.9 m) thick. Mark Meyer of the USBM reported (oral commun., 1990) indicated reserves (see appendix B for definition of terminology) are 10 to 100 million short tons and inferred reserves are 300 million short tons. Evaluation of the Coal Valley area of the field apparently was never made; according to Atwood (1911, p. 103) the some of the highest quality coal is found in that part of the field.

Conwell and Triplehorn (1978) made brief examination of the coal at Mine Harbor and found it to be high volatile B bituminous, having 20 percent ash content and amenable to washing, reducing the ash content to 10 percent and resulting in coal rated at 12,000 BTU. Their test results are similar to results reported by Dall (1896, p. 807; also Stone, 1905, pp. 170-171) and Atwood (1911, p. 105). Conwell and Triplehorn (1978) also found that trace metal content was low, particularly with respect to metals of potential environmental hazard. R.L. Detterman (oral commun., 1988) thought additional exposures of coal at Coal Bluff on Herendeen Bay were of Tertiary age, rather than Cretaceous like most rocks of the Herendeen Bay field.

Good quality coal unquestionably exists in the Herendeen Bay field; however, the extremely faulted and structurally complex nature of the host rocks has made mining of the coal an uncertain proposition. Modern drilling and exploration techniques may remove some of this uncertainty; nevertheless the faulting will complicate mining. We suggest that the indicated and inferred reserves reported by the USBM are, at best, estimates of marginal and inferred marginal reserves (see appendix B for definition of terminology).

Other coal occurrences

At Coal Bay, a few kilometers east of Cape Tolstoi, a small area underlain by the Unga Formation contains interbedded thin coal, conglomerate, and siltstone. At this location the Unga Formation extends less than 1 km inland. Other outcrops of the Unga Formation on the mainland, as far northwest as Balboa Bay, typically do not contain coal seams. The small areal extent of the beds containing coal precludes the likelihood that this coal represents a significant resource beyond subsistence use.

Thin seams of coal of small lateral extent are found in the nonmarine part of the Tôlstoi Formation, particularly in the vicinity of Ivanof Bay and on Egg Island in Humpback Bay. These seams, where found, typically are no more than 5 cm thick, are lignitic, and pinch out within distances of a few meters.

Summary

Unquestionably, we still do not have sufficient data to fully evaluate the coal resource of the Herendeen Bay Coal Field. The coal appears to be of reasonably good quality; however, the structural complications of the host rocks hinder complete evaluation and certainly have deterred mining in the past. After more than 60 years of little interest, the oil embargo of 1973 and rising petroleum prices resulted in a flurry of interest in the area and its coal. Decreasing oil prices since have minimized that interest; however, rising petroleum costs may again ignite interest in coal in the future.

Geothermal resources

Assessment of the geothermal resources of the Port Moller study area is difficult due to sparse data. In a broad, general sense, the presence of three Holocene volcanic centers -- Stepovak Bay (Wilson, 1989), Mt. Dana, and the Pavlof group of volcanos (Kennedy and Waldron, 1955) -- and a number of small areas underlain by Quaternary volcanic rocks indicate a relatively high potential for geothermal resources compared to much of Alaska. However, in general the volcanic rocks in the Port Moller region are not considered to be the optimum character and type for geothermal resources.

The definitions of three important terms need to be stated in order to discuss the geothermal resources of a region. The first of these, <u>resource base</u> is "*** all of a given material in the Earth's crust, whether its existence is known or unknown and regardless of cost considerations." (Schurr and Netschert, 1960, p. 297 cited by Muffler and Guffanti, 1979). The <u>accessible resource base</u> is defined by Muffler and Guffanti (1979, p. 4) as "*** that part of the resource base shallow enough to be reached by production drilling in the foreseeable future." Finally, the <u>useful accessible resource base</u> or <u>resource</u> is "*** the thermal energy that could be extracted and used at some reasonable future time ***" (Muffler and Guffanti, 1979, p. 4).

A number of locales (table 5) within the study area show the presence of higher than background levels of geothermal energy that can be reasonably classified as part of the accessible resource base and have potential to be considered geothermal resources. However, quantification of the resource base and the accessible resource base for the study area is not possible based on the available data. Nonetheless, description and preliminary assessment of the known locales is possible. The igneous-related geothermal systems of Pavlof Bay in the Port Moller study area (table 5) and Mount Dana were considered by Smith and Shaw (1975) and Smith and others (1978) in their compilation of igneous-related geothermal systems. However, none of these systems were listed in their table of systems that have remaining thermal energy (Smith and Shaw, 1979). In the case of Mount Dana this may have been due to insufficient data; however, for the Pavlof volcanoes it was because these systems are basaltic and therefore probably have magma chambers at too great a depth to be considered part of the accessible resource base.

Pavlof volcanoes

The Pavlof volcanoes, including Pavlof, Pavlof Sister, Little Pavlof, Double Crater, and Mount Hague are a nearly linear array of basaltic(?) shield volcanoes built on the east side of Emmons Caldera (Kennedy and Waldron, 1955; Miller and Yount, 1988). These volcanoes are all of Holocene age; however, an older and long inactive Quaternary and more silicic volcanic center lies about 13 km to the northwest of Pavlof Sister at Trader Mountain. Pavlof volcano has erupted repeatedly in historic time and steam is generally emitted from its summit. Pavlof volcano lies on the eastern rim of Emmons Caldera, a pre-Holocene caldera complex. Smith and Shaw (1979) considered the Emmons Caldera igneous system as a significant geothermal resource, having approximately 1.44×10^{21} joules of thermal energy remaining in the system, equal to the highest of any Alaskan system they considered. Though Emmons caldera is located marginally outside of and west of the Port Moller study area boundary, the Pavlof group of volcanoes must be considered a manifestation of the same igneous-related geothermal system.

Stepovak Bay area

The volcanoes of Stepovak Bay are primarily andesitic volcanic centers. Silica content tends to decrease with age at these centers; the youngest samples are high-silica andesite (Wilson, 1989). The higher silica content of lavas from these volcanoes, compared to the Pavlof group of volcanoes, may suggest a shallower magma chamber. In addition, existing fumarolic activity indicates it may be appropriate to consider these centers in the accessible geothermal resource base. In further support of this suggestion, an exploratory petroleum drill hole, the Phillips Petroleum Big River No. 1, located approximately 8 km southeast of these volcanoes, had a bottom-hole temperature of more than 200°C (400°F) at 3,466 m depth, significantly higher than all other drill holes on the Alaska Peninsula (table 4) and indicating a geothermal gradient of at least 55°C/km in the area. However, quantifying the contribution of these volcanic centers to the accessible resource base is not possible due to insufficient data.

Mount Dana

Mount Dana is a Holocene silicic volcanic center characterized by multiple and extensive Holocene pyroclastic deposits. Over a wide area east of the volcano, ridge-top swales have air-fall deposits containing plentiful lapilli of hornblende dacite. In the immediate vicinity of the volcano, ash-flow tuff deposits are abundant and have an estimated volume of 0.3 to 0.5 km^3 based on a mapped area of 113 km^2. A crater 1 km in diameter caps the volcano and a small tufa mound is located on its flank. Except for the lack of hot-spring or fumarolic activity in the vicinity of the volcano, this center displays many of the factors that would suggest it is part of the accessible geothermal resource base. An exploratory drill hole located about 13 km south of Mt. Dana (table 4, Canoe Bay well) had a geothermal gradient (28°C/km) that was average compared to other drill holes on the Alaska Peninsula (table 4) and significantly less than that of the Big River No. 1 drill hole near the volcanoes of Stepovak Bay.

Hot Springs

Moller Hot Springs has long been known to exist on the south shore of Port Moller (table 4 and sheet 1). Mapping studies conducted as part of this resource assessment also located a warm stream draining into the west side of Herendeen Bay (table 4 and sheet 1); time and weather precluded the determination of the source of its warm or hot(?) waters. Moller Hot Springs and the nearby Herendeen Bay warm stream are both spatially associated with a lobe of a low-angle thrust fault that emplaced Mesozoic and early Tertiary rocks over late Miocene rocks (Wilson and others, in press). Both northeast and southwest of this lobe, late Tertiary and Quaternary volcanic rocks crop out, which may suggest that related igneous rocks may be found below the thrust and serve as the source for the geothermal anomaly. For Moller Hot Springs, Motyka and others (1981) estimated a reservoir temperature of 101°C; from this they concluded its temperature was too low and the spring too remote to be useful "*** except perhaps for local space heating and recreation." In fact, Moller Hot Springs has a long history of just such use. Archaeological excavation of a pre-contact village at the site shows an interrupted history dating back as much as 6,000 years (Okada and Okada, 1974; Okada and others, 1976, 1979). In the case of the Herendeen Bay warm stream, a similar assessment of the accessible geothermal resource is the best that can be expected, even though it may on further examination be found to have a warm or hot spring as its source.

CONCLUSIONS

The resource assessment of the Port Moller, Stepovak Bay, and Simeonof Island quadrangles shows the region to have significant potential for many types of resources. The area is very favorable for epithermal gold vein and porphyry copper deposits. Historical data show that at least one porphyry copper-type and a few epithermal gold vein deposits are present. Polymetallic vein deposits and placer deposits of various types are likely to be present; however, the studies done as part of the resource assessment were insufficient to define the probability for these types of deposits beyond a very crude estimate. The area is permissive for other types of deposits, such as hot-spring mercury, porphyry copper skarn-related, and sandstone-hosted lead-zinc deposits although no data that clearly suggests that these types of deposits occur in the area has been collected.

Coal is present at a number of localities in the study area; however, it is unlikely to ever become an economic resource because of small quantities and structural complications. Good quality coal in the Herendeen Bay field has the highest potential, assuming the structural complications can be resolved and a market developed.

Geothermal resources of the study area are at present unquantifiable due to extremely limited data. The Emmons Caldera system, on the west boundary of the study area is considered to contain a significant geothermal resource. Volcanic centers near Stepovak Bay and the Mt. Dana center have a number of characteristics suggesting that they could contribute to the accessible resource base. Moller Hot Springs is at present in local recreational use; archaeological excavations of an important pre-contact village at the site indicate the hot springs may have been in use for as long as 6,000 years. Over the long term, these hot springs may be the most significant resource of the entire study area.

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Table 1. Mineral resource sub-tracts and supporting geologic, geochemical and remote sensing evidence, Port Moller, Stepovak Bay, and Simeonof Island quadrangles, Alaska Peninsula.
[conc, heavy-mineral concentrates; stm seds, stream sediments; Fm, Formation; [1] see Wilson and others, 1988 for explanation of coding]

Sub-tract	Selected evidence for deposits in tract: Geology	Selected evidence for deposits in tract: Geochemistry	Selected evidence for deposits in tract: Remote sensing and geophysics	Example deposits and mineral occurrences[1]
	Porphyry copper mineral deposit model			
A Ivanof	Small granitic plug intruding Hoodoo Fm; surrounded by strong color anomaly in siltstone. Well-developed sericitic alteration in creeks and associated stockwork pyrite veins in Hoodoo Fm and granitic intrusion.	Anomalous As, Au, Cu, Mo, Pb, Sb, and Zn in rocks, Ag, As, Cu, and Mo in conc and Ag, Cu, and Pb in stm seds. Minerals in conc include chalcopyrite, galena, molybdenite, and pyrite.	Near flattened gravity gradient and residual low.	SB001
B Osterback Creek	Meshik Volcanics possibly over-lying Tolstoi Formation. Reported color anomaly surrounding quartz diorite plug, stockwork mineraliz-ation, phyllic, propylitic, and argillic alteration. However, no plutons were actually located in reconnaissance mapping. Several altered zones, in or near Tertiary granitic plutons were reported by MacKevett and Holloway (1977) and Hollister (1978).	Anomalous Cu in conc, Au in rocks and As, Pb, and Zn in rocks on ridges around valley.	Northeast-sloping gentle gravity gradient.	SB006 SB023(?)
C Dent Point	Late Miocene volcanic rocks over-lying sandstone of Tolstoi(?) Fm and intruded by hornblende-andesite porphyry. Altered zone spatially surrounding granitic pluton reported by MacKevett and Hollo-way (1977). Stockwork pyrite veins in phyllically and propylitically altered volcanic(?) rocks (Butherus and others, 1979).	Anomalous Au and Ag in rocks, Cu, Ag, Mo in stm seds and Cu, Au, Ag, As, Mo, Zn, and Pb in conc. Minerals in conc include barite-celestite, galena, pyrite, and sphalerite.	Enhanced Landsat imagery shows well-developed areas of alteration in southern part of tract. East flank of residual gravity low.	SB003
D1 Pyramid to Mud Bay	Multiple small hypabyssal porphyry plugs intrude sedimentary rocks of Stepovak and Tolstoi Formations. Alteration halos are commonly apparent. Pyramid porphyry deposit anchors southwest end of tract, however a number of small mineral occurrences are located throughout the tract.	Anomalous Cu in all media, some Ag, As, and Mo on periphery. Abundant Pb at Pyramid. Anomalous Zn and Pb in stm seds and conc. Au and Sb in conc. Minerals in conc include barite-celestite, galena, molybdenite, pyrite, scheelite-powellite, and sphalerite.	Enhanced Landsat imagery shows multiple areas of alteration in tract, generally corresponding to periphery of small intrusions. PM010, Pyramid deposit shown particularly well. Flattened gravity gradient; residual gravity low.	PM010 PM002? PM068
D2 Lower Beaver River	Hoodoo Fm (Kh) on extension of sub-tract D1. No obvious alteration or mineralization.	Multiple anomalies in Zn, Ag, Sb, As, Mo, Pb in rocks and conc, Cu in all media.	Apparent low gravity saddle between two gravity highs.	
E Canoe Bay to Sapsuk Lake	Contact metamorphosed and hydro-thermally altered Mesozoic sedi-mentary rocks and Tertiary volcanic rocks. A number of shallow intru-sive bodies are found in the north-eastern part of tract. Sub-tract trends parallel to trend of sub-tracts D1 and D2. Abundant hydrothermal alteration and mineralization occurs in tract. At Canoe Bay, a rhyolite dome that intrudes the Hoodoo Fm contains multiple porphyritic phases. A tourmaline-cemented breccia has also been reported (Freeport Exploration Co., 1985).	Anomalous Cu in stm seds and conc, Au in rock on south side of tract, Ag in all media, especially at east end of Sapsuk Lake. Also east of Sapsuk Lake, Zn, Pb, and Mo are anomalous in all media. Abundant As occurs throughout tract. Minerals in conc include barite-celestite, cinnabar, galena, gold, molybdenite, pyrite, sphalerite, and scheelite-powellite.	Enhanced Landsat imagery shows fairly well-developed areas of alteration, corresponding to PM076 and PM087. Eastern part of area of flattened gravity gradient.	PM049 PM076 PM087
F Dolgoi Is.	Small hypabyssal plug intruding Belkofski Fm and possibly Miocene volcanic rocks. Quartz diorite(?) plug surrounded by propylitic and argillic alteration.	Anomalous Cu in stm seds, Au in rock, Ag in all media. Minor As, Mo, Pb, and Zn in all media. Minerals include barite-celestite, pyrite, cinnabar, and sphalerite.	Enhanced Landsat imagery shows area of alteration, in spite of beach cliff exposure for bulk of tract. Northwest flank of gravity low.	PM054
G Zachary	Quartz diorite intruding altered andesite of Popof volcanic rocks. Most of area is alluvium covered; however, propylitic, quartz-sericite, and magnetite-plagioclase alteration and mineralization reported spatially associated with feldspar porphyry on west edge of large color anomaly. Drilled in 1975 (Dircks and Richards, 1976).	Anomalous Au, Ag, As, Cu, Mo, Sb, Pb, and Zn in all media. Drilling and sampling in 1975 by Duval had assays to 0.36% Cu, 0.004% Mo, 0.08 oz/ton Ag and 0.016 oz/ton Au. Minerals include barite-celestite, gold, molybdenite, and pyrite.	Minor areas of alteration shown on enhanced Landsat image. Flattened gravity gradient. Near southeast margin of regional gravity low.	PM048

Table 1. Mineral resource sub-tracts and supporting geologic, geochemical and remote sensing evidence, Port Moller, Stepovak Bay, and Simeonof Island quadrangles, Alaska Peninsula -- Continued.

Sub-tract	Selected evidence for deposits in tract: Geology	Geochemistry	Remote sensing and geophysics	Example deposits and mineral occurrences[1]
Polymetallic vein mineral deposit model				
H Fishrack Bay	Margin of Devils batholith. Hornfelsed mudstone in contact with hypabyssal andesite plug.	Highly anomalous in Cu, Ag, and Zn in rock, moderately anomalous in As.	Flattened gravity gradient	SB020
I1 Mitrofania Is.	Margin of southernmost extension of Devils batholith. Multiple mineralized veins in country rock.	Highly anomalous in Cu, Mo, Ag, As, Pb, Zn, and Au in rock. Also anomalous in Bi, Cd, Sb.	Flattened gravity gradient	SB009 SB017 SB018
I2, I3 Seal Bay and Cape Ikti	Margin of southern part of main Devils batholith. Not sampled within study area. Multiple mineralized veins in country rock.	Highly anomalous in Cu, Mo, Ag, As, Pb, Zn, and Au in rock. Also anomalous in Bi, Cd, Sb.	South flank of gravity low	SB009 SB017 SB018
J	Lava flow and small intrusion of Tertiary age overlying and intruding Mesozoic and early Tertiary sedimentary rocks. No reported alteration or mineralization.	Anomalous in Cu, Au, Ag As, Mo, and Zn in rocks, Ag in stm seds and Pb and Zn in conc.	Nose on south flank of gravity low	SB026
K1 Egg Island	Sandstone, shale, and coal beds intruded by andesite sills and a hypabyssal andesite plug. Thrust fault mapped through area. Calcite veins present in intensely fractured zone within andesite. Galena, sphalerite and pyrite present in veins.	Anomalous in Cu, Ag, As, Pb, and Zn in rock.	Flattened gravity gradient	SB024
K2 Road Island	Lahar deposits on small island	Highly anomalous Au and minor Cu and As in rocks.	Flattened gravity gradient. Apparent gravity low.	SB025
K3 Kupreanof Peninsula	Meshik Volcanics and Miocene volcanic rocks probably overlying Stepovak Fm on extension of structural discontinuity. Minor alteration and mineralization. Reported color anomaly surrounding quartz diorite plug, with stockwork mineralization, and phyllic, propylitic, and argillic alteration. No plutons were located by our reconnaissance mapping through several altered zones, in or near Tertiary granitic plutons were reported by MacKevett and Holloway (1977) and Hollister (1978).	Highly anomalous Ag, As, Au, Mo, Pb, Sb, and Zn in rocks. Cu, Mo, and Pb in conc and Ag in stm seds.	Flattened gravity gradient	SB006 SB016 SB023
L Hag Peak	Hypabyssal andesite plug intruding coal-bearing sedimentary rocks. Multiple normal(?) faults and calcite-coated shear zones in andesite breccia altered to shades of pink and tan along shear zones.	Anomalous in Ag, As, Mo, Pb, and Zn in rocks.	Flattened gravity gradient	--
M Ivanof Polymetallic	Small granitic plug intruding Hoodoo Fm and surrounded by strong color anomaly in siltstone. Well-developed sericitic alteration in creeks and associated stockwork pyrite veins in Hoodoo Fm and granitic intrusion.	Anomalous As, Au, Cu, Mo, Pb, Sb, and Zn in rocks, Ag, As, Cu, and Mo in conc and Ag, Cu, and Pb in stm seds. Chalcopyrite in conc.	Near flattened gravity gradient and small residual low.	SB001
N Dent Point Polymetallic	Late Miocene volcanic rocks overlying sandstone of Tolstoi(?) Fm intruded by hornblende-andesite porphyry. Altered zone spatially surrounding granitic pluton reported by MacKevett and Holloway (1977). Stockwork pyrite veins in phyllically and propylitically altered volcanic(?) rocks (Butherus and others, 1979).	Anomalous Au and Ag in rocks, Cu, Ag, Mo in stm seds and Cu, Au, Ag, As, Mo, Zn, and Pb in conc.	Enhanced Landsat imagery shows well-developed areas of alteration in southern part of tract. Residual gravity low.	SB003

Table 1. Mineral resource sub-tracts and supporting geologic, geochemical and remote sensing evidence, Port Moller, Stepovak Bay, and Simeonof Island quadrangles, Alaska Peninsula -- Continued.

Sub-tract	Selected evidence for deposits in tract: Geology	Geochemistry	Remote sensing and geophysics	Example deposits and mineral occurrences[1]
O American Bay	3.5-Ma quartz diorite pluton intruding undivided volcanic rocks and Stepovak Fm. Also 8-Ma dikes in country rock. Hornfels(?) Stepovak Formation rocks to southwest of pluton extends area. Hydrothermal alteration and hornfels around American Bay pluton, merges with sub-tract N to the north. Mineralized veins are found on east shore of American Bay.	Multiple Cu in stm seds and Cu, As, Pb, and Mo anomalies in rocks, and sparse Au, Ag, Zn, and Sb anomalies in rocks.	South end of apparent gravity high, possibly an artifact of contouring program.	PM062 PM063 PM064? PM065?
P Left Hand Bay to Mud Bay	Shallow porphyry intrusions into sedimentary rocks of Stepovak and Tolstoi Formations.	Most anomalies in southwest part of tract, sparse Au in rock and conc, multiple Ag, in stm seds and conc, As in rocks and conc, Mo in all media, also Pb, and Zn. Minerals include barite-celestite, pyrite, galena, molybdenite, scheelite-powellite, and sphalerite. See also sub-tracts D1 and D2, included wholly within this sub-tract.	Enhanced Landsat image shows multiple areas of alteration in tract, generally corresponding to the periphery of small intrusions. General gravity high. Superimposed gravity lows near sub-tracts D1 and D2.	PM068 PM070 PM086
Q Moss Cape	Large 3.2-Ma granodioritic pluton intrudes Belkofski Fm and Miocene(?) volcanic rocks. Volcanic rocks are propylitically altered. At Moss Cape, sulfide-bearing quartz veins found cutting altered volcanic(?) rocks.	Anomalous Ag, As, and Cu in rocks and Pb and Zn in conc.	No evident correlation with gravity field.	--
R Nagai Is.	Turbidite sandstone and siltstone of Shumagin Fm near contact with late Tertiary Shumagin batholith. Regional low greenschist-facies metamorphism and local contact metamorphism near pluton.	Anomalous Au, Cu, Ag, Mo, Sb, and Pb in rock, Zn primarily in stm seds.	Minor area of alteration shown in southern part of tract. North-sloping regional gravity gradient.	PM051
S Big Koniuji Island	Turbidite sandstone and siltstone of Shumagin Fm near contact with late Tertiary Shumagin batholith. Regional low greenschist-facies metamorphism and local contact metamorphism near pluton.	Anomalous Au, Ag, Mo, and Pb in rock, Cu and Zn primarily in stm seds.	Flattened north-sloping regional gravity gradient.	--
		Epithermal gold vein model		
U	Units Qv and QTv(?) from Mount Veniaminof. Little data, no alteration known.	Highly anomalous Sb and moderately anomalous As and Hg in rocks.	Small (one station) gravity high	--
V Kametolook River	Unit Tm near Perryville, inlier or embayment in Mesozoic sedimentary rocks. Interbedded Stepovak Fm, minimal alteration and veining east of Perryville.	Highly anomalous Sb and As in rocks.	Very flat gravity gradient	SB021
W Red Bluff	Meshik(?) Volcanics. Includes Red Bluff, a small highly silicified and iron-stained andesite plug(?), cut by vuggy quartz veins, surrounding lava flows, and coal-bearing sandstone of Tolstoi Formation.	Anomalous in Cu, Au, Ag, Sb, Hg, As, Mo, and Zn in rocks, Ag in stm seds and Pb and Zn in conc.	Very flat gravity gradient	SB026
X	Meshik Volcanics overlying Mesozoic sedimentary rocks, minimal interbedded Stepovak Fm; no alteration noted.	Highly anomalous Sb and anomalous As in rocks.	Near residual gravity low, north-trending gravity gradient.	--

Table 1. Mineral resource sub-tracts and supporting geologic, geochemical and remote sensing evidence, Port Moller, Stepovak Bay, and Simeonof Island quadrangles, Alaska Peninsula -- Continued.

Sub-tract	Selected evidence for deposits in tract: Geology	Geochemistry	Remote sensing and geophysics	Example deposits and mineral occurrences[1]
Y Stepovak Bay volcanoes	Late Tertiary and Quaternary volcanic rocks overlying Bear Lake and Milky River Fms on northwest and Tolstoi and Bear Lake Fms on southeast. Hydrothermal alteration is common in volcanic and underlying sedimentary rocks. Minor mineralization noted in reconnaissance mapping. Sub-tract includes some igneous rocks of Miocene age in southwest. Eakins (1970) reported minor alteration near active fumarole which also suggests current hydrothermal activity.	Highly anomalous Au, Ag, Cu, Mo, Pb, Zn, Hg, Sb, and As in rocks; anomalous Cu and Pb in stm seds and highly anomalous As and Cu in conc.	Enhanced Landsat imagery shows many streams draining this area of high relief carry abundant altered debris, indicating extensive alteration of the country rock. No evident correlation with gravity field.	PM001 PM004 PM010 PM080 PM081 PM082 PM005? PM063? PM079?
Z1 Kupreanof Islands	Meshik Volcanics and interbedded Stepovak Fm, may overlie Chugach terrane. No alteration known.	Highly anomalous Au, As, and Hg in rocks.	Gentle northeast-sloping gravity gradient.	--
Z2 Kupreanof Peninsula	Meshik Volcanics and Miocene volcanic rocks, probably overlie Stepovak Fm, on extension of structural discontinuity (Wilson and others, 1985a). Reported color anomaly surrounding quartz diorite plug; associated stockwork mineralization, and phyllic, propylitic, and argillic alteration. Several altered zones, in or near Tertiary granitic plutons reported (MacKevett and Holloway, 1977; Hollister, 1978). However, no plutons were actually located during reconnaissance mapping.	Highly anomalous Au, Ag, and Sb in rocks. Anomalous Ag in stm seds.	Gentle northeast-sloping gravity gradient.	SB006 SB016 SB023
Z3	Unit Tm and interbedded rocks of unit Ts.	Highly anomalous Ag, and Sb, anomalous As in rocks.	Gentle northeast-sloping gravity gradient.	--
Z4	Unit Tm and interbedded rocks of unit Ts.	--	Gentle northeast-sloping gravity gradient.	--
Z5	Unit Tm(?) south of Ivanof porphyry occurrence, similar to sub-tract Z2. May overlie structural discontinuity.	Anomalous As in rocks	West of small apparent gravity low; very flat regional gradient.	--
AA	Units QTv and Qv(?) overlying units Tmr and Tbl(?) northwest of Stepovak Bay volcanoes. Sporadic minor alteration noted at base of lava flows.	Highly anomalous Au and As in rocks, anomalous As in conc.	Enhanced Landsat imagery shows minor alteration in southcentral part of tract. Steep northwest-sloping regional gravity gradient.	--
AB	Popof volcanic rocks. Undescribed mineral occurrence on island.	Au and Ag in rocks and Ag in conc	Flattened regional gravity gradient	PM018
AC	Popof volcanic rocks overlying Tolstoi and Stepovak(?) Fms Small area underlain by Unga Fm and Popof volcanic rocks in western part of sub-tract. Altered dacite cut by quartz veins reported in southeast part of sub-tract.	Highly anomalous Au and As in rocks.	Gentle gravity gradient east of low-amplitude high.	PM058
AD	Popof volcanic rocks and minor Miocene volcanic rocks and dacite plugs cut by two major NE-SW-trending fault zones. Abundant local alteration and mineralization. Many notable mineral occurrences including the Alaska-Apollo and Sitka mines and the Shumagin, Suzy Adit, and Herman Lode prospects.	Hg in rocks and Au, Ag, As, and Sb in rocks and conc. Minerals in conc include barite-celestite, cinnabar, fluorite, pyrite, molybdenite, and sphalerite.	Enhanced Landsat imagery shows strong alteration small areas of tract, particularly near PM048, 085. Mainly on southeast flank of large gravity low; flat gradient area.	PM003-006 PM009 PM011-017 PM026-043 PM044-048 PM050,052 PM055-057 PM059 PM085,089
AE	Meshik Volcanics overlying Mesozoic sedimentary rocks on west side of Port Moller. Basaltic lava flows and breccia and interbedded rocks of Stepovak Formation. No reported alteration or mineralization.	Highly anomalous Sb and Hg, anomalous Au, Ag, As in rocks, highly anomalous Au and Ag in conc.	Residual gravity low	--

Table 1. Mineral resource sub-tracts and supporting geologic, geochemical and remote sensing evidence, Port Moller, Stepovak Bay, and Simeonof Island quadrangles, Alaska Peninsula -- Continued.

Sub-tract	Selected evidence for deposits in tract: Geology	Geochemistry	Remote sensing and geophysics	Example deposits and mineral occurrences[1]
AF	Miocene(?) and older volcanic rocks. Highly altered volcanic and hypabyssal rocks. Extensive silicification, hydrothermal alteration, and quartz veining. Largest area of continuous alteration in region.	Au, Sb, As, and Hg in rocks, Ag in all media. Minerals in conc include barite-celestite, fluorite, galena, molybdenite, pyrite, and sphalerite.	Enhanced Landsat imagery shows extensive alteration in central part of tract, corresponding to occurrences PM002, 020, 021, 067, 069. Residual gravity high of about 10 mGal.	PM002 PM020 PM021 PM066 PM067 PM069
AG	Miocene volcanic rocks overlying Bear Lake and Stepovak(?) Formations. No known alteration or mineralization.	Highly anomalous Au and As in rocks.	Northwest-trending gradient between gravity high and low.	PM019
AH	Undivided volcanic rocks, probably Meshik(?) Volcanics or older(?) rocks. Fault bounded tract. Some propylitic alteration, minor localized sericitic and argillic alteration.	Highly anomalous Au, Sb, and As, anomalous Ag in rocks.	Enhanced Landsat imagery shows west end of tract to have multiple small areas of alteration. Crest and southeast flank of gravity high.	--
AJ	Multiple ash-flows and minor felsic domes. Rhyolite dome intruding Hoodoo Fm on south flank of Mount Dana.	Au, As, Sb, and Hg in rocks and Ag in all media. Minerals in conc include pyrite, galena, molybdenite, cinnabar, barite-celestite, and sphalerite.	Enhanced Landsat imagery shows areas of alteration around Mount Dana. Residual gravity low of about 10 mGal.	--
AM	Miocene volcanic rocks (Tv) overlying unit Tbe.	Highly anomalous Au, Ag, Sb, and As in rocks.	North-sloping regional gravity gradient.	PM053
AN	Miocene volcanic rocks (Tv) overlying unit Tbe.	Highly anomalous Au, As, and Hg, anomalous Sb in rocks and anomalous Ag in all media. Minerals in conc include pyrite, cinnabar, barite-celestite, and sphalerite.	Residual low of 5+ mGal	--
AO	Hypabyssal dacite plug in volcanic pile (QTv, Qv). No known alteration or mineralization.	Anomalous Ag in rocks	Major regional gravity low of 15 mGal.	--
AP	Basaltic volcanic rocks, post-Emmons(?) Caldera. Minor alteration directly related to volcanos; however, no mineral occurrences reported except sulfur.	Au in rocks, As in rocks and conc	Enhanced Landsat imagery shows multiple areas of alteration throughout tract on unit Qv. South margin of major regional gravity low. Northeast-trending steepened gradient.	PM025
AR	Propylitically altered volcanic rocks in Iliasik Islands. No reported mineral occurrences. Pervasive propylitic alteration.	Au in rocks.	North-sloping gentle gravity gradient.	--

Table 2. Appraisal of mineral resource tracts, Port Moller, Stepovak Bay, and Simeonof Island quadrangles, Alaska Peninsula.

[[1]Potential and certainty given as narrative ranking using terminology of Appendix A; numerical ranking of probability given as numbers of additional undiscovered deposits based on confidence of 10, 50, or 90 percent]

Tract	Rock units and geology	Possible mineral deposit types	Example deposits: Within map area	Example deposits: Within extensions to map area	Sub-tracts	Probability for additional deposits[1]	10	50	90
Pavlof area (1)	Quaternary (including Holocene) volcanic centers ranging in composition from andesite to basalt.	Epithermal Au	---	---	AO, AP	L/B	1	0	0
Mt. Dana (2)	Holocene volcanic center emplaced through Mesozoic sedimentary rocks; also small hypabyssal intrusive bodies of intermediate composition.	Epithermal Au	---	---	AJ	M/B	1	1	0
		Porphyry Cu	---	---	E	M/C	2	1	0
		Hot springs Hg	---	---	E	L/B	1	0	0
		Placer Au	---	---	E, AJ	M/B	2	0	0
		Polymetallic vein.	---	---	(E)	M/B	1	0	0
Cape Tolstoi (3)	Meshik Volcanics and Miocene volcanic rocks interbedded with and overlying sedimentary rocks of Tolstoi, Stepovak and Unga Formations.	Epithermal Au	---	---	AH	L/B	1	0	0
Cape Aliaksin to Mud Bay (4)	Small hypabyssal to shallow plutonic intrusive bodies of intermediate composition, units Ti and Tiu. Country rocks are Hoodoo, Stepovak, and Unga Formations, Meshik Volcanics, and Miocene volcanic rocks.	Porphyry Cu	Pyramid	---	D	H/C	4	1	0
		Polymetallic vein.	---	---	P	M/B	2	0	0
		Epithermal Au	---	---	AE, AF AG	M/C	3	2	1
		Placer Au	---	---	AF, P	M/B	3	0	0
		Sandstone Pb-Zn	---	---	not def.	L/B	1	0	0
Port Moller to Bear Lake (5)	Late Tertiary or Quaternary volcanic rocks overlying volcaniclastic sedimentary rocks of Milky River and Bear Lake Formations. Possible volcanic center.	Epithermal Au	---	---	AA	L/C	1	0	0
American Bay to Mount Veniaminof (6)	Dominated by Quaternary volcanic centers, tract includes Pliocene plutonic rocks, Oligocene, late Miocene, and Pliocene volcanic rocks intruding or overlying Mesozoic to Pliocene sedimentary rocks. In the vicinity of Left Head, includes propylitically-altered welded tuff of probable late Tertiary age.	Epithermal Au	---	---	X, Y	M/B	1	1	0
		Porphyry Cu	---	---	C	M/C	1	1	0
		Polymetallic vein.	---	---	N, O	M/B	4	0	0
Humpback Bay to Kupreanof Peninsula (7)	Meshik Volcanics and Miocene volcanic rocks overlying Tolstoi Formation and interbedded with and overlying Stepovak Formation. Intruded by small hypabyssal intrusive bodies of intermediate composition.	Epithermal Au	---	---	Z	L/B	1	0	0
		Porphyry Cu	---	---	A, B	M/C	2	1	0
		Polymetallic vein.	---	---	K, L, M	M/C	1	0	0
Perryville (8)	Meshik Volcanics overlying Tolstoi Formation and interbedded with Stepovak Formation. On north, late Tertiary or Quaternary lava flow(?) overlies Mesozoic sedimentary rocks.	Epithermal Au	---	---	U, V, W	M/B	1	0	0
		Sandstone U	---	---	not def.	L/B	1	0	0
Devils batholith (9)	Late Miocene granodiorite pluton intruding Late Cretaceous to Miocene sedimentary rocks and late Miocene volcanic rocks.	Polymetallic vein.	---	Warner Bay	H, I	M/B	2	0	0

Table 2. Appraisal of mineral resource tracts, Port Moller, Stepovak Bay, and Simeonof Island quadrangles, Alaska Peninsula -- Continued.

Tract	Rock units and geology	Possible mineral deposit types	Example deposits: Within map area	Example deposits: Within extensions to map area	Sub-tracts	Probability for additional deposits[1]	10	50	90
Pavlof Islands (10)	Miocene volcanic rocks overlying the Belkofski Fm on the southwest and the Unga Fm on the north-east. Intruded by Miocene and Pliocene hypabyssal to plutonic rocks.	Porphyry Cu	---	---	F	L/B	1	0	0
		Epithermal Au	---	---	AN, AM, AR	L/C	1	0	0
		Polymetallic vein.	---	---	(F), Q	L/B	1	0	0
		Hot-springs Hg	---	---	AN	L/B	1	0	0
Inner Shumagin Islands (11)	Meshik Volcanics interbedded with sedimentary rocks of Stepovak Formation. Intruded by Miocene hypabyssal stocks and overlain by late Miocene volcanic rocks on northwest.	Epithermal Au	AK.-Apollo Shumagin Mary Lou	---	AB, AC, AD	H/C	5	2	1
		Porphyry Cu	---		G	M/C	1	1	0
		Polymetallic vein.	---	---	(G)	L/C	1	0	0
		Hot-springs Hg	---	---	AD2	M/B	1	0	0
		Placer Au	---	---	G, AD	M/C	1	0	0
Outer Shumagin Islands (12)	Flysch of Shumagin Fm. metamorphosed to lower greenschist and intruded by Paleocene granitic plutons. Minor contact-metamorphic alteration.	Polymetallic vein	---	---	R, S	M/B	2	0	0

Table 3. Predicted number of undiscovered mineral deposits by deposit type in the Port Moller study area.

[Prediction derived from convolution (D.A. Singer, written commun., 1993) of estimated numbers of undiscovered deposits shown in table 2. Expected value calculated using the equation: EV = 0.233(90th percentile) + 0.4(50th percentile) + 0.225(10th percentile) + 0.045(5th percentile) + 0.03(1st percentile) where in this case, the 10th percentile is used for the 1st and 5th also]

Deposit type	Confidence level 90	50	10	Expected value
Epithermal gold vein	5	8	11	7.7
Porphyry copper	3	5	8	5.1
Polymetallic vein	1	4	8	4.2
Hot spring mercury	0	1	2	1.0
Placer gold	0	2	3	1.7

Table 4. Total depth, bottom hole temperature, and geothermal gradient of exploratory drill holes on the Alaska Peninsula.

[Quadrangles: CB, Cold Bay; CG, Chignik; KR, Karluk; PM, Port Moller; SW, Sutwik Island; UG, Ugashik. Bottom hole temperatures measured during logging, equilibration time ranged from 2 to 32 hours. Gradient calculated assuming surface temperature of 15°C]

Drill hole	Quadrangle (1:250,000)	Total depth ft	Total depth m	Temperature °F	Temperature °C	Gradient °C/km
Cathedral River 1	CB	14301	4359	278	137	28
David River 1A	PM	7956	2425	122	50	14
Canoe Bay 1	PM	6642	2024	160	71	28
Hoodoo Lake 2	PM	11243	3427	208	98	24
Hoodoo Lake 1	PM	8048	2453	134	57	17
Big River A-1	SB	11371	3466	400	204	55
Sandy River 1	CG	13068	3983	260	127	28
Port Heiden 1	CG	15020	4578	282	139	27
CUSA Koniag 1	SW	10905	3324	266	130	35
Wide Bay 1	KR	12566	3830	240	116	26
Painter Creek 1	UG	7907	2410	180	82	28
Great Basins 1	UG	10700	3261	183	84	21
Ugashik 1	UG	9479	2889	198	92	27
Becharof State 1	UG	9021	2750	210	99	31
Bear Creek 1	KR	14374	4381	152	67	12

Table 5. Sites of geothermal energy release and potential geothermal energy resources, Port Moller study area

Site Latitude Longitude	Areal extent and volume	Description	Rock types	Evidence of geothermal energy
Moller Hot Spring 55°51.7'N 160°29.5'W	----	Hot spring on headland between Port Moller and Moller Spit. Located 16 km south of cannery at Port Moller. Principal thermal springs near head of 0.5 km-long N-S trending trough (Motyka and others, 1981).	Herendeen Fm. calcarenite of Early Cretaceous age overlain to the south by volcanic rocks of late Eocene age. Hot spring flows through upper plate rocks near low-angle thrust (Wilson and others, in press)	Spring having a maximum temperature of 71.3° C and flow rate of 52 lpm. "Several additional warm seeps, about 20° C *** occur *** east of principal hot spring" (Motyka and others, 1981, p. 141).
Herendeen Bay warm stream 55°45.7'N 160°43.2'W	----	Warm stream entering ocean near Mine Harbor on Herendeen Bay reported by J.W. Miller and K.P. Helmold (oral commun., 1985). Located north of Bluff Point in sec. 9, T. 51 S., R. 74 W.	Stream drains valley in rocks of the Herendeen Fm. calcarenite of Early Cretaceous age. Rocks at stream and west to Marble Point are altered by introduction of calcium carbonate. Stream drains upper plate rocks near low-angle thrust as above.	Stream warmer than ambient temperature. Abandoned shed or sauna(?) up stream from beach. No temperature measurement made.
Mt. Dana volcano 55°37'N 161°12'W	1.6 km^2 4-16 km^3 (Smith and Shaw, 1975)	Small Holocene volcano having summit crater and multiple block-and-ashflow deposits. Located on north side of Canoe Bay.	Small dacitic(?) volcanic center emplaced through Mesozoic sedimentary rocks. Sedimentary rocks are domed upward by the volcano and a large block of the Early Cretaceous Staniukovich Fm is pushed up to form part of crater wall.	Small tufa mound on flank of volcano about 1.5 km southeast of Knutson Lake. Water below surface reported as "not hot and not cold" (M.E. Yount, N.B. Shew, and C.L. Connor, written commun., 1982).
		PAVLOF BAY REGION		
Mt. Hague 55°22'N 161°59'W	----	Holocene volcano 1,516 m high located at east margin of study area in secs. 33 and 34, T. 55 S., R. 83 W.	Post-caldera basaltic volcanic center located on east side of Emmons Caldera of Miller and Yount (1988)	Holocene basalt(?) lava flows extend west from volcano to shore of Emmons Lake in adjacent Cold Bay 1:250,000-scale quadrangle. Numerous fumaroles are located between 1,050 and 1,250 m (Kennedy and Waldron, 1955, p. 15) on the southeast side of volcano.
Double Crater 55°23'N 161°57'W	----	Holocene volcano 1,356 m high located 2 km northeast of Mt. Hague in sec. 26, T. 55 S, R. 83 W. "Two large, partly coalescing craters ***" projecting "*** above a surrounding icefield" (Kennedy and Waldron, 1955, p. 12).	Post-caldera basaltic volcanic center located on east side of Emmons Caldera.	Early Holocene(?) eruptive center.
Pavlof volcano 55°25'N 161°54'W	----	Holocene volcano 2,550 m high located west of Pavlof Bay in sec. 18, T. 55 S., R. 84 W. One of the most consistently active volcanoes in Alaska; a small crater lies on the northeast side of the volcano near its summit.	Post-caldera basaltic volcanic center located on east side of Emmons Caldera. Classically-shaped cone volcano, though asymmetrical in a northeast-southwest direction. Continuous with Mt. Hague, Double Crater, Little Pavlof, and Pavlof Sister. Includes a parasitic center.	Actively steaming basaltic volcano.

Table 5. Sites of geothermal energy release and potential geothermal energy resources, Port Moller study area -- Continued.

Site Latitude Longitude	Areal extent and volume	Description	Rock types	Evidence of geothermal energy
Pavlof Sister volcano 55°27'N 161°51'W	----	Holocene volcano 2,105 m high located west of Pavlof Bay in secs. 32 and 33, T. 54 S, R. 84 W. A crater, possibly 75 m in diameter (Kennedy and Waldron, 1955, p. 11) located at the summit.	Northeasternmost of the post-caldera basaltic volcanic centers on the east side of Emmons Caldera. Kennedy and Waldron (1955) describe two "recent" lava flows that originated from Pavlof Sister.	Lava flows reported by Kennedy and Waldron (1955, p. 11) indicate late Holocene activity.
		STEPOVAK BAY REGION		
Unnamed volcano (no. 4 of Wilson, 1989) 55°57.0'N 159°57.6'W	----	Active fumaroles and sulphur deposits (Eakins, 1970) at an elevation of about 920 m. Holocene debris flow at head of unnamed valley west of Big River.	Fumaroles found in snowfield overlying Pleistocene and Holocene(?) basaltic lava flows (Wilson, 1989).	Active fumaroles and evidence of Holocene volcanic activity. No warm springs observed, however this volcano may be "Kupreanof Volcano" as reported by Waring (1917, p. 44), although actual Kupreanof volcano is northeast of this location.
Unnamed volcanos (no. 2 and 3 of Wilson, 1989) 55°54.6'N 160°02.4'W	----	Volcano capped by cinder cone and Holocene lava flow.	Holocene andesite lava flow originating from cinder cone at summit of volcano 2, similar andesite flow originates at summit of volcano 3.	Holocene cinder cone 200 m high and andesite lava flow suggest high level of heat flow.
Unnamed volcano (no. 1 of Wilson, 1989) 55°52.2'N 160°05.4'W	----	Shield-type volcano having an inferred summit crater and weakly inferred fumarole.	Southeasternmost of a group of Quaternary volcanic centers. Erupted through and deposited on Late Tertiary(?) welded tuff. Extensive low-silica andesite to dacite lava flows.	No clear evidence of Holocene activity; however, 1962 aerial photographs suggest minor fumarolic activity.

SECTION A

Geology of the Pyramid porphyry copper deposit, Alaska Peninsula, Alaska

by W.H. White, J.S. Christie, M.R. Wolfhard, and F.H. Wilson

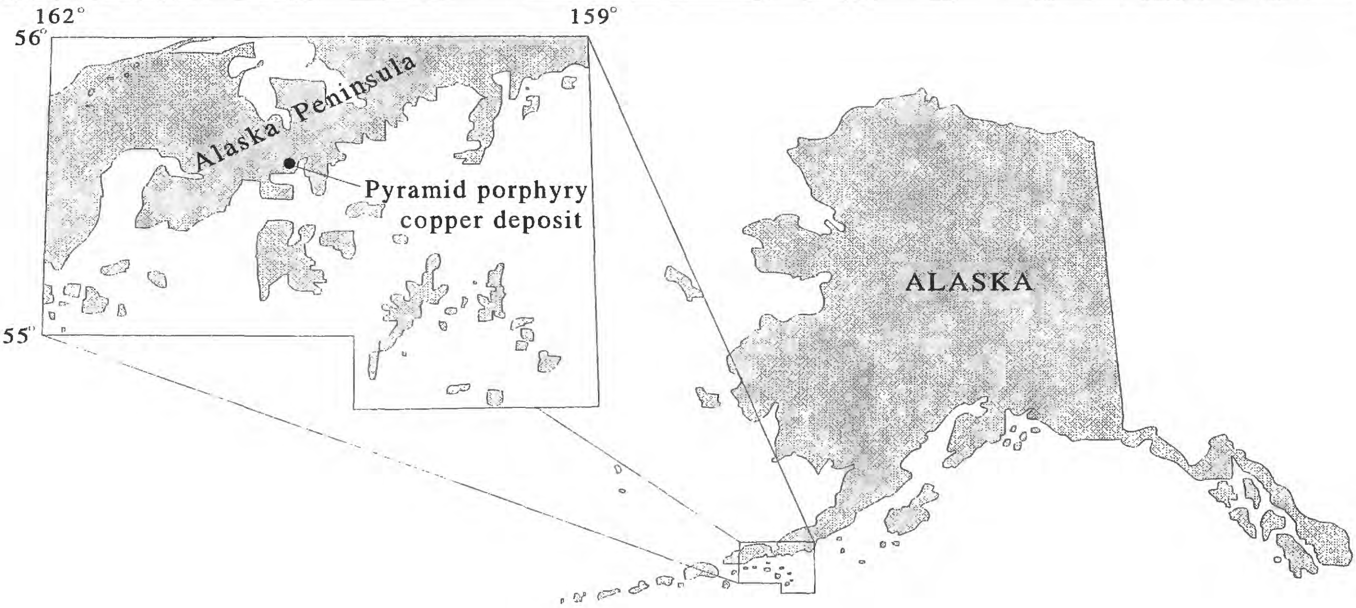

Figure A1. Index map showing location of Pyramid porphyry copper deposit.

INTRODUCTION

The Pyramid porphyry copper deposit lies at the head of a 300-m-high valley on the southwest flank of Pyramid Mountain on the Alaska Peninsula. It is located about 5 km from the Pacific Ocean and 900 km southwest of Anchorage (fig. A1). The property has been known since at least the mid-1950's and may have been staked then (B.L. Reed, U.S. Geological Survey, written commun., 1989). A notice on a post at the Pyramid claims indicates the property was staked by Pan American Petroleum in 1965. No drilling resulted from this staking. In 1974 the property was rediscovered, mapped, and sampled by a joint exploration venture of The Aleut Corporation, and the Quintana Minerals and Duval Corporations. Initial mapping identified a 1.29-km^2 altered and mineralized zone. In 1976 this zone was tested by 19 short vertical core holes totaling 1,695.6 m (5,563 feet) (fig. A2). This report presents results of geologic mapping by Christie and Wolfhard in 1974 and 1975; ore zoning studies by Christie in 1975; and core logging, petrography, and discussion of chemical analyses by White in 1989.

Armstrong and others (1976, p. B240-B241) presented a brief description of the Pyramid deposit in a discussion of K-Ar ages of Cenozoic porphyry copper deposits of the North American Cordillera. With the exception of an abstract by Christie and Wolfhard (1977), subsequent regional compilations by MacKevett and Holloway (1977, p. 28), Hollister (1978, p. 73), Nokleberg and others (1987, p. 42), and Wilson and others (1988, p. 12) rely chiefly on the discussion of Armstrong and others (1976).

GEOLOGIC SETTING

At the latitude of the Pyramid deposit (55°37'30" N., 160°40'01" W.), the Alaska Peninsula is an active volcano-plutonic arc located at the boundary between the converging Pacific and North American plates. Late Jurassic to Holocene sedimentary rock units reflect numerous marine transgressions (shallow-water shelf facies, turbidite units) and regressions (fluvial beds, deltaic units) that may in part record earlier periods of movement along the plate margin (Wilson and others, in press). To the north of Pyramid, northeast-striking thrust faults emplace Mesozoic and early Tertiary sedimentary and volcanic rocks over late Miocene sedimentary rocks of the Bear Lake Formation (Wilson and others, in press). Immediately south of Pyramid, a major vertical fault system having Miocene or younger offset also strikes northeast (Wilson and others, 1985).

The Pyramid deposit is the largest and best defined of at least six early and late Tertiary porphyry-type hydrothermal systems in the area (Wilson and Cox, 1983). Most deposits are spatially and genetically associated with subduction-generated hypabyssal intrusions of andesite, dacite, quartz diorite, or tonalite. These were emplaced during the formation of the Meshik and Aleutian magmatic arcs (Wilson and Cox, 1983) and range in age from 3.65 to about 37 Ma (Wilson and others, 1981; Wilson and Shew, 1992). The late(?) Miocene Pyramid stock formed during the early evolution of the modern Aleutian Arc.

GEOLOGY

The Pyramid porphyry copper system is centered upon a quartz diorite porphyry stock that is emplaced in and contact metamorphoses the early Tertiary Tolstoi Formation, composed largely of sandstone and lesser siltstone (fig. A3). The Pyramid stock is elongate northeast, about 1800 m long by 730 m wide. It cross-cuts the northwest strike of the gently south-dipping wall rocks. Hornblende from a dacite sill 1.1 km northeast of the unmineralized core of the Pyramid stock, and believed to be part of the igneous events associated with that stock, yielded a K-Ar age of 6.65±0.26 Ma (Wilson and others, 1994). Hydrothermal biotite from the biotite zone gave an age of 6.2±0.2 Ma (Armstrong and others, 1976).

The stock has a main porphyritic(?) phase, which has been largely altered by hydrothermal alteration and a less extensive quartz-feldspar porphyry phase present as masses and dikes. Although intense alteration masks original rock mineralogy and obliterates most primary texture within the main phase, nearly unaltered rocks are locally present. In these, the estimated modal proportion of quartz (10 percent), plagioclase (60 percent), and mafic mineral pseudomorphs (30 percent) suggests that quartz diorite was the original composition. The most common primary texture is porphyritic, as phenocrysts compose at least 60 percent of the rock. Numerous subhedral plagioclase phenocrysts as much as 3 mm in diameter are set in a finely crystalline groundmass of plagioclase and minor quartz. Pseudomorphs composed of secondary biotite and magnetite suggest that biotite, and possibly hornblende, were the original mafic minerals.

Quartz-feldspar porphyry masses and dikes and breccia pipes were emplaced late in the intrusive history of the Pyramid porphyry system. The quartz-feldspar porphyry masses and dikes are emplaced within and peripheral to the stock. They are less altered than the main phase of the stock and appear to have been emplaced late in, and locally after, the main period of copper mineralization (fig. A3). The quartz-feldspar porphyries, in comparison to the main phase, have more quartz, larger but less abundant plagioclase phenocrysts, and, rarely, near-hypidiomorphic granular textures. The breccia pipes, also emplaced late in, and after the mineralizing episode, are commonly elongate northeast within and adjacent to the stock (fig. A3). The pipes contain variably altered and mineralized clasts of hornfels, as well as pre- and post-mineralization intrusive rock clasts. Breccia pipes in the eastern part of the map area (fig. A3) differ in that they contain clasts of hornfels that are conspicuously less altered than adjacent rocks, which suggests that the clasts were transported over greater vertical distances within these pipes.

ALTERATION

BIOTITE ZONE

The biotite zone, which is entirely within the stock, forms a 550- by 275-m core around which the copper deposit and other alteration zones are centered (fig. A2). It is characterized by the alteration of primary biotite and hornblende(?) to secondary biotite and magnetite. Primary plagioclase is unaltered. The outer boundary of the zone is placed where secondary biotite is no longer observed.

In hand specimen, the biotite-rich rock is equigranular-appearing and composed of zoned white plagioclase crystals and dark-brown biotite. Average grain size of the plagioclase is 3 mm, although crystals as large as 8 mm long are present. Chlorite-magnetite, biotite-magnetite, quartz-chlorite, and quartz veins are common; chalcopyrite veins are rare. The rock is strongly magnetic.

In thin section, subhedral, twinned plagioclase (andesine) shows well-developed oscillatory zoning. Rare sericite is present within selected zones and sparse potassium feldspar partially replaces and locally veins plagioclase, otherwise plagioclase is unaltered. No carbonate minerals (calcite?) were observed. Brown biotite, locally altered to chlorite along cleavage traces, forms 2.5-mm-long clusters interstitial to plagioclase. Most quartz is anhedral and interstitial, although quartz veins are common. Magnetite forms aggregates of euhedral crystals, commonly within clusters of biotite.

QUARTZ-SERICITE-ANDALUSITE ZONE

The quartz-sericite-andalusite zone forms an annular shell as much as 950 m wide, that surrounds the biotite core and affects both the stock and the adjacent hornfels (fig. A2). It is characterized by pervasive alteration of mafic minerals to coarse sericite, carbonate minerals, leucoxene, trace chlorite, and minor rutile, pervasive alteration of plagioclase to sericite and, locally, andalusite, and abundant pyrite. More intense quartz veining and silicification in the inner parts of the zone, closest to the biotite core, and locally abundant andalusite, suggest that the quartz-sericite-andalusite zone might be divided into subzones.

The outer boundary of the quartz-sericite-andalusite zone (fig. A2) is defined by the presence of sericite selvages on quartz veins. The inner boundary, which overlaps the biotite zone, is defined as the point where pervasive sericite is no longer observed. The northeastern boundary of the zone is yet to be mapped.

Hand specimens of altered quartz diorite(?) within the zone are greenish gray, finely crystalline, and sugary textured. In thin section these samples show a systematic mosaic of interlocking anhedral quartz crystals and irregular masses of sericite that reflect completely replaced plagioclase. Typically, no original texture survives alteration, but in less-altered quartz diorite(?), sericite pseudomorphs of plagioclase are common. Altered hornfels is dark gray, massive, and has textures that are patchy and less regular. Average grain size is 0.15 mm for igneous rocks and less than 0.05 mm for hornfels.

In addition to sericite, alteration products of plagioclase include albite, andalusite, carbonate minerals (calcite?), and undetermined clay mineral(s). Albite is present in sericite masses, which are former primary plagioclase sites, and in quartz veins, where it is interstitial to quartz. Albite is also present locally in composite aggregates of subhedral, ragged-edged, inclusion-charged plagioclase crystals that lack the oscillatory zoning of primary plagioclase. Albite is locally replaced by sericite.

In altered igneous rocks, andalusite forms prismatic crystals as much as 0.3 mm long in masses of sericite, and is found in andalusite or quartz-andalusite veins. Crystals are locally pleochroic pale green to colorless, suggesting variable iron and manganese contents (Deer and others, 1966, p. 38). Andalusite is replaced by sericite as indicated by deeply embayed remnants of andalusite in sericite, sericite along andalusite cleavage traces, and sericite pseudomorphs of parts of andalusite crystals. Andalusite in hornfels is evenly distributed as skeletal crystals that locally show strong apple-green to colorless pleochroism. Andalusite in veins is not pleochroic.

Minor calcite and clay minerals, some of which is kaolinite, are locally present in sericite. Clusters of iron-oxide-stained carbonate minerals (calcite?), locally coarse sericite, leucoxene, red-brown crystals of rutile, and uncommon, very pale green chlorite probably formed from the destruction of primary mafic minerals. Rare fluorite is interstitial to quartz in quartz-sericite veins and interstitial to sericite in wall rocks adjacent to veins. Accessory zircon is present in most rocks; apatite is uncommon.

Quartz veins contain local vugs of euhedral quartz, interstitial pyrite, and zoned carbonate minerals. Late veins of pink rhodochrosite and dolomite are also present.

CHLORITE ZONE

The outer chlorite zone encircles, but does not overlap, the quartz-sericite-andalusite zone. It is characterized in altered dike rocks by partial alteration of plagioclase to sericite, epidote, and calcite; chlorite, magnetite, trace epidote, and calcite after hornblende; and chlorite and epidote after biotite. The inner boundary is mapped where megascopic chlorite is no longer apparent; the outer boundary of the zone is not mapped.

DISCUSSION OF ALTERATION HISTORY

Andalusite occurs in the alteration envelopes of pre-Main Stage veins at Butte, Montana, where it replaces plagioclase and forms andalusite-alkali feldspar-quartz and andalusite-muscovite-alkali feldspar-quartz assemblages between the veins and adjacent, relatively unaltered quartz monzonite (Brimhall, 1977). At the El Salvador copper deposit in Chile, an andalusite-alkali feldspar assemblage, considered to be part of an early period of potassic alteration, is present at deeper levels in the mine (Gustafson and Hunt, 1975). Also at El Salvador, an andalusite-sericite assemblage, thought to have formed in a transitional period between the early potassic and later sericitic alteration, is present at higher levels. Andalusite replaces plagioclase in both the early and transitional assemblages, but is more abundant in the higher level transitional zones where it locally constitutes as much as 40 percent of the rock (Gustafson and Hunt, 1975).

At Pyramid, textural evidence suggests that most andalusite formed prior to sericite. It is possible, however that andalusite formed along with sericite, both from albite after andesine, and directly from andesine. For example, andalusite may have replaced plagioclase during an early period of high-temperature alteration, possibly at temperatures exceeding the stability of sericite. As temperatures decreased and hydrogen-ion activity increased, andalusite and sericite, and then finally, only sericite may have become the dominant stable phase. Alteration of andalusite to sericite in altered igneous rocks is minor and possibly the result of retrograde adjustments to lowering temperature.

SULFIDE MINERAL DISTRIBUTION AND THE ORE DEPOSIT

The extended pyrite halo around the Pyramid porphyry copper deposit is about 3300 m in diameter (Armstrong and others, 1976). The highest total-sulfide content, reaching 5 to 10 percent, overlaps the inner part of the chlorite zone and the outer part of the quartz-sericite-andalusite zone. High pyrite to chalcopyrite ratios (50:1 or more) are associated with low copper grades (less than 0.15 percent Cu) and very low molybdenum grades (0.00X percent Mo). Total-sulfide content and pyrite to chalcopyrite ratios diminish inward through the quartz-sericite-andalusite zone, as copper grade increases to 0.3-0.4 percent Cu. Molybdenite also becomes more abundant inward as intensity of quartz veining increases, reaching 0.03-0.05 percent molybdenum in the innermost part of the quartz-sericite-andalusite zone.

Inward, at the first appearance of biotite, total-sulfide content drops below 1 percent and both copper and molybdenum grades diminish. In the biotite zone, beyond the inner limit of sericite, total sulfide content is less than 0.25 percent and both copper and molybdenum grades are on the order of 0.00X percent.

In general, the grain size of sulfide minerals diminishes inward. In the most copper-rich parts of the system, the majority of sulfide minerals are finely disseminated, although significant amounts occur as thin fracture fillings.

Supergene chalcocite and covellite contribute significantly to grade. Trace amounts of copper pitch, copper-manganese, copper-carbonate, chrysocolla, and cuprite are also present. Chalcopyrite is most strongly replaced by the secondary copper minerals, although skins of chalcocite are also common on pyrite. Very fine grained sulfide minerals make visual estimation of copper grade difficult.

Chalcocite blankets derived from supergene enrichment as much as 90 m thick are indicated by drill cores in some areas at Pyramid. However, the best copper grades are found in the upper 30 m or so of the chalcocite zone where the highest degree of chalcocite replacement has occurred.

The thickest chalcocite blankets do not coincide exactly with the zones of deepest oxidation. For example, in hole BBS1-3 (fig. A2) the oxidized zone is only 19 m thick, but the chalcocite zone exceeds 90 m in thickness. This likely reflects lateral-downslope transport of copper, or alternatively, that part of the oxidized cap may have been glacially eroded. In the latter case then, the chalcocite blanket at Pyramid is not entirely due to present-day conditions.

The Pyramid copper deposit contains 126,000,000 tons averaging 0.403 percent copper and 0.025 percent molybdenum, based on a lateral cutoff at 0.25 percent copper, and a basal cutoff at the projected bottom of the chalcocite blanket. Defined in this way, the deposit is elongate northeast, about 2,012 m (6,600 ft) long by 700 m (2,300 ft) wide (fig. A4). The top of the deposit is about 46 m (150 ft) deep and the bottom is 91 m (300 ft). It has an 823-m-(2,700 ft) by 350-m-(1,150 ft) wide centrally located barren core (fig. A2). Projected to the surface, the deposit outline approximates that of the quartz-sericite-andalusite zone; and the barren core approximates that of the biotite zone (fig. A2). Additional barren zones within the deposit are the result of post-mineral breccia pipes and igneous intrusions. Although chalcocite-enriched rocks form the bulk of the deposit, the distribution of higher grade ore within the secondary mineralization is thought to reflect the distribution of higher grades in the underlying protore.

CHEMISTRY

The geochemical signature of the Pyramid deposit was determined by comparison to rock samples collected as part of the Port Moller, Stepovak Bay, and Simeonof Island 1:250,000-scale quadrangles mineral resource assessment (Angeloni and others, 1985; Wilson and others, 1987). Chemical datasets composed of intrusive rock and sandstone samples from these quadrangles were compared to a set of contact-metamorphosed rocks collected from near the Pyramid deposit and to chemical data from drill core at Pyramid. The data shows that manganese, strontium, and zinc are depleted in the Pyramid copper deposit, relative to intrusive rocks and sandstone, whereas silver and molybdenum are enriched (table A1, fig. A5). For manganese and strontium, the depletion relative to background levels, is least in the biotite zone and greatest in the quartz-sericite-andalusite zone. We think that the degree of destruction of mafic minerals and plagioclase may be the reason for this depletion. Hornblende has been replaced and biotite and plagioclase remain in the biotite zone, whereas these minerals are completely replaced in the quartz-sericite-andalusite zone. The presence of an outer zinc halo is suggested by zinc concentrations higher than background in contact-metamorphosed rocks between 1.6 and 4.8 km from the center of the mineralizing system. However, comparison with a dataset of fine-grained sedimentary rocks from the Port Moller study area indicates that the zinc concentration in the contact-metamorphosed rocks is about the same as these fine-grained rocks.

Although gold is enriched relative to background in sandstone, maximum gold values of about 0.1 parts per million (ppm) at Pyramid are far below the greater than 0.4 ppm expected in the so-called gold-rich porphyry systems of the South Pacific or the average grade of 0.31 ppm gold at Bingham Canyon, Utah (Sillitoe, 1988). The gold values at Pyramid are statistically indistinguishable from average gold values for plutonic rocks throughout the Port Moller region; it must be recognized however, that the Port Moller region is a gold-rich province, as indicated by a number of known gold deposits and numerous gold prospects.

Silver, although strongly enriched relative to background in intrusive and unaltered sedimentary rocks at Pyramid, is low (about 1 ppm, table A1) relative even to silver-poor porphyry copper deposits which tend to be above a few ppm silver and range to more than 100 ppm (see Sillitoe, 1988, table 1). Although porphyry copper deposits with silver-poor interiors commonly have silver-rich peripheral halos, at Pyramid no peripheral silver anomaly is apparent (Sillitoe, 1988). The relative depletion of manganese, strontium, and zinc, and the enrichment of gold and silver in the copper-rich zone is typical of many porphyry copper deposits (Chaffee, 1982; Sillitoe, 1988).

SUMMARY

The late Miocene molybdenum-bearing Pyramid porphyry copper deposit contains annular zones of wall rock alteration and sulfide mineral(s) concentration centered on a quartz diorite porphyry stock emplaced in Paleogene sandstone and siltstone of the Tolstoi Formation. An inner biotite zone, characterized by hydrothermal biotite and magnetite is bounded outward by a quartz-sericite-andalusite zone, which is in turn bordered by a chlorite zone. Depletion of manganese and strontium within the quartz-sericite-andalusite zones is attributed to the destruction of original mafic minerals and plagioclase. The Pyramid deposit contains between 0.05 and 0.10 ppm gold and is not a gold-rich copper porphyry as defined by Sillitoe (1988).

Pyrite is typical of the entire width of the quartz-sericite-andalusite zone, whereas chalcopyrite and molybdenite are concentrated only within the inner part of the quartz-sericite-andalusite zone and largely absent elsewhere. The orebody owes its grade and tonnage to the presence of chalcocite and covellite derived from supergene enrichment of the chalcopyrite protore. With the exception of andalusite in the alteration assemblage, the Pyramid porphyry copper deposit is typical of those formed in the principal magmatic arc above moderate to steeply dipping subduction zones (Sillitoe, 1981).

The biotite, quartz-sericite-andalusite, and chlorite alteration zones of the Pyramid deposit correspond to the potassic, phyllic, and propylitic zones of hydrothermal alteration outlined by Lowell and Guilbert (1970). In many porphyry copper deposits, particularly in the southwest U.S., copper concentrations are in the potassic, rather than phyllic zone as at Pyramid (Titley, 1982, p. 98). In most porphyry copper deposits, phyllic alteration is shown to be younger than potassic and propylitic alteration, and even though phyllic alteration is between the two earlier zones in plan, it is actually superimposed upon them (Beane, 1982, p. 121). Perhaps the copper concentrations at Pyramid were originally formed in the outer part of the potassic-zone which was subsequently overprinted by phyllic alteration. This would also explain the presence of gold in the phyllic zone, as gold in most porphyry copper deposits is in the potassic zone (Sillitoe, 1988). Gold concentrations at Pyramid are equivalent in the potassic (biotite) and phyllic (quartz-sericite-andalusite) zones.

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Table A1. Average concentrations of Ag, Au, Cu, Mn, Mo, Sr, and Zn in selected rock and drill core from the Pyramid deposit and surrounding areas.

[Results reported in parts per million; Analytical methods: AA, Atomic absorption; SES, Semiquantitative emission spectrography; * also indicates semiquantitative emission spectrography. Analysts were E.A. Bailey, Floyd Brown, and Z.A. Brown. Some of the datasets reported here contained qualified data (i.e. N (not detected) and L (detected, but lower than the determination limit). The values for these samples were quantified by assigning 0.5 times the determination limit to samples qualified with an N and assigning a value of 0.7 times the determination limit to samples qualified with an L]

Element Method	Ag AA	Au AA	Cu AA	Mn SES	Mo SES	Sr SES	Zn AA	No. samples
Detection Limit	0.05 (0.5)*	0.05	5 (5)*	10	5	100	5	
Rock unit								
1	<0.5*	0.08	152*	963	7	478	49	87
2	<0.05	<0.05	661	101	30	183	11	11
3	1.30	.08	4658	183	259	<100	16	32
4	.53	.09	1678	639	160	<100	28	41
5	.25	<0.05	529	360	12	200	43	5
6	1.40	.07	3618	365	175	<100	34	35
7	.85	.10	5643	131	283	104	15	28
8	.52	<0.05	53*	135	50	127	11	11
9	<0.5*	<0.05	40*	1070	<5	282	101	19
10	<0.5*	<0.05	31*	1099	<5	405	70	705

Rock units:

1. All intrusive rock samples from the Port Moller and Stepovak Bay quadrangles. Samples were collected during USGS field mapping studies (Angeloni and others, 1985; Wilson and others, 1987) and include mineralized, as well as, unmineralized rock samples.
2. Post-mineral intrusive rocks cutting the Pyramid stock and adjacent hornfels. Samples are from drill hole BBS1-4; each sample represents 10 ft of split core.
3. Quartz-sericite-andalusite zone within defined copper deposit, based on a 0.25 percent copper cutoff, within the Pyramid stock. Samples are from drill hole BBS1-3; each sample represents 10 ft of split core.
4. Quartz-sericite-andalusite zone and biotite zone overlap within the Pyramid stock. Samples are from drill hole QP-1; each sample represents 10 ft of split core.
5. Biotite zone within the Pyramid stock. Four samples are from drill hole QP-12 and one is a surface rock sample, 88AWw-349. Each drill hole sample represents 10 ft of split core.
6. Quartz-sericite-andalusite zone within defined copper deposit, based on a 0.25 percent copper cutoff, within the Pyramid stock. Samples are from drill hole QP-5; each sample represents 10 ft of split core.
7. Quartz-sericite-andalusite zone within defined copper deposit, based on a 0.25 percent copper cutoff, in hornfels. Samples are from drill hole QP-6; each sample represents 10 ft of split core.
8. All hornfels rock samples collected during USGS field mapping studies (Angeloni and others, 1985; Wilson and others, 1987) within 0.8 km of the center of the barren core. Samples include:

83AAi-36b	83AAi-38	83AAi-39a	83APk-40a	83APk-40b	83APk-41a
83APk-42a	83APk-43a	83APk-43b	83APk-44	83APk-46.	

9. All surface hornfels rock samples collected during USGS field mapping studies (Angeloni and others, 1985; Wilson and others, 1987) between 1.6 and 4.8 km from the center of the barren core. Samples include:

82ACc-12	82ACc-13	82ACc-15	83ADt-117	86ADt-387	86ADt-388
86ADt-389	86ADt-390	85ADg-12	85ADg-13	83AJm-599	85AWr-119a
85AWr-120	85AWr-121	85AWr-122	85AWr-123	85AWr-125	85AWr-126
85AWr-128					

10. All sandstone rock samples collected during USGS field mapping studies in the Port Moller, Stepovak Bay, and Simeonof Island quadrangles (Angeloni and others, 1985; Wilson and others, 1987).

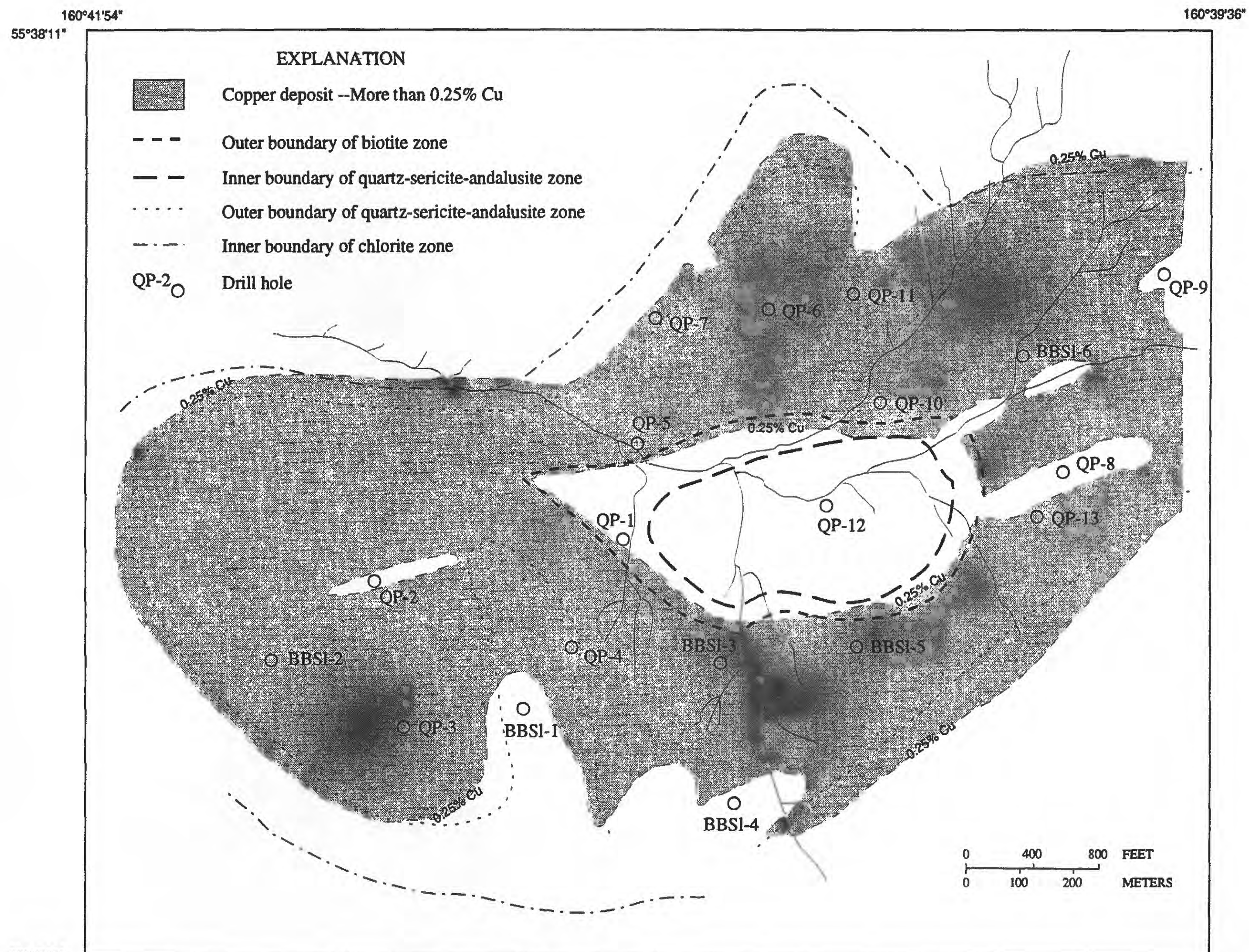

Figure A2. Map of Pyramid porphyry copper deposit showing drill holes, alteration zones, and extent of copper.

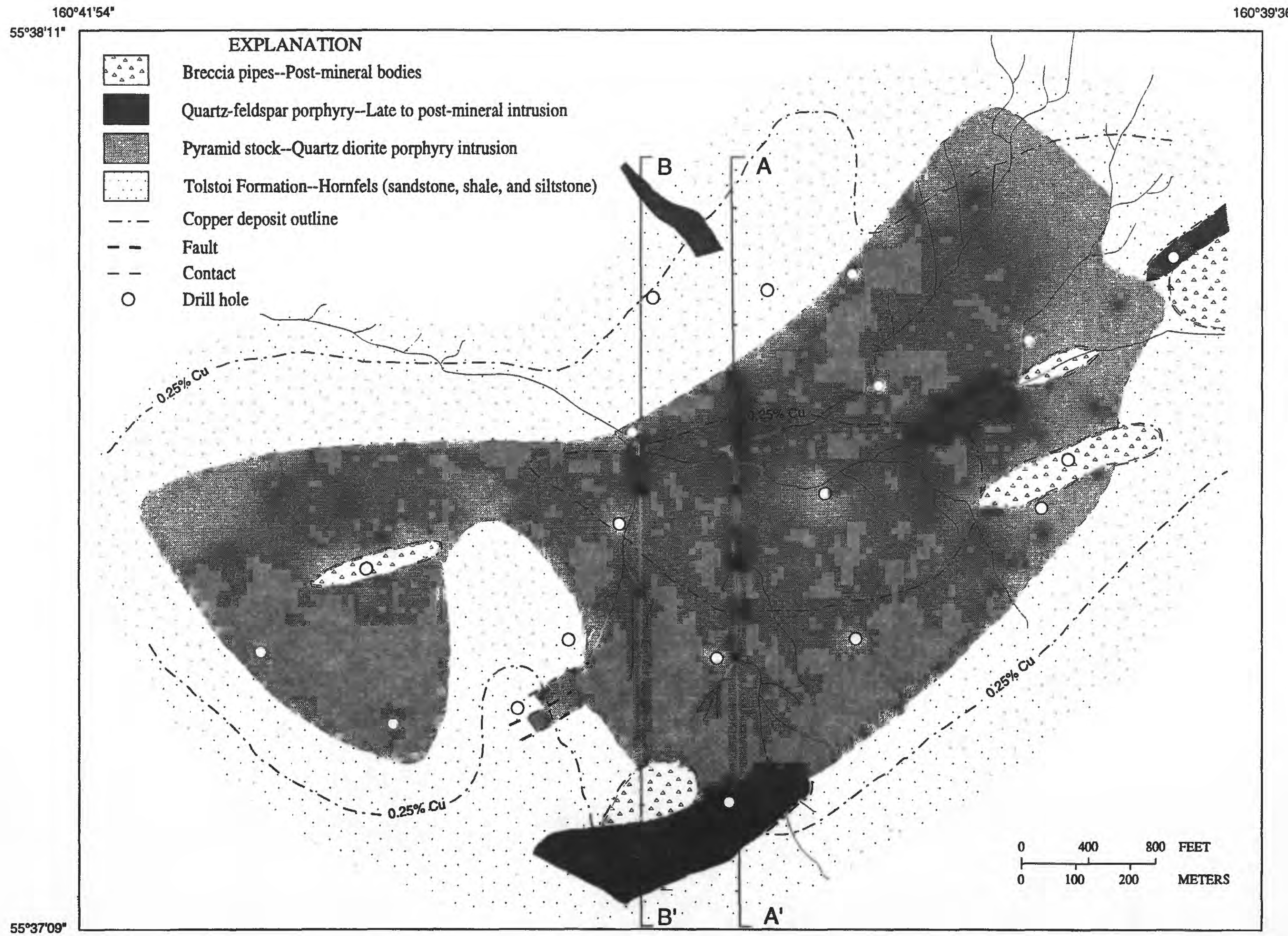

Figure A3. Generalized geology and outline of copper deposit projected to surface at Pyramid. See figure A4 for cross sections.

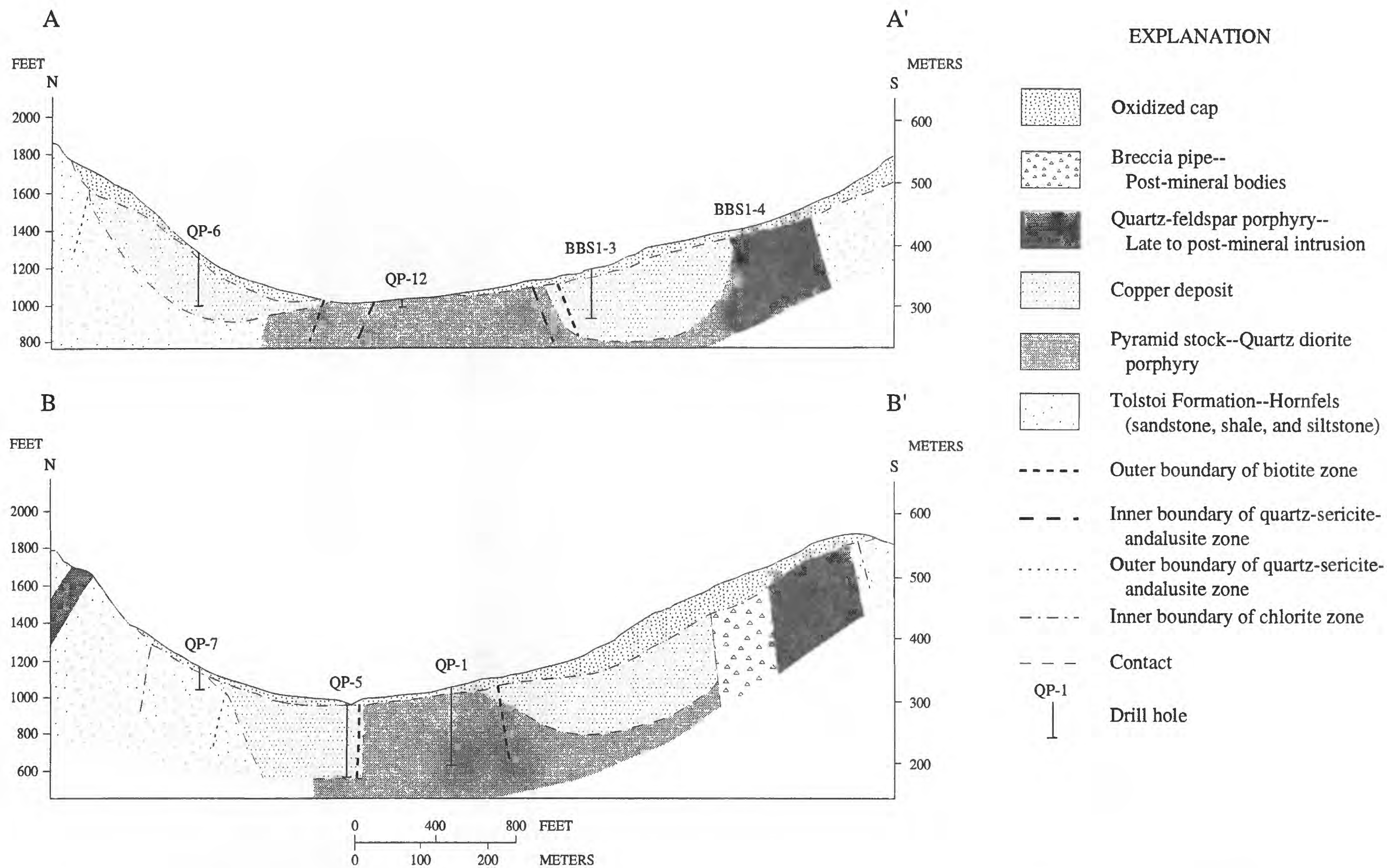

Figure A4. Cross section *A-A'* and *B-B'* showing geology, alteration, and copper deposit at Pyramid. Sections look east. See figure A3 for location of cross sections.

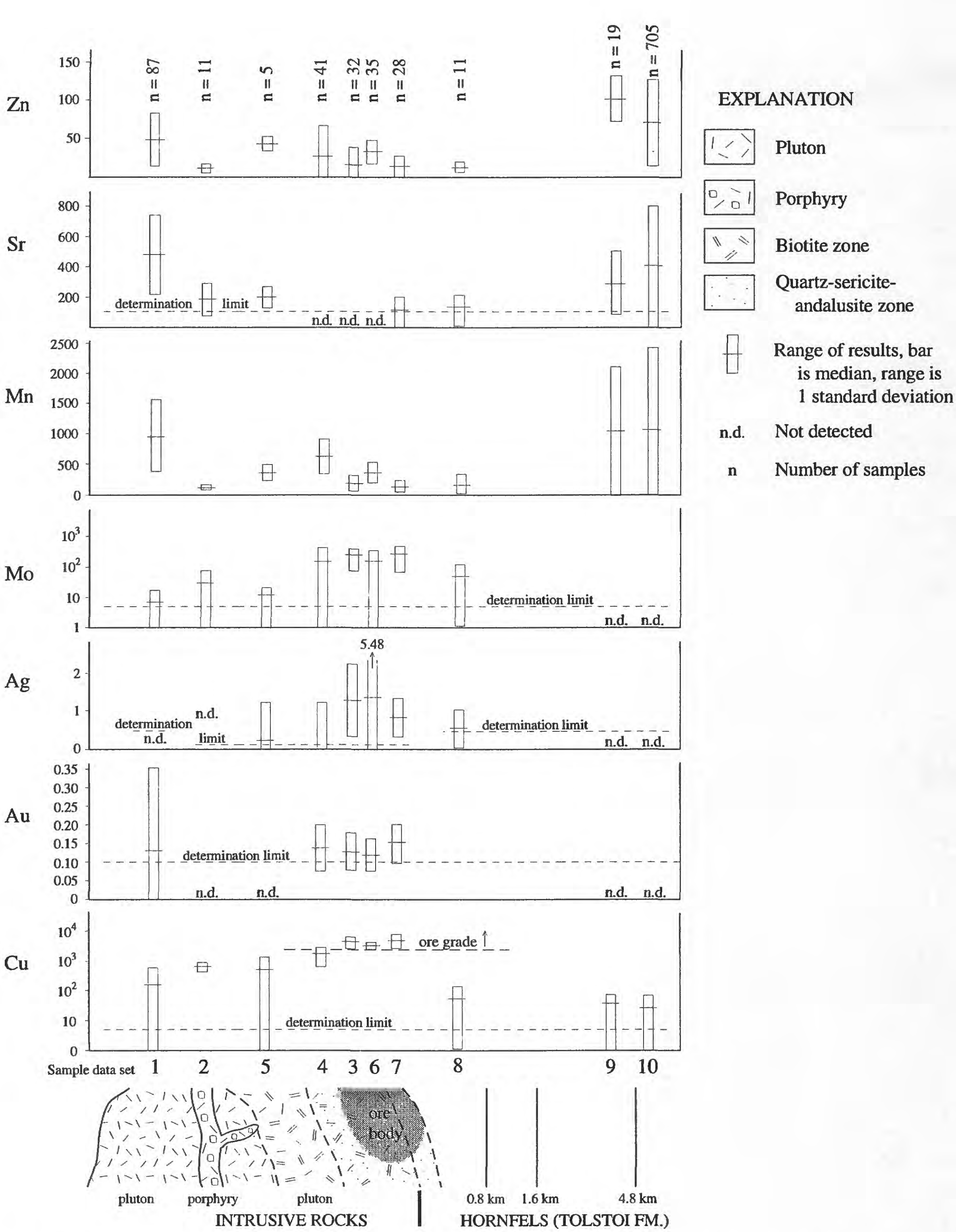

Figure A5. Graphs showing geochemical concentrations of selected elements for the Pyramid porphyry copper deposit and nearby host rock. All concentrations in parts per million. See table A1 for description of sample data sets used to prepare illustration.

SECTION B

Description of the Shumagin epithermal gold vein deposit

by W.H. White and L.D. Queen

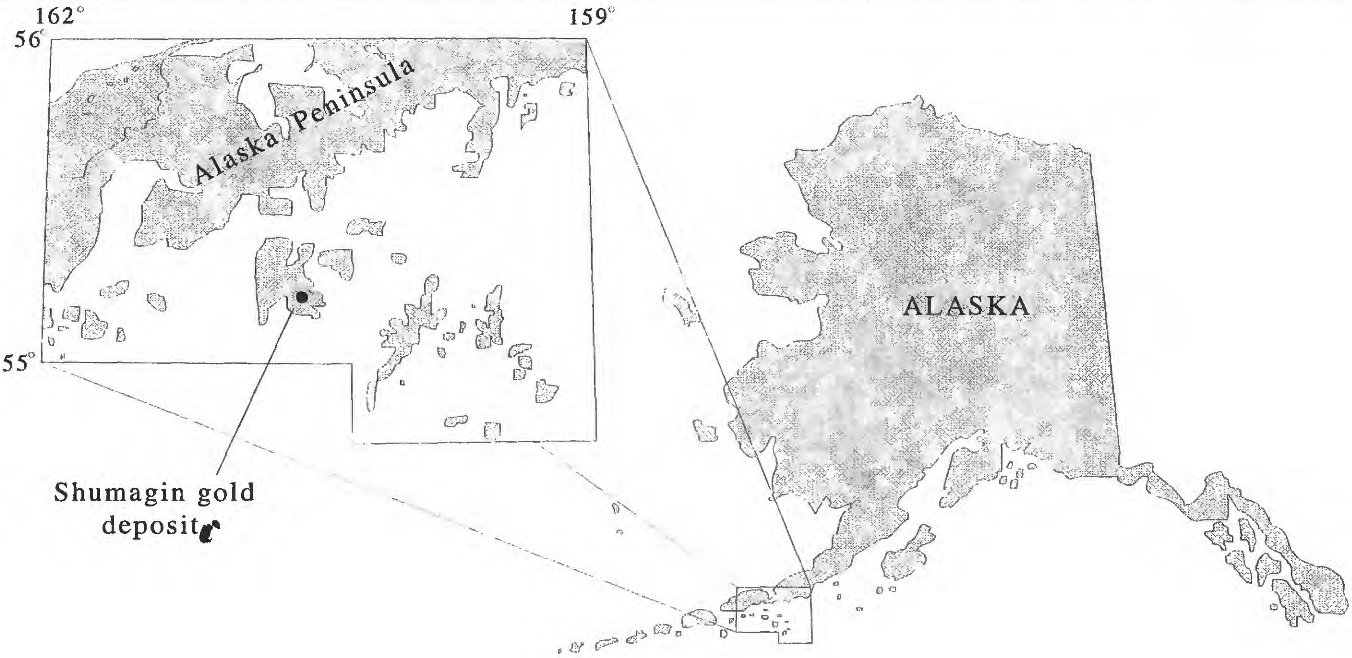

Figure B-1 -- Index map showing location of Shumagin gold deposit.

INTRODUCTION

The Shumagin gold deposit is located at the head of Baralof Bay on Unga Island (fig. B1). Atwood (1911) reported prospecting on the Shumagin claims around the turn of the 20th century and during the period 1983 to 1987, Alaska Apollo Gold Mines Ltd. explored the Shumagin deposit with 2,825 m (9,269 ft) of core drilling (Queen, 1988) and established an estimated reserve of 245,106 T (270,000 short tons) grading 16.8 g/t Au and 68 g/t Ag (Mining Journal, 1987).

The deposit occurs within the Aquila-Shumagin Fault Zone, which strikes northeast across the entire island. The Aquila-Shumagin Fault Zone strikes N. 60°E. for a distance of at least 1,463 m and dips 80 to 85° SE. The surface trace of the fault zone is marked by outcrops of silica-cemented, clast-supported fault breccia and matrix-supported quartz breccia veins having an average width of about 12 m. Although sense of movement in the fault zone is uncertain, faults having similar trends in the vicinity of the Aquila-Shumagin Fault Zone are up on the southeast, suggesting high-angle reverse displacement (J.R. Riehle, USGS, written commun., 1988). The southeast wall is crystal lithic tuff, whereas the northwest wall is andesite. The fault zone is offset laterally as much as 15 m by northwest-trending cross faults having either left- or right-lateral displacements.

Two fault breccia units, at least four individual veins, and two vein systems occur within the Shumagin gold deposit. The fault units, from older to younger, are (1) pyrite-rich cataclasite, and (2) clast-supported fault breccia; the veins and vein systems, from oldest to youngest, are (3) the Union composite vein, (4), matrix-supported quartz breccia vein, (5) Greenbaum vein, (6) Lucky Friday vein, (7) vuggy watercourse vein system, and (8) carbonate vein system (figs. B2 and B3). Cross-cutting relationships of the Greenbaum and Lucky Friday veins were not observed, therefore their positions in the sequence are tentative.

FAULT UNITS

The fault units, pyrite-rich cataclasite (1), and clast-supported fault breccia (2), occur within the Aquila-Shumagin Fault Zone and most likely are products of fault movement (fig. B3). Pyrite-rich cataclasite is primarily found on the hanging wall of the fault. It forms a discontinuous 4-cm-thick zone and contains angular crystal and rock fragments as much as 1 mm in diameter in a matrix of finely crystalline quartz laced with pyrite.

The clast-supported fault breccia is the principal fault unit and contains angular clasts of andesite, crystal-lithic tuff, and pyrite-rich cataclasite as much as 5 cm in diameter. It also contains angular quartz clasts generally less than 5 mm in diameter and calcite occurring as individual crystals and in pockets within the breccia. Some calcite crystals are euhedral and appear to have grown in place, others; however, are angular and may represent breccia fragments. Pockets of calcite are as much as 12 cm in diameter. The matrix of the breccia, which constitutes 10-15 percent of the rock, is predominantly gray, finely crystalline quartz with minor leucoxene and chlorite(?). Locally, pyrite, calcite, and chlorite also replace selected clasts. In outcrop, the breccia has a sharp, planar footwall contact with country rock; however, where exposed by trenching, the hanging-wall contact is an irregular, rough surface caused by a web-like network of quartz matrix surrounding cavities from which breccia clasts and calcite have been removed. Locally coating the irregular surface is a 40-cm-thick zone of crumbly black manganese oxide, coating rare Johannsenite which has been observed locally at surface, but not in drill hole.

UNION VEIN

The Union vein is a composite of individual veins that are sinuous, commonly open-growth, and generally less than 10 cm wide (Queen, 1988). The vein, principal target of most drilling on the Shumagin property, is developed over an approximately 3-m-wide zone in the hanging-wall tuff of the Aquila-Shumagin Fault Zone. Within individual veins, open vugs are common and irregular and alternating layers of quartz and green chlorite are bounded internally by inward-penetrating quartz crystals as much as 2 cm long. Gray, finely crystalline galena and pale-yellow sphalerite form clots within chlorite layers that are generally aligned parallel to the vein contacts and are as much as 3 mm long. Pyrite is disseminated in chlorite; microscopic native gold is present with the galena and sphalerite.

The attitude of the vein approximates that of the fault system, but both strike and dip of the Union vein vary slightly, such that the vein locally intersects and crosscuts the clast-supported fault breccia. The Union vein, on the basis of surface exposure and drill hole intercepts, is only about 370 m long, and does not appear to extend the entire length of the Aquila-Shumagin Fault Zone (fig. B2).

Parallel to the Union vein, though as far as 6 m away from it, are sparsely distributed subsidiary quartz veins of similar character, but lesser width. These veins do not constitute ore in and of themselves, but where proximal to the Union vein, these veins can extend the width of the ore zone. The Union vein contains the highest gold concentrations at the Shumagin property, and it essentially constitutes the Shumagin gold deposit.

QUARTZ BRECCIA VEIN

The matrix-supported quartz breccia vein is largely composed of a matrix of white quartz that constitutes at least 30 percent and commonly as much as 70 percent of the vein. The remainder of the breccia vein consists of angular clasts of crystal-lithic tuff, andesite, finely crystalline gray silica, and sulfide-bearing Union vein fragments. Clasts derived from the Union vein are most abundant in the breccia adjacent to areas of the Union Vein in the wall rock, suggesting that clasts did not move significantly from their original pre-breccia positions. The quartz breccia vein appears restricted to the Aquila-Shumagin Fault Zone, where it transects the clast-supported fault breccia and generally constitutes the largest volume of material between the fault boundaries. It pinches and swells both vertically and horizontally, but where present, forms the most persistent outcrops of any unit on the Shumagin property. Like the clast-supported fault breccia, the breccia vein in outcrop locally has an irregular surface with cavities that contain calcite and manganese oxide.

The quartz breccia vein contains rare 1-mm-long crystals of galena and sphalerite that are entrained along the terminal edges of quartz crystals in individual quartz growth zones within the breccia matrix. The sulfides contain only traces of gold, however, and the quartz breccia vein forms ore only in areas where it contains clasts derived from the Union vein. In addition, rare 3-mm-thick rims of arsenopyrite occur on andesite clasts within the breccia near the footwall of the Aquila-Shumagin Fault Zone.

GREENBAUM AND LUCKY FRIDAY VEINS

The Greenbaum vein (Queen, 1988) strikes N. 55° E. and dips 83° SE. in a single outcrop about 24 m northwest of the Aquila-Shumagin Fault Zone. Exposed again only in the underlying Lucky Friday adit, and in a single drill hole, its strike length is unknown, but the vein does extend at least 80 m down dip. The 1-m-wide Greenbaum vein is composed mostly of finely crystalline "cherty"-appearing gray quartz with small amounts of more coarsely crystalline vuggy quartz. Cross-cutting relationships are not exposed; minor gold is reported to be present in it, associated with pyrite and marcasite (Queen, 1988).

The Lucky Friday vein strikes about N. 50° E. and dips 70° NW. Exposed at the surface and in the Lucky Friday crosscut, the 1-m-wide vein extends at least 40 m along strike and 35 m down dip. The Lucky Friday is a breccia vein containing clasts of andesite and a matrix of white quartz. Minor chlorite and gold are reported (Queen, 1988). Although cross-cutting relationships were not observed, the breccia character of the vein suggests that it might be equivalent to the matrix-supported quartz breccia vein.

VUGGY WATERCOURSE AND CARBONATE VEIN SYSTEMS

The vuggy watercourse vein system is characterized by open cavities lined with iron-oxide-stained crystals of quartz. The veins are white, locally include clasts derived from the Union vein, and cut the matrix-supported quartz breccia vein. Rare sphalerite and galena are present on quartz in vugs; sparse entrained galena and sphalerite crystals less than 1 mm in diameter border edges of quartz crystals in areas where vugs are not present. No gold is known to occur in this vein type. Except for the prevalence of open cavities, the vuggy watercourse veins are similar in character to the matrix-supported quartz breccia vein.

Carbonate (calcite) veins appear to cut all other veins at the Shumagin deposit (L.D. Queen, personal commun., 1988).

ALTERATION AND CHEMISTRY

Wall-rock alteration, based strictly on megascopic examination, consists of strong argillization extending as much as 45 m or more from the Shumagin deposit and quartz-sericite-pyrite alteration adjacent to the Union and matrix-supported quartz breccia veins. Although adularia has not been observed at the Shumagin deposit, its presence is strongly suspected. Adularia is common in the Alaska-Apollo vein (Becker, 1898, p. 84), a nearby companion system to the Shumagin system. Preliminary interpretation of geochemical data from a drill-hole through the Shumagin system indicates that the assemblage gold, silver, tellurium, lead, and zinc is associated with ore formation (White and Queen, 1989, p. 9). The data from the drill-hole shows elevated arsenic and mercury concentrations in the wall rocks and White and Queen (1989, p. 9) suggest this indicates "*** a broad aureole extending outward from the Union vein for at least 75 m." Copper is primarily concentrated in the quartz breccia vein and "*** may be a distinctive indicator element of the quartz breccia vein (White and Queen, 1989, p. 9)."

SUMMARY OF THE SHUMAGIN DEPOSIT DESCRIPTION

The Shumagin gold deposit is developed within the Aquila-Shumagin Fault Zone and is a fault-controlled, epithermal, volcanic-hosted quartz vein occurrence. The Aquila-Shumagin Fault Zone apparently developed in two stages, the first consisting of possible incipient movement recorded by the pyrite-rich cataclasite; the second and principal movement reflected in the development of the clast-supported fault breccia. Subsequent emplacement of veins included the gold-rich hydrothermal event recorded by the Union vein; the hydrothermal breccia event that produced the matrix-supported quartz breccia vein and deposited minor sulfides; minor gold-bearing events indicated by the Greenbaum and the Lucky Friday veins; a late event that produced the vuggy watercourse vein system and also deposited minor sulfides; and a carbonate-depositing event indicated by the cross-cutting carbonate vein system. The absence of enargite, and the presence of sericite alteration, presumed adularia, probable rhodonite, and chlorite suggest that the Shumagin deposit is an adularia-sericite type hydrothermal system as defined by Heald and others (1987).

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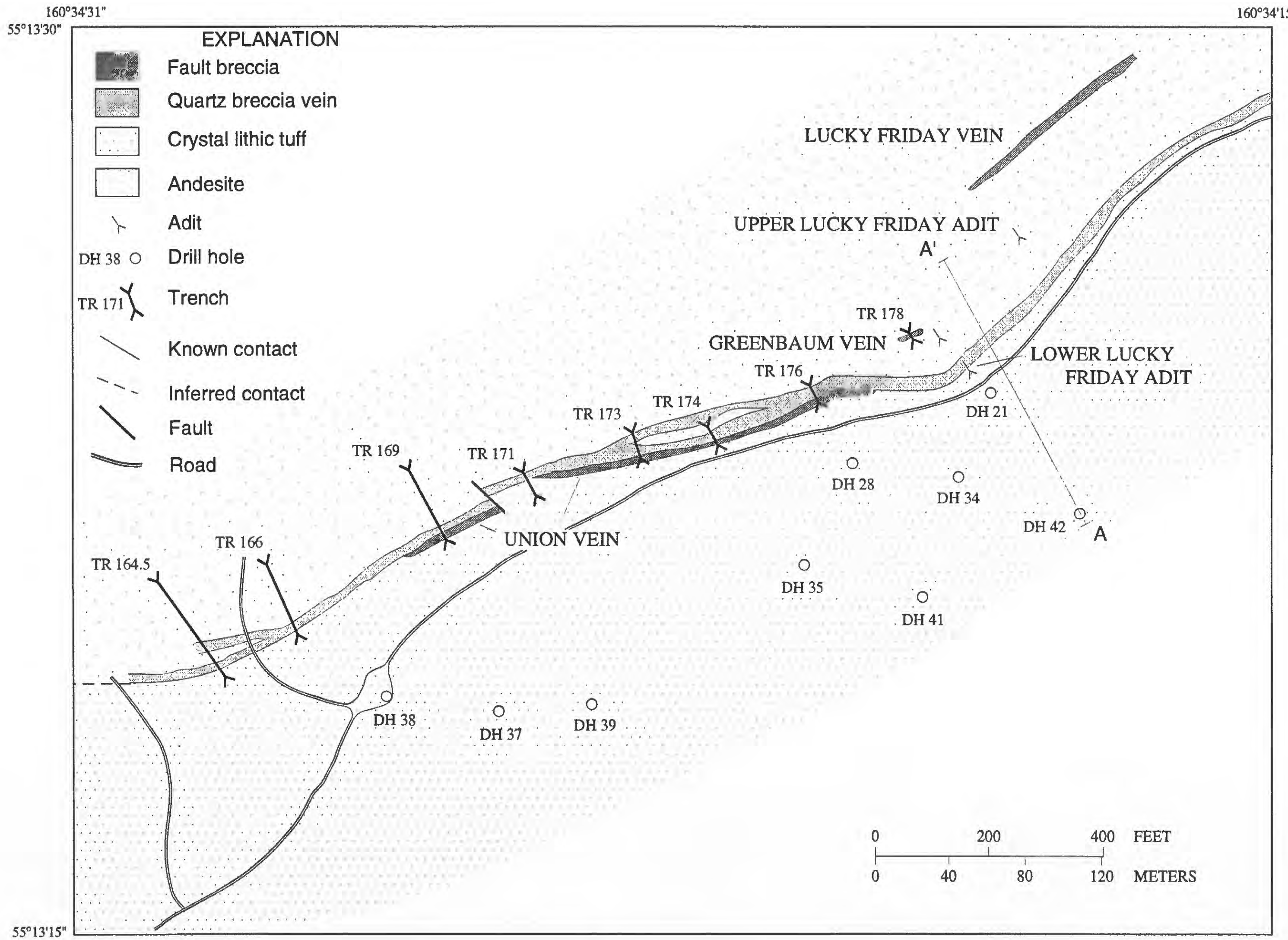

Figure B2. Geologic map of south half of Shumagin prospect showing Union, Greenbaum, and Lucky Friday veins and trace of Aquila-Shumagin Fault Zone marked by fault breccia and quartz breccia vein (from Queen, 1988). See figure B3 for cross section.

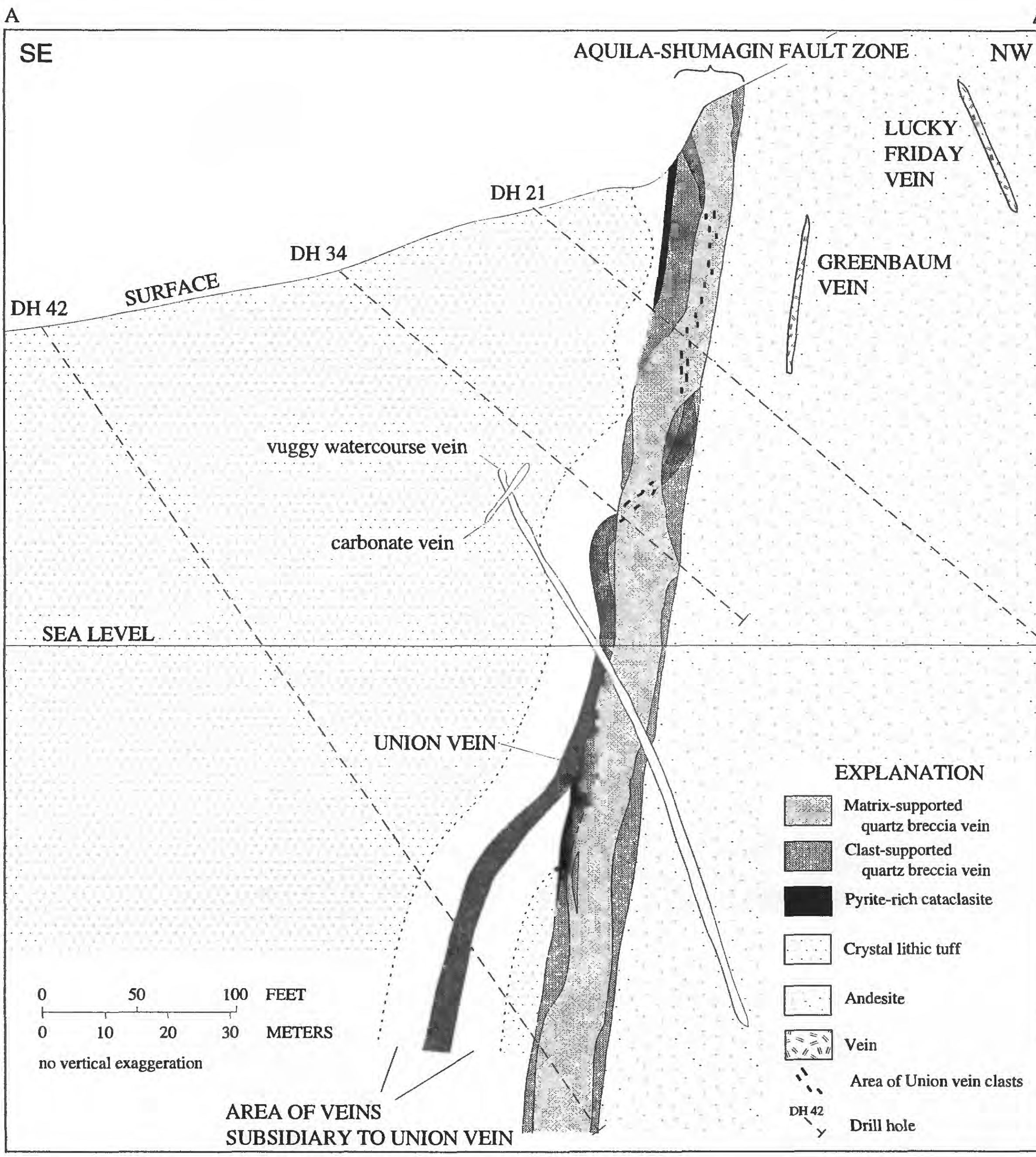

Figure B3. Generalized geology of cross section *A-A'*, looking southwest, Shumagin prospect. Drill hole 34 is projected 49 m to section and aligned with the footwall of Aquila-Shumagin Fault Zone. See figure B2 for location of cross section.

APPENDIX A

DEFINITION OF LEVELS OF MINERAL RESOURCE POTENTIAL AND CERTAINTY OF ASSESSMENT

LEVELS OF RESOURCE POTENTIAL

H **HIGH** mineral resource potential is assigned to areas where geologic, geochemical, and geophysical characteristics indicate a geologic environment favorable for resource occurrence, where interpretations of data indicate a high degree of likelihood for resource accumulation, where data support mineral-deposit models indicating presence of resources, and where evidence indicates that mineral concentration has taken place. Assignment of high resource potential to an area requires some positive knowledge that mineral-forming processes have been active in at least part of the area.

M **MODERATE** mineral resource potential is assigned to areas where geologic, geochemical, and geophysical characteristics indicate a geologic environment favorable for resource occurrence, where interpretations of data indicate a reasonable likelihood of resource accumulation, and (or) where an application of mineral-deposit models indicates favorable ground for the specified type(s) of deposits.

L **LOW** mineral resource potential is assigned to areas where geologic, geochemical and geophysical characteristics define a geologic environment in which the existence of resources is permissive. This broad category embraces areas with dispersed but insignificantly mineralized rock as well as areas with little or no indication of having been mineralized.

N **NO** mineral resource potential is a category reserved for a specific type of resource in a well-defined area.

U **UNKNOWN** mineral resource potential is assigned to areas where information is inadequate to assign a low, moderate, or high level of resource potential.

LEVELS OF CERTAINTY

A Available information is not adequate for determination of the level of mineral resource potential.
B Available information only suggests the level of mineral resource potential.
C Available information gives a good indication of the level of mineral resource potential.
D Available information clearly defines the level of mineral resource potential.

LEVEL OF RESOURCE POTENTIAL →

A	B	C	D
U/A	H/B HIGH POTENTIAL	H/C HIGH POTENTIAL	H/D HIGH POTENTIAL
UNKNOWN POTENTIAL	M/B MODERATE POTENTIAL	M/C MODERATE POTENTIAL	M/D MODERATE POTENTIAL
	L/B LOW POTENTIAL	L/C LOW POTENTIAL	L/D LOW POTENTIAL
			N/D NO POTENTIAL

LEVEL OF CERTAINTY →

Abstracted with minor modifications from: Taylor and Steven (1983), Taylor and others (1984), and Goudarzi (1984).

APPENDIX B

RESOURCE/RESERVE CLASSIFICATION

	IDENTIFIED RESOURCES			UNDISCOVERED RESOURCES	
	Demonstrated		Inferred	Probability Range	
	Measured	Indicated		Hypothetical	Speculative
ECONOMIC	Reserves		Inferred Reserves		
MARGINALLY ECONOMIC	Marginal Reserves		Inferred Marginal Reserves		
SUB-ECONOMIC	Demonstrated Subeconomic Resources		Inferred Subeconomic Resources		

Major elements of mineral resource classification, excluding reserve base and inferred reserve base. Modified from: U.S. Bureau of Mines and U.S. Geological Survey (1980, p. 5).