GEOLOGICAL SURVEY CIRCULAR 855

The Alaska Mineral Resource Assessment Program: Guide to Information about the Geology and Mineral Resources of the Ketchikan and Prince Rupert Quadrangles, Southeastern Alaska

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ABSTRACT

The Ketchikan and Prince Rupert 1-degree by 2-degree quadrangles, which encompass about 16,000 km² at the south tip of southeastern Alaska, have been investigated by integrated field and laboratory studies in the disciplines of geology, geochemistry, geophysics, and Landsat data interpretation to determine their mineral-resource potential. Mineral deposits in the study area have been mined or prospected intermittently since about 1900, and production of small tonnages of ores containing gold, silver, copper, lead, zinc, and tungsten has been recorded. Extensive exploration and development currently (1981) is underway at a molybdenum prospect about 65 km east of Ketchikan. Our mineral-resource assessment indicates that the area contains potentially significant amounts of those metallic commodities, as well as of molybdenum, iron, antimony, and barite. The results of these studies have been published in a folio of maps accompanied by descriptive texts, diagrams, tables, and pertinent references. The present report serves as a guide to these investigations, provides relevant background information, and integrates the component maps and reports. It also describes revisions to the geology based on studies completed since the folio was published and includes a list of specific and general references on the geology and mineral deposits of the study area.

INTRODUCTION

PURPOSE AND SCOPE

This report and a separately published folio of maps and accompanying tables are part of a series of U.S. Geological Survey publications released to provide public information on the mineral resources and mineral-resource potential of Alaska. This work is part of the Alaska Mineral Resource Assessment Program (AMRAP) and is intended to provide information both for long-range national minerals policy and for decisions by State, Federal, commercial, environmental, and Native interests concerning the future use of Alaskan lands and resources. In addition, AMRAP aims to increase geologic knowledge of the State and to provide guidance for mineral exploration.

Most basic data for the maps and tables in the Ketchikan-Prince Rupert folio were collected during 1975 and 1977, when an interdisciplinary team of earth scientists conducted the field and laboratory investigations necessary for a mineral-resource appraisal. The folio and this report describe the results of their individual investigations and the results of integrating those investigations for the resource assessment.

GEOGRAPHY AND ACCESS

The Ketchikan-Prince Rupert study area (fig. 1) comprises all but a small part of the Alaskan parts of the Ketchikan and Prince Rupert 1:250,000-scale 1-degree by 2-degree topographic

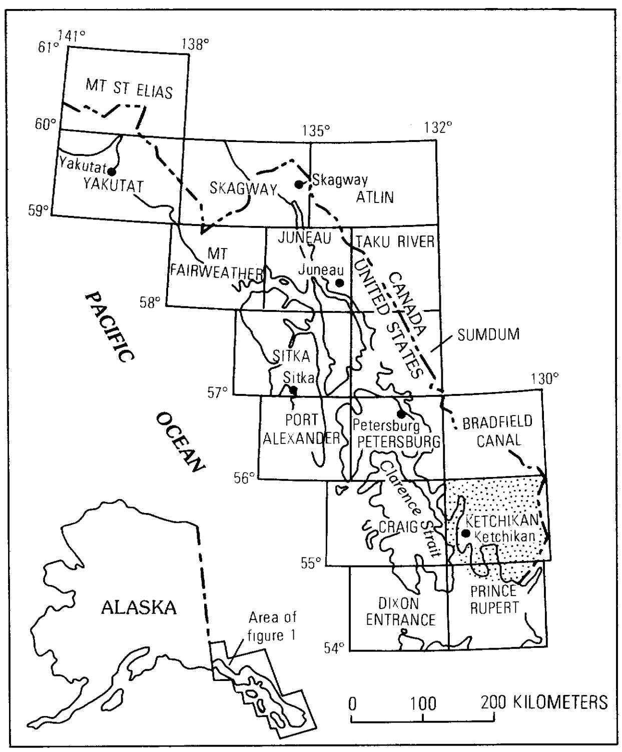

FIGURE 1.—Location of Ketchikan and Prince Rupert quadrangles, and area of this investigation (dot pattern).

quadrangles. The area covers about 16,000 km^2 at the south tip of the southeastern Alaska panhandle between lat 54°45′-56°00′ N. and long 130°00′-132°00′ W.; it is bounded on the east and south by the United States-Canadian (British Columbia) border, and on the west by Clarence Strait.

The study area, which lies mainly in the Pacific Coast Mountains physiographic province, is characterized by islands and peninsulas deeply dissected by a complex network of coastal and inland tidal waterways. The terrain ranges from heavily forested rolling uplands on the southwest to bare rugged mountains with active glaciers on the northeast. The average relief increases from about 1,000 m on the southwest to about 1,500 m on the northeast; the highest point within the study area is a 2,200-m-high nunatak that rises above perennial snowfields and glaciers near the northeast corner of the Ketchikan quadrangle.

Landforms in the study area are dominated by such glacially sculpted features as fiords and broad U-shaped valleys walled by sheer cliffs 300 m or more high. Most of the area was completely overridden by glacial ice that produced broad rounded ridge crests. In the northeast corner, however, the mountaintops locally stood above the highest level of the ice and include many sharp pinnacles and knife-edge ridges.

The prevailing maritime climate is characterized by heavy precipitation, probably equivalent to more than 250 cm of rainfall per year. Vegetation consists of dense, nearly impenetrable rain forest at low elevations and of brush, moss, and lichens at higher levels.

Except for scattered logging or mining camps and a few isolated cabins, nearly all the permanent population of the study area is concentrated in and near Ketchikan, Alaska, and adjacent parts of Gravina Island (population, approx 10,000 in 1970), in and near the Native village of Metlakatla (population, approx 1,000 in 1970), and at Hyder (population, approx 50 in 1970). The only town in the study area that can be reached by highway from Canada and the United States is Hyder, which is linked by way of Stewart, British Columbia, to western Canada, Alaska, and the Pacific Northwest. Other than to Hyder, access to and throughout the study area is by boat or aircraft.

PREVIOUS INVESTIGATIONS

Before starting the AMRAP systematic mineral appraisal of the Ketchikan and Prince Rupert quadrangles in 1975, the U.S. Geological Survey had conducted numerous reconnaissance and local investigations of the geology and mineral deposits in the study area, beginning around 1900 (fig. 2). The most significant results of these investigations were presented in the reports by Brooks (1902), Wright and Wright (1908), Smith (1915), Chapin (1918), Buddington (1929), Robinson and Twenhofel (1953), West and Benson (1955), Byers and Sainsbury (1956), Sainsbury (1957a, b), Berg (1972a, b, 1973), Smith (1973), Berg and others (1977a), and Smith (1977). In addition, information on the geology and mineral deposits in the study area is contained in the regional reports by Martin (1926), Buddington and Chapin (1929), Berg and Cobb (1967), and Berg and others (1972).

AMRAP AND SUBSEQUENT INVESTIGATIONS

AMRAP investigations in the Ketchikan and Prince Rupert quadrangles began in 1975, when an interdisciplinary team of earth scientists and technicians undertook systematic geologic mapping and geochemical, geophysical, Landsat, and mineral-deposit studies leading to a mineral-resource assessment of the study area (table 1). These collateral field and laboratory studies were completed early in 1978, when the results were combined and integrated into the mineral assessment that culminated AMRAP in the study area. In addition, certain topical and regional geologic and mineral-resource investigations begun by team members and guest scientists during the AMRAP study have been completed, and the results published in several reports. These reports describe the tectonic and structural setting of the study area and neighboring parts of Alaska and Canada (Berg and others, 1977b, 1978d); the petrology and geologic setting of the porphyry molybdenum deposit at Quartz Hill (Elliott and others, 1976; Hudson and others, 1977, 1978, 1979); metamorphosed lower(?) Paleozoic trondhjemite on the southern part of the Portland peninsula (Koch and others, 1977); and metallogenesis

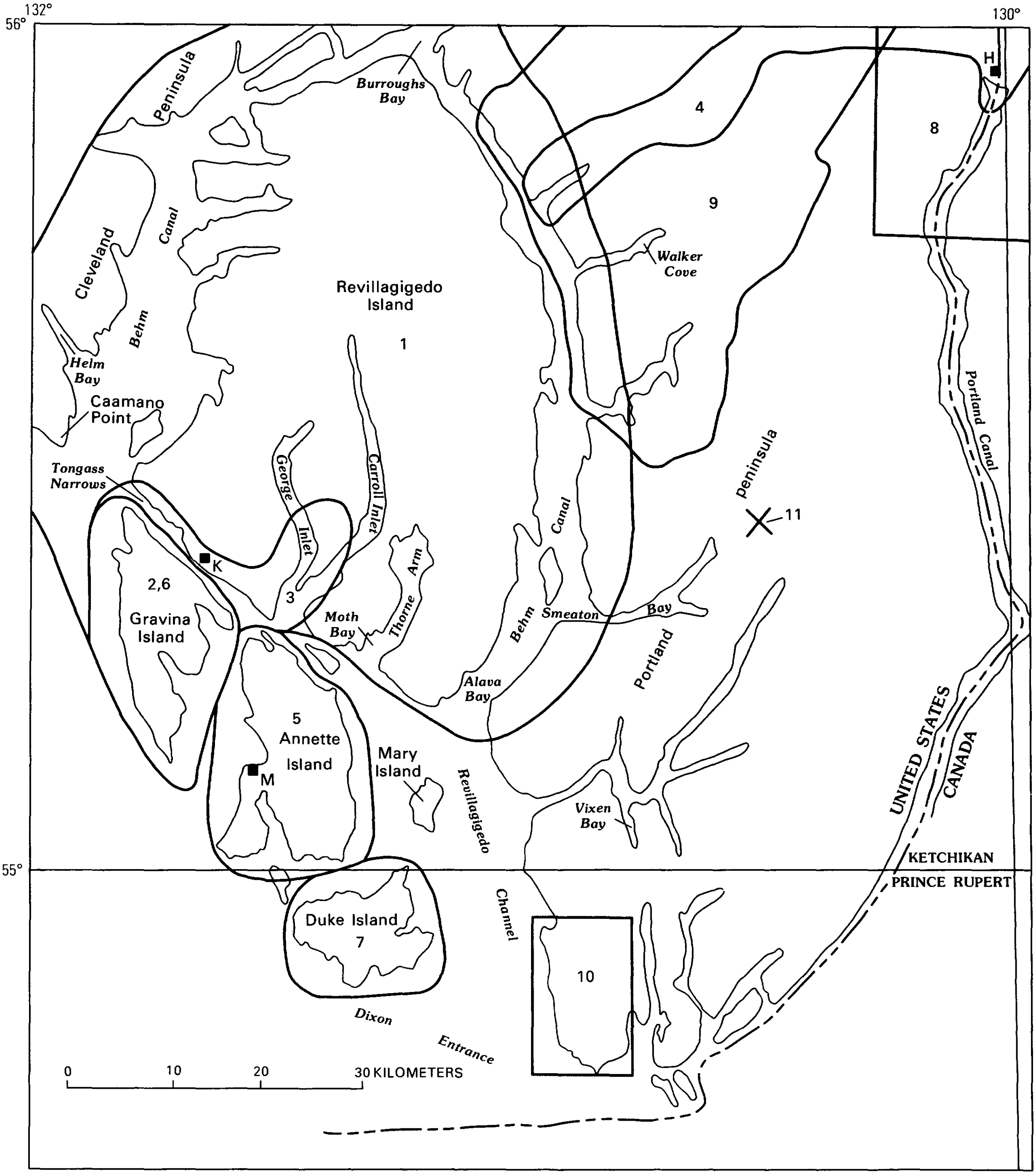

FIGURE 2.—Ketchikan and Prince Rupert quadrangles, showing areas described in selected geologic reports (see table 1): 1, Brooks (1902); 2, Smith (1915); 3, Chapin (1918); 4, Buddington (1929); 5, Berg (1972a); 6, Berg (1973); 7, Irvine (1974); 8, Smith (1977); 9, Berg and others (1977a); 10, Koch and others (1977); 11, Elliott and others (1976) and Hudson and others (1977, 1978, 1979). H, Hyder; K, Ketchikan; M, Metlakatla.

TABLE 1.—*Component maps and reports of the Ketchikan and Prince Rupert quadrangles mineral-resource assessment*

U.S. Geological Survey Open-File Report	*Subject*
72-17 (Barnes, 1972)[1]	Bouguer gravity maps
77-359 (U.S. Geological Survey, 1977)	Aeromagnetic-contour map
78-73-A (Berg and others, 1978b)	Geologic map
-B (Elliott and others, 1978)	Mineral-deposit map and table
-C (Koch and others, 1978a)	Geochemical-anomaly map: Cu
-D (Koch and others, 1978c)	Geochemical-anomaly map: Pb
-E (Koch and others, 1978h)	Geochemical-anomaly map: Zn
-F (Koch and others, 1978f)	Geochemical-anomaly map: Mo
-G (Koch and others, 1978b)	Geochemical-anomaly map: Au, Ag
-H (Koch and others, 1978d)	Geochemical-anomaly map: Cr
-I (Koch and others, 1978e)	Geochemical-anomaly map: Co
-J (Koch and others, 1978g)	Geochemical-anomaly map: Ni
-K (Steele and Albert, 1978)	Landsat interpretation map
-L (Griscom, 1981)	Aeromagnetic interpretation map
-M (Berg and others, 1978a)	Mineral-resource assessment map and tables
-N (Smith and Diggles, 1981)	Map and table of potassium-argon age determinations
78-156-A (Koch and Elliott, 1978b)	Analyses of rock geochemical samples, Ketchikan quadrangle
-B (Koch and Elliott, 1978a)	Analyses of rock and stream-sediment geochemical samples, Prince Rupert quadrangle
-C (Koch and Elliott, 1978c)	Analyses of stream-sediment geochemical samples, Ketchikan quadrangle

[1]Information from this report and from subsequent AMRAP-supported gravimetric studies were included in the resource assessment.

in the accreted terranes of southeastern Alaska (Berg, 1979, 1981).

ACKNOWLEDGMENTS

Throughout this report I use the term "we" in describing the scientific investigations and results of the AMRAP resource appraisal of the Ketchikan and Prince Rupert quadrangles. "We" includes my fellow members of the interdisciplinary team of energetic and talented earth scientists who successfully completed this difficult and complex investigation well within its tight budget and schedule, and I thank these colleagues for their collaboration, dedication, and professionalism. I am especially grateful to J. G. Smith, R. L. Elliott, R. D. Koch, R. B. Carten, M. F. Diggles, C. D. Holloway, R. J. Miller, R. J. Rudser, and B. D. Wiggins for their contributions to the geologic mapping; to J. G. Smith for isotopically (K-Ar) dating scores of rocks from throughout the study area; to R. D. Koch for leading the geochemical program with singular dedication, skill, and energy; to Andrew Griscom and D. F. Barnes for their aeromagnetic and gravimetric geophysical interpretations; to W. C. Steele and N. R. D. Albert for their pioneering Landsat data interpretation of the study area; and to W. D. Menzie and D. A. Singer for their advice and guidance on the culminating resource assessment.

I also acknowledge the special skills and contributions of my U.S. Geological Survey colleagues D. L. Jones, whose biostratigraphic studies led to new tectonic interpretations of the study area and neighboring regions; T. L. Hudson, who led our investigations at the Quartz Hill molybdenum prospect; J. G. Arth and T. W. Stern, for uranium-lead geochronology and rubidium-strontium isotope studies of the plutonic rocks; J. J. Criscione for his rubidium-strontium isotope studies of the metasedimentary rocks; and Fred Barker for rare-earth- and trace-element investigations of key volcanic units.

Finally, I thank the crew of the U.S. Geological Survey research vessel *Don J. Miller II* and G. A. ("Bud") Bodding, master of the charter vessel *Mytime*, for providing comfortable and efficient base camps for our field investigations; Kenneth C. Eichner, Barry Roberts, and Mike Salazar of Temsco Helicopters, Ketchikan, Alaska, for providing us with outstanding helicopter support; and Ed Todd and Dixie Jewett of Todd's Air Service, Ketchikan, for providing reliable fixed-

wing aircraft support, often under adverse weather conditions.

DESCRIPTIONS OF COMPONENT MAPS AND REPORTS OF THE KETCHIKAN AND PRINCE RUPERT QUADRANGLES AMRAP FOLIO AND OF SUBSEQUENT RELATED INVESTIGATIONS

The following sections of this report briefly describe the six interdisciplinary components of the AMRAP mineral-resource assessment of the Ketchikan and Prince Rupert quadrangles: (1) geology, (2) mineral-deposit site studies, (3) geochemistry, (4) geophysics, (5) earth-satellite (Landsat) data, and (6) resource analysis. The first five of these components were collateral field and laboratory research investigations that yielded extensive new data in several branches of earth science relating to mineral resources. The sixth component integrated these data into the culminating resource assessment, which identifies tracts of land favorable for the occurrence of specific types of mineral deposits and, where the data permit, predicts at different probabilities the number, size, and grade of those deposits. The following sections also summarize the results of our geologic and mineral-resource investigations in the study area since the AMRAP folio was published early in 1978.

GEOLOGY
(Open-File Report 78-73-A)

The geologic map of the Ketchikan and Prince Rupert quadrangles resulting from this investigation (Berg and others, 1978b) describes the rocks between the United States-Canadian border and Clarence Strait (fig. 1). We did not map the small areas of rocks on the west side of the strait because they are part of a separate investigation by the U.S. Geological Survey.

The rocks that we mapped include diverse rock types and range in age from Silurian or older to Quaternary. Our investigations show that they are most conveniently treated within three geographic areas, each underlain by a characteristic assemblage of rocks with distinctive lithologic, structural, or metamorphic features.

GRAVINA-ANNETTE-MARY-DUKE ISLANDS AREA

The Gravina-Annette-Mary-Duke Islands area includes the islands bounded by Clarence Strait, Dixon Entrance, Tongass Narrows, and Revillagigedo Channel and makes up about a sixth of the study area. The area contains the most diverse rock types and the most complete suite of stratified rocks in the Ketchikan and Prince Rupert quadrangles; it also includes the least metamorphosed and least deformed pre-Tertiary rocks in the map area. The bedded rocks range in age from Silurian or older to Late Jurassic or Cretaceous; the mapped intrusive rocks range in age from Silurian or older to Cretaceous. Plug-like gabbro plutons on northeastern Gravina Island (too small to show on the map), previously assigned a probable Cretaceous age (Berg, 1973), instead probably correlate with presumed Oligocene or Miocene gabbro near Ketchikan. Especially distinctive units include a Silurian or older stock of leucocratic trondhjemite, an Upper Triassic sequence of rhyolite, basalt, and sedimentary rocks, and a Cretaceous zoned ultramafic intrusive complex that contains spectacular zones of rhythmically layered dunite and peridotite (Irvine, 1974). Mineral occurrences include barite- and base- and precious-metal-bearing volcanogenic sulfide deposits in the Upper Triassic rocks; veins carrying gold, silver, and other metals in Upper Jurassic or Cretaceous andesitic metatuff; and stratiform titaniferous magnetite deposits in the zoned ultramafic rocks.

New age assignment of rocks on Annette and Gravina Islands.—The age of the Puppets Formation and its unnamed correlatives, and of an unnamed conformably overlying massive limestone and dolomite unit on Annette and Gravina Islands (fig. 3), is here revised from middle Paleozoic (Berg, 1973) to Late Triassic. This new assignment is based on the discovery (H. C. Berg, unpub. data, 1979) of Late Triassic marine fossils within the limestone unit in two localities on eastern Annette Island (fig. 3). The fossils were identified by Anita G. Harris of the U.S. Geological Survey as follows (written commun., 1980):

Field No. 79ABG091A: E. coast of Annette Island about 33.9 km SE. of Ketchikan. Small cove about 1.6 km S. of Kwain Bay in sec. 26, T. 78 S., R. 93 E. (lat 55°04′50″ N., long 131°21′20″ W.). Moderately massive to slaty very fine

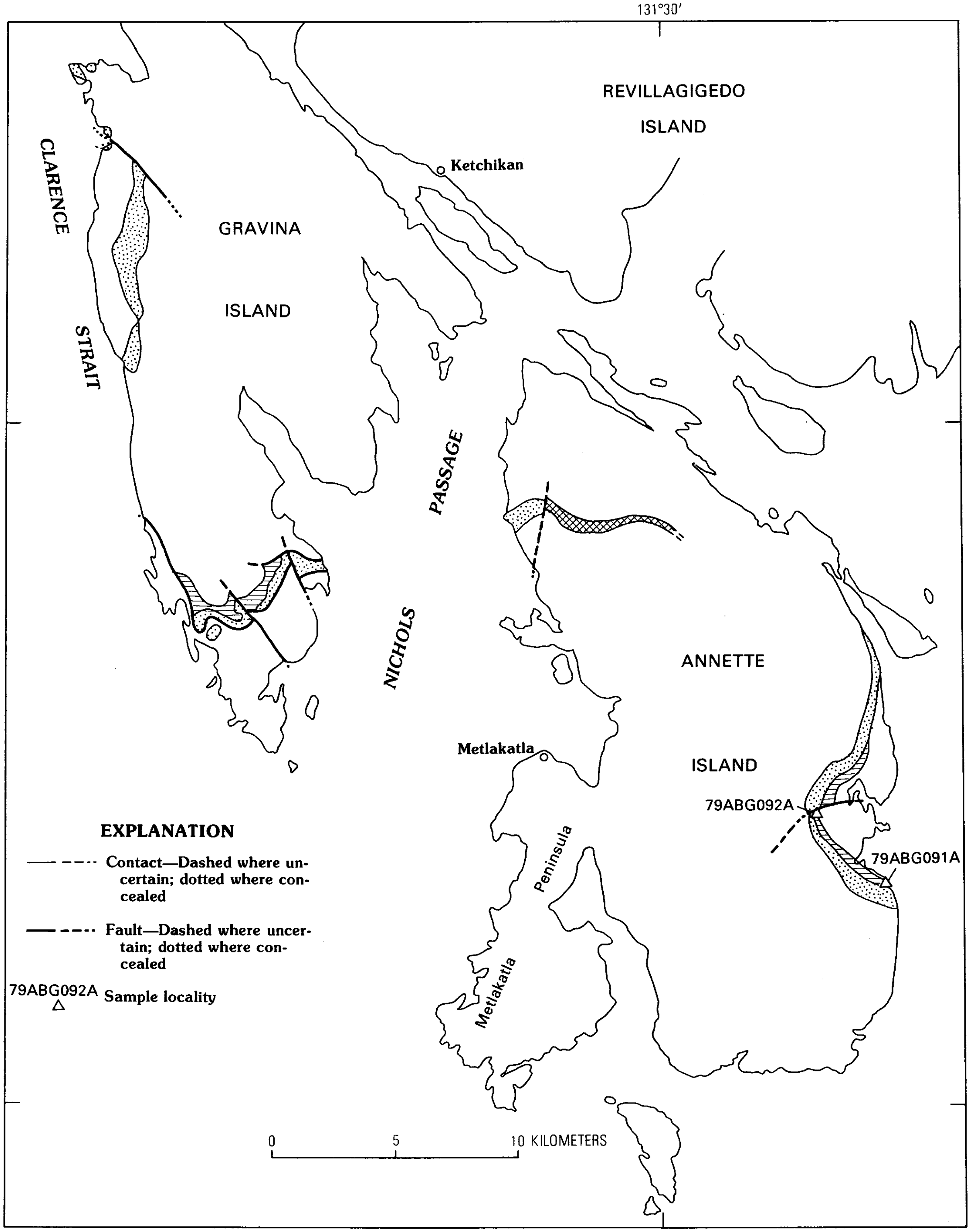

FIGURE 3.—Annette and Gravina Islands, showing distribution of Puppets Formation and its correlatives (dot pattern), unnamed conformably overlying massive limestone and dolomite unit (line pattern), an outcrop area where these units were not mapped separately (crosshatch pattern), and localities of samples collected in 1979 containing Upper Triassic fossils. Geology modified from Berg (1972a, 1973) and Berg and others (1978b).

grained crystalline metacarbonate containing sparse corals. Metacarbonate overlies rhyolite metatuff; exposed thickness of carbonate, about 30 m; 5.48 kg of metacarbonate was processed for conodonts (1.2 kg of plus-20-mesh insoluble residue) and yielded:

1 *Epigondollela* sp.

This genus is restricted to the Late Triassic.

Field No. 79ABG092A: East side of Annette Island about 29.4 km SE. of Ketchikan. Locality is a cave at outlet of lake at elev approx 70 m in sec. 16, T. 77 S., R. 92 E. (lat 550°6′35″ N., long 131°23′55″ W.). Massive to thin-bedded fine-grained dark-gray metacarbonate, locally containing sandy lenses and layers, some of which seem to consist of comminuted organic material. Carbonate is about 100 m thick, overlies rhyolite metatuff, and probably correlates with limestone at field No. 79ABG 091A; 4.9 kg of metacarbonate was processed (330 g of plus-20-mesh insoluble residue) and yielded:

1 *Epigondollela* sp.

Age: Late Triassic.

REVILLAGIGEDO ISLAND AND THE CLEVELAND PENINSULA

The central third of the map area is underlain by diverse plutonic rocks and by multiply deformed and metamorphosed strata that include small outcrop areas of: (1) very sparsely fossiliferous Permian and Middle Triassic sedimentary and volcanic rocks; and (2) slate, graywacke, and augite (hornblende) porphyry that we tentatively correlate with Jurassic or Cretaceous sedimentary and volcanic rocks of the Gravina Island Formation. By far the most abundant strata are metamorphosed and deformed bedded rocks whose premetamorphic age is unknown, and which we have subdivided into map units on the basis of lithology. These undated units include: (1) dark-gray phyllite and metagraywacke and dark-gray pyritic metapelite intercalated with subordinate rusty-weathering felsic and intermediate metatuff; (2) green basaltic pillow flows, breccia, and metatuff; (3) volumetrically minor but locally conspicuous metaconglomerate and marble; (4) paragneiss and amphibolite; and (5) a catchall unit of several metamorphic-rock types too limited in extent to show individually on the geologic map. We have assigned the undated units an age of late Paleozoic or Mesozoic because this assignment brackets the age of the oldest (Permian) fossiliferous strata known in this area, and of the oldest (Late Jurassic) isotopically dated plutonic rocks that intrude it. The youngest rocks known are basalt and andesite lava flows, breccia, and tuff that mainly coincide with or postdate Quaternary glaciation but may in part be as old as late Tertiary (5.5 m.y.). Key pre-Tertiary bedded units include: light-gray locally dolomitic marble that locally contains crinoid disks, conodonts, and brachiopods of Permian age (N. J. Silberling and B. R. Wardlaw, written commun., 1980); dark-gray pyritic metapelite and subordinate rusty-weathering felsic or intermediate metatuff, and basaltic pillow flows and breccia that are intercalated with crinoidal marble; dark-gray carbonaceous (graphitic) and locally concretionary limestone, mudstone, and siltstone locally containing Middle Triassic fossils (N. J. Silberling and B. R. Wardlaw, written commun., 1980); basaltic pillow flows, breccia, and tuff, and pelitic basalt-siltstone clast conglomerate that apparently are interbedded with Triassic strata; and metaconglomerate in the Carroll Inlet and Thorne Arm that contains conspicuous relict roundstones of quartz diorite or trondhjemite and quartzite(?) in a pelitic, tuffaceous, or calcareous matrix. Although we have not yet found fossils in the metaconglomerate, field relations suggest that at least some of it is gradational or intercalated with the crinoidal marble.

The oldest radiometrically (K-Ar) dated pluton in this area is a 140-m.y.-old (Late Jurassic) granodiorite stock near Moth Bay. The largest pluton is a radiometrically dated mid-Cretaceous foliated quartz diorite batholith on northern Revillagigedo Island and the adjacent Cleveland Peninsula. Other radiometrically dated plutons include a swarm of varyingly metamorphosed and deformed stocks, diapirs(?), dikes, and sills of garnet-bearing and locally plagioclase porphyritic granodiorite that give Late Cretaceous potassium-argon (Smith and others, 1979) and uranium-lead (T. W. Stern, oral commun., 1979) ages; and a composite Oligocene or Miocene gabbro to granodiorite intrusive complex near Ketchikan. Other intrusive rocks, mainly of known or assumed Cretaceous or older age, include stocks or sheets of aplite or alaskite, pluglike metadiorite bodies, a zoned ultramafic complex at Alava Bay, and several other small ultramafic bodies.

Regional structures in the pre-Tertiary strata include southwest-verging overturned to recumbent refolded isoclines cut by bedding-plane thrusts and blastomylonite zones, and by high-angle faults that postdate the thrusts. The rocks are regionally metamorphosed progressively from greenschist facies on the southwest to amphibolite facies on the northeast; this metamorphism, radiometrically dated as Cretaceous or older, locally is overprinted by contact metamorphism as intense as hornblende-hornfels facies. "Feather schist" or "garbenschiefer," a metamorphic rock distinguished by locally conspicuous feathery crystal aggregates of actinolite in a matrix of garnet-bearing silvery muscovite schist, is widespread on central and southwestern Revillagigedo Island; its distinctive mineralogy and texture suggest polymetamorphism of a bedded unit significantly different in original composition from the adjoining strata.

Mineral occurrences that have been productive or extensively explored include massive lead- and zinc-sulfide veins, auriferous quartz veins, and a stibnite vein in the undated metapelite and metatuff unit; and stratiform titaniferous magnetite deposits in the zoned ultramafic complex at Alava Bay.

PORTLAND PENINSULA

The east half of the Ketchikan-Prince Rupert study area is a peninsula, bounded by the (east) Behm Canal, Revillagigedo Channel, and Portland Canal, that we informally call the "Portland peninsula" (fig. 2). The youngest consolidated rocks known on the Portland peninsula correlate with the Tertiary or Quaternary basalt and andesite described on Revillagigedo Island. Except for small outcrop areas of these volcanic rocks, the peninsula is underlain mainly by the Coast Plutonic Complex of Brew and Ford (1978, 1981), which is bordered on the west by a fringe of enigmatic metamorphosed bedded and plutonic rocks and on the northeast by probable lower Mesozoic rocks that underlie only a small area at the northeast corner of the map area. Figure 4 shows revisions to the geology of the southern part of the Portland peninsula, based on investigations completed since the publication of Open-File Report 78-73-A.

The Coast Plutonic Complex is a heterogeneous group of massive and foliated plutonic rocks and amphibolite-facies regionally metamorphosed bedded rocks that form septa, screens, roof pendants, and xenoliths within or between the plutons. The premetamorphic age of the bedded rocks is unknown; we assign them a Paleozoic or Mesozoic age to bracket the ages (1) of possibly correlative Paleozoic or older isotopically dated nearly identical metamorphosed bedded rocks of the so-called Central Gneiss Complex (Hutchison, 1970) of the Coast Plutonic Complex in the neighboring part of British Columbia (Wanless and others, 1975; Armstrong and Runkle, 1979), and (2) of the oldest isotopically dated (Jurassic) plutons known to intrude them.

According to our radiometric-age data, the plutons were emplaced during Late Jurassic, Eocene, and Oligocene or Miocene time (Smith and others, 1979). Their structure ranges from gneissic to massive, and their composition from gabbro to granite; the most abundant rock type is foliated granodiorite. Not shown on the map are myriads of Oligocene or younger lamprophyre (Smith, 1973; Hudson and others, 1979) and quartz porphyry (Hudson and others, 1979) dikes. The metamorphic age of the foliated plutonic and bedded rocks is Eocene or older (Smith and others, 1979). Structural trends, isograds, and lithologic units strike northwest to north-south. In the Ketchikan-Prince Rupert study area, the westernmost unit of the Coast Plutonic Complex is a north-south-trending set of elongate foliated quartz diorite or tonalite plutons that beyond the project area coalesce into a remarkably persistent sill which marks the southwest limit of the Coast Plutonic Complex throughout southeastern Alaska (Brew and Morrell, 1979; Brew and Ford, 1981).

Adjoining the Coast Plutonic Complex on the west is a wedge-shaped outcrop belt of greenschist- to amphibolite-facies regionally metamorphosed bedded and intrusive rocks. The east limit of this belt is the west contact of the Coast Plutonic Complex, and the west limit is a northwest-trending linear fault zone that has been mapped from Harry Bay to beyond Kah Shakes Cove (fig. 4). The premetamorphic age of the bedded and intrusive rocks is largely unknown; a discordant potassium-argon determination on one

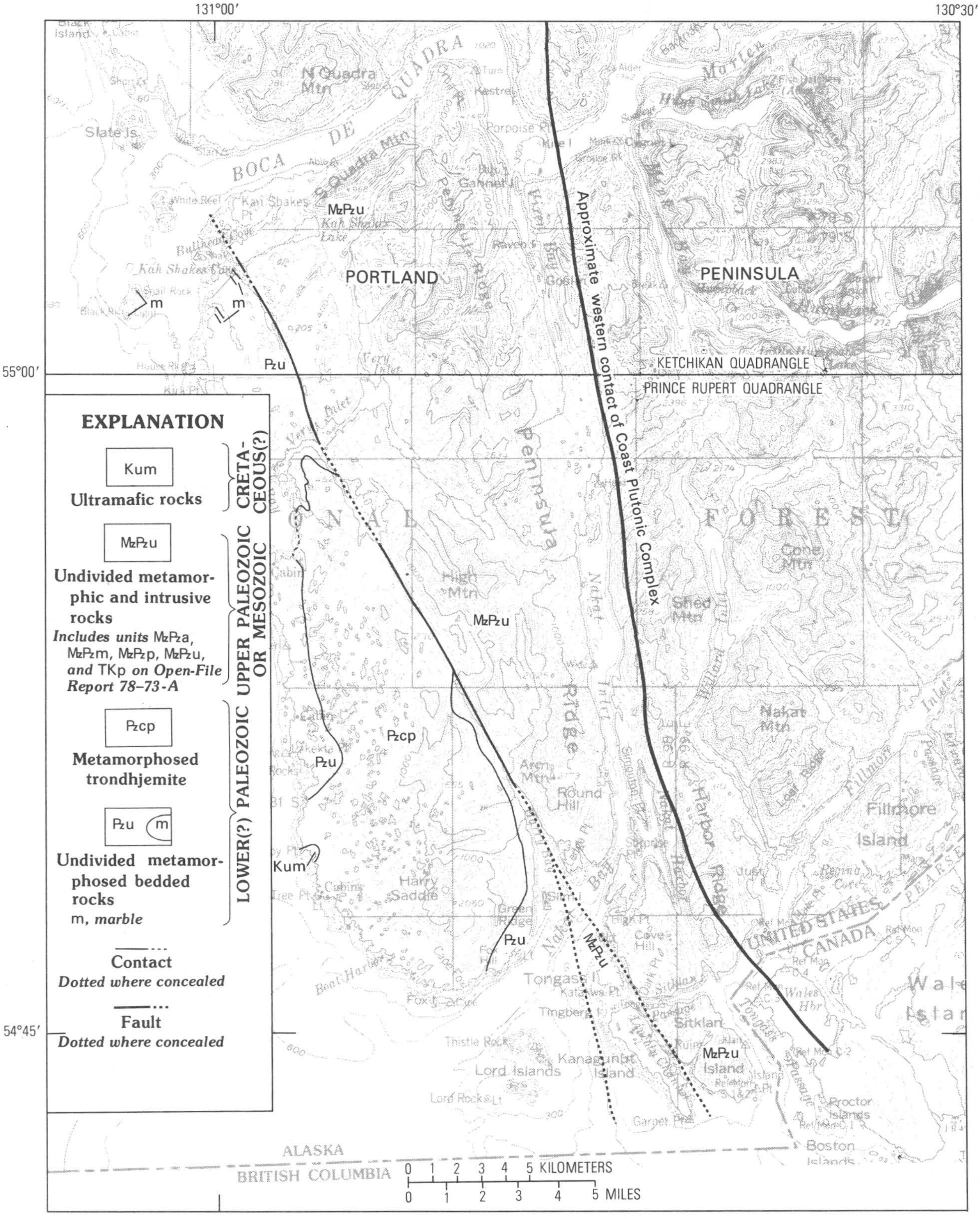

FIGURE 4.—Southwestern part of Portland peninsula, showing revisions based on geologic investigations completed since publication of Open-File Report 78-73-A. Base from U.S. Geological Survey, scale 1:250,000; Ketchikan and Prince Rupert, 1959.

pluton suggests that it was emplaced before or during Late Cretaceous time. Other potassium-argon age determinations suggest Cretaceous or Tertiary metamorphism for both the bedded and intrusive rocks. Very sparse objects, doubtfully identified as crinoid disks implying a late Paleozoic age (H. C. Berg and C. D. Holloway, unpub. data, 1976), occur in marble layers along Very Inlet, and most of the other strata are lithologically similar to the rocks on central and southwestern Revillagigedo Island, to which we assign a late Paleozoic or Mesozoic age. For these reasons, we also assign these rocks a late Paleozoic or Mesozoic age.

The most widespread unit southwest of the Harry Bay-Kah Shakes Cove fault zone is a metamorphosed trondhjemite stock that we correlate, on the basis of similar lithology and texture, with the Silurian or older Annette pluton on Annette Island (Koch and others, 1977). If this correlation is correct, the strata intruded by this pluton must be Silurian or older. Following this assumption, we assign these rocks an age of early(?) Paleozoic. However, most of the metamorphosed bedded rocks southwest of the fault are lithologically indistinguishable from those northeast of it. This observation suggests that: (1) nearly identical rock types of different age crop out on both sides of the fault, or (2) there has been at least local tectonic transport and mixing of possible younger Paleozoic or Mesozoic metamorphosed bedded rocks from northeast of the fault with the presumed lower Paleozoic country rocks intruded by the trondhjemite, or (3) both these interpretations. In any case, intense deformation and metamorphism, as well as poor exposures, prevented us from mapping any outcrop areas of these possibly younger rocks southwest of the fault.

About 30 km^2 of the northeasternmost corner of the Ketchikan-Prince Rupert study area is underlain by recrystallized Triassic or Jurassic volcanic, sedimentary, and plutonic rocks. These rocks, which were cataclastically deformed during Mesozoic or early Cenozoic time and then intruded and locally contact metamorphosed by Eocene plutons of the Coast Plutonic Complex, differ markedly in degree of deformation and metamorphism from the more intensely deformed and higher grade regionally metamorphosed rocks to the southwest in the Coast Plutonic Complex. We infer that the boundary between these two contrasting assemblages was a moderately northeast dipping thrust zone which subsequently was intruded and largely obliterated by the Eocene plutons (Berg and others, 1977a, p. 29).

The currently (1981) most commercially attractive mineral deposit on the Portland peninsula is the large porphyry molybdenum lode in an Oligocene granite porphyry at Quartz Hill (11, fig. 2). Other mineral deposits that have recently been explored include another porphyry molybdenum occurrence just across the mouth of Burroughs Bay from the Portland peninsula; gold, silver, and base-metal veins and disseminated deposits in the Triassic or Jurassic volcanic and intrusive rocks near Hyder; massive base-metal sulfide deposits in the metamorphosed bedded rocks southwest of Smeaton Bay and near Humpback Lake; and copper-, zinc-, and silver-bearing sulfide veins and disseminations in paragneiss at Walker Cove.

POTASSIUM-ARGON AGE DETERMINATIONS

(Open-File Report 78-73-N)

By James G. Smith

This map and accompanying tables (Smith and Diggles, 1981) list all known potassium-argon age determinations on rocks and minerals from the Ketchikan-Prince Rupert study area as of mid-1980. Altogether, more than 130 determinations have been made, of which about 50 were previously unpublished; about 80 of the determinations were reported previously, most without complete analytical data. Where possible, the unpublished analytical data and sample locations have been supplied. We especially thank M. A. Lanphere of the U.S. Geological Survey for furnishing analytical data for samples from Annette and Duke Islands.

In 1976 the International Union of Geological Sciences' Subcommission on Geo- and Cosmochronology recommended adopting a new set of abundance and decay constants (Steiger and Jäger, 1977). Since then, most laboratories have adopted the new constants. For our report, we recalculated all ages using the new constants; therefore, radiometric ages reported more than a few years ago may differ by a few percent from those given in Open-File Report 78-73-N.

The potassium-argon age determinations in our report, as well as the uranium-lead age determinations on zircons by T. W. Stern (Smith and others, 1979), indicate at least three episodes of metamorphism and seven episodes of igneous intrusion in the study area, extending in time from the Silurian through the Miocene. Owing to these multiple episodes of metamorphism and igneous intrusion, most of the potassium-argon age determinations on mineral pairs are discordant and must be interpreted with caution.

The oldest radiometrically dated rocks in the study area are from the Annette pluton (Berg, 1972a), which has yielded a potassium-argon age of 424 m.y. on hornblende and a uranium-lead (zircon) age of 375 m.y. (J. G. Arth, written commun., 1978). Allowing for analytical uncertainty, this trondhjemite stock probably was emplaced during Silurian time. The difference in apparent radiometric ages is within the limits of analytical precision for the two methods and probably can be accounted for by locally moderate shearing and recrystallization of the pluton (J. G. Arth, written commun., 1978).

Zoned ultramafic complexes yielding Cretaceous potassium-argon ages occur on and near Duke Island and at Alava Bay. These determinations mostly fall between 99.0 and 135 m.y. Apparent ages younger than 115 m.y. east of Revillagigedo Channel are discordant and, therefore, assumed to be partially reset.

Before our radiometric-dating studies, all the plutonic rocks on Revillagigedo Island and the Portland peninsula, and in adjacent areas to the south in Canada, were considered to be part of a single poorly documented Late Triassic to Late Cretaceous orogeny (Buddington and Chapin, 1929). Our studies show, instead, that plutonism occurred in several separate pulses, some more widespread and intense than others. The oldest dated pluton in this part of the study area is the Texas Creek Granodiorite, which was emplaced about 205 m.y. ago and consequently is assigned a Late Triassic or Early Jurassic age (Berg and others, 1977a). No other plutons are known on Revillagigedo Island or the Portland peninsula that are so old, although the subsequent intense metamorphic and plutonic events could have completely reset the radiometric clocks of older plutons to make them radiometrically indistinguishable from younger intrusive rocks.

Jurassic (140 m.y. old) quartz diorite and granodiorite intrude migmatite and gneiss on the Portland peninsula and lower grade metasedimentary and metavolcanic rocks on southern Revillagigedo Island. Heating by subsequent metamorphic-plutonic events was great enough to reset the potassium-argon clocks in these rocks, and only the uranium-lead clocks in zircons still record this event (Smith and others, 1979).

During Cretaceous or earlier time, the bedded rocks on northern Revillagigedo Island and on the neighboring Cleveland Peninsula were regionally metamorphosed. Then, about 90 m.y. ago, they were intruded by a batholith of quartz diorite and by numerous smaller plutons of garnet-bearing and plagioclase porphyritic granodiorite, all of which are more or less foliated and recrystallized. Plutons of this age have not yet been identified east of the (east) Behm Canal and of the topographic low that marks its extension through Vixen Bay and Nakat Inlet.

A suite of coalescing Eocene quartz monzonite to granodiorite batholiths intruded the eastern Portland peninsula about 52 to 42 m.y. ago. Plutons in this age range are nearly all confined to that part of the study area, although a few are recognized elsewhere on the Portland peninsula. However, no plutons of this suite have been recognized on Revillagigedo Island, the Cleveland Peninsula, or the Portland peninsula west of Vixen Bay and Nakat Inlet.

Emplacement of the Eocene plutons was accompanied by a resetting of potassium-argon clocks throughout the Coast Plutonic Complex that has been attributed to widespread heating of enigmatic origin (Smith and others, 1979) or to regional uplift and cooling (Hutchison, 1970).

During Oligocene and Miocene time, 31 to 19 m.y. ago, a suite of widely scattered and volumetrically small epizonal plutons was emplaced; this suite ranges in composition from gabbro and syenodiorite to granite porphyry. The molybdenum deposits at Quartz Hill and Burroughs Bay are associated with the granite plutons.

TECTONOSTRATIGRAPHIC TERRANES AND STRUCTURAL FRAMEWORK OF THE KETCHIKAN AND PRINCE RUPERT QUADRANGLES

Regional tectonic and biostratigraphic investigations completed since our preliminary geologic map was published in 1978 show that the pre-Cenozoic strata in the Ketchikan-Prince Rupert quadrangles area can be interpreted as constituting five fault-bounded assemblages, each characterized by its own distinctive stratigraphy and tectonic history (Berg and others, 1977b), 1978d). Northeastward from Clarence Strait, these five tectonostratigraphic assemblages are known as the Annette subterrane (of the Alex-

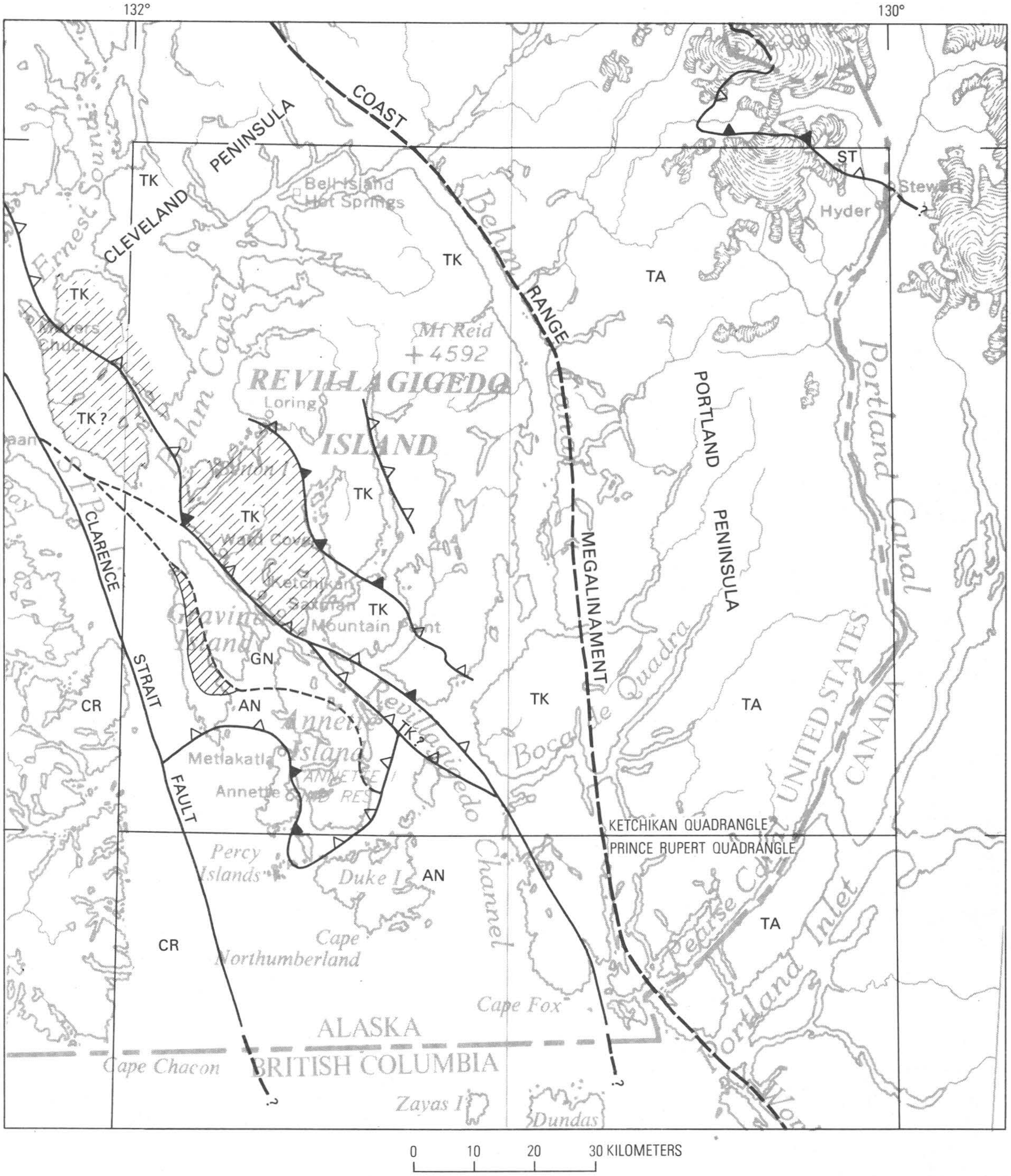

FIGURE 5.—Tectonostratigraphic terranes and structural elements in Ketchikan and Prince Rupert quadrangles. Base from National Atlas of the United States of America, 1970.

ander terrane), the Gravina-Nutzotin belt, the Taku terrane, the Tracy Arm terrane, and the Stikine terrane (fig. 5).

ANNETTE SUBTERRANE

The Annette subterrane, typified by pre-Jurassic strata on Annette and Gravina Islands, is a subdivision of the Alexander tectonostratigraphic terrane, which mainly lies west of Clarence Strait (Berg and others, 1978d). The subterrane is distinguished by a heterogeneous assemblage of pre-Silurian, Silurian, and Devonian intrusive, extrusive, clastic, and carbonate rocks on and near Annette Island, and by the absence of any known post-Middle Devonian Paleozoic strata. The youngest pre-Cenozoic stratigraphic unit assigned to the Annette subterrane is the Upper Triassic Chapin Peak Formation (Berg, 1973).

These rocks record several episodes of magmatic-arc and possibly rift related volcanism, sedimentation, and intrusion that began at least as long ago as early Paleozoic time. They also record a history of deformation and metamorphism that, depending on their age and location, range from penetrative multiple folding and polymetamorphism as intense as amphibolite and hornblende-hornfels facies, to relatively simple folding accompanied by slaty cleavage and only slight recrystallization.

The Annette subterrane is separated from the Craig subterrane of the Alexander terrane by the Clarence Strait fault, and from the Taku terrane by east-dipping mapped and inferred thrust faults and zones of blastomylonite. On Annette and Gravina Islands, its contact with the Gravina-Nutzotin belt is an unconformity locally cut by normal and reverse faults.

GRAVINA-NUTZOTIN BELT

The Gravina-Nutzotin belt comprises Late Jurassic or Early Cretaceous volcanic and sedimentary rocks, and presumed subvolcanic dioritic to ultramafic plutons. The assemblage is interpreted as the remnants of a collapsed late Mesozoic volcanic arc (Berg and others, 1972). The bedded rocks are regionally metamorphosed to prehnite-pumpellyite and greenschist facies, and are folded into southwest-verging locally refolded isoclines whose axial surfaces dip moderately northeast. On the southwest, the Gravina-Nutzotin belt is in faulted stratigraphic contact with the Annette subterrane. On the northeast, the extent and distribution of Gravina-Nutzotin belt rocks are not yet known. In places, the belt is separated from the Taku terrane by mapped and inferred northeast-dipping thrust faults and zones of blastomylonite; in other places, the Taku terrane contains undated pelite and tuff that may in part correlate with Jurassic or Cretaceous strata in the Gravina-Nutzotin belt.

TAKU TERRANE

The Taku terrane contains very sparsely fossiliferous late Paleozoic and Middle or Late Trias-

EXPLANATION

Tectonostratigraphic terrane—Queried where assumed

GN **Gravina-Nutzotin belt—Unpatterned, basement not exposed. Line pattern shows distribution of mapped (solid lines) and assumed (dashed lines) rocks of Gravina-Nutzotin belt overlying subjacent terranes. Extent of assumed rocks of Gravina-Nutzotin belt in Taku terrane is unknown**

Alexander terrane

CR **Craig subterrane**

AN **Annette subterrane**

TK **Taku terrane**

TA **Tracy Arm terrane**

ST **Stikine terrane**

Contact

Mapped high-angle fault—May coincide in strike with reverse or thrust fault

Inferred fault

Thrust fault—Sawteeth on upper plate. May coincide in strike with high-angle fault

Mapped thrust fault

Inferred thrust fault

? **Undefined boundary of terrane; queried where continuation is uncertain or speculative** sic volcanic and sedimentary rocks, as well as undated pelitic and tuffaceous rocks that in part may correlate with Jurassic or Cretaceous strata in the Gravina-Nutzotin belt. The stratigraphic key to the terrane is a thick sequence of late Paleozoic basaltic tuff and agglomerate that occurs in this terrane mainly north of the Ketchikan-Prince Rupert study area and that is not known in any of the other terranes. The stratigraphic base of the Taku terrane is not known; clasts of leucocratic quartz diorite or trondhjemite in metamorphosed roundstone conglomerate in Carroll Inlet and at Thorne Arm on Revillagigedo Island are lithologically similar to trondhjemite in the Silurian or older Annette pluton (Berg, 1972a), which may have been their source, but there is no stratigraphic evidence of pre-late Paleozoic crystalline basement beneath the presently mapped extent of the Taku terrane. Although we have not found fossils in the metaconglomerate unit, field relations suggest that at least some of it is intercalated with, or grades structurally downward into, crinoidal marble of late Paleozoic age (p. 12). If the premetamorphic age of the metaconglomerate also is late Paleozoic and the source of the clasts was the Annette pluton, then this unit may record structural juxtaposition (amalgamation) of the Annette (Alexander) and Taku terranes during late Paleozoic time.

The Taku terrane is intruded by myriad probable Late Cretaceous dikes, sills, and stocks, mainly of distinctive plagioclase porphyritic and garnet-bearing granodiorite; by a batholith of Cretaceous quartz diorite; and by diverse other plutons, ranging in age from Late Jurassic to Oligocene or Miocene and in composition from quartz monzonite to peridotite. The terrane is characterized by Late Cretaceous or older northeastward-increasing regional metamorphism from greenschist to amphibolite facies, locally overprinted by contact metamorphism as intense as hornblende-hornfels facies. Regional structures include northeast-dipping thrust faults and zones of blastomylonite cut by younger high-angle faults. The stratified rocks are complexly folded into southwest-verging overturned to recumbent locally refolded isoclines. Regionally the terrane may be a giant melange or megabreccia, consisting of dismembered blocks of relatively competent rocks surrounded by pelitic and tuffaceous phyllite and semischist. The terrane is bounded on the southwest by northeast-dipping thrusts and blastomylonite zones. In the Ketchikan-Prince Rupert study area, the northeast boundary of the Taku terrane is a line connecting the west contacts of a northwest- to north-south-trending series of elongate stocks of foliated quartz diorite (tonalite). Beyond the limits of the study area, these stocks apparently coalesce into a persistent sill that marks the southwest boundary of the Coast Plutonic Complex (Brew and Ford, 1981) and that probably was emplaced along a Mesozoic suture which corresponds to the contact between the Taku and Tracy Arm terranes (Berg and others, 1978d; Brew and Morrell, 1979). This boundary also is spatially related to the Coast Range megalineament (Brew and Ford, 1978), an enigmatic topographic, structural, and geophysical feature that locally coincides with the southwest edge of the Coast Plutonic Complex.

TRACY ARM TERRANE

The Tracy Arm terrane is a belt of high (sillimanite)-grade regionally metamorphosed bedded rocks that form roof pendants, screens, and xenoliths within the Coast Plutonic Complex. Correlative rocks in the neighboring parts of British Columbia are known as the Central Gneiss Complex (Hutchison, 1970). In and near the Ketchikan-Prince Rupert study area, this terrane consists of sequences of pelitic and semipelitic paragneiss and schist, minor marble and amphibolite, and very sparse ultramafic rocks. These rocks are much less abundant than the massive to gneissic plutons of the Coast Plutonic Complex. Radiometric dating of rocks in the study area yields Late Jurassic, Eocene, and Oligocene to Miocene emplacement ages for the plutons and an Eocene metamorphic age for the metapelite and amphibolite; however, the premetamorphic age of the stratified rocks in the Tracy Arm terrane is unknown. Radiometric dating of possibly correlative rocks in the Central Gneiss Complex near Prince Rupert in British Columbia suggests that at least some of these stratified rocks have a premetamorphic age of late Paleozoic (Armstrong and Runkle, 1979) and Precambrian or early Paleozoic (Wanless and others, 1975).

In the Ketchikan-Prince Rupert study area, the southwest limit of the Tracy Arm terrane and of the Coast Plutonic Complex that generally envelops it is the west contact of the series of elongate foliated quartz diorite (tonalite) plutons, discussed in the foregoing description of the Taku terrane. The northeast limit of the Tracy Arm terrane is inferred to be a northeast-dipping thrust zone that has been intruded and largely obliterated by Eocene plutons (Berg and others, 1977a, p. 29).

STIKINE TERRANE

Rocks assigned to the Stikine terrane crop out only in a 30-km^2 area in the northeast corner of the study area. The rocks consist of Late Triassic or Early Jurassic andesitic tuff and agglomerate, volcanic graywacke and argillite, and granodiorite that have been regionally metamorphosed to greenschist facies and then intruded and thermally metamorphosed by Eocene quartz monzonite and granodiorite. The Mesozoic rocks make up the southwesternmost fringe of a late Paleozoic and younger assemblage of marine and nonmarine volcanic, intrusive, and sedimentary rocks that crop out almost entirely in British Columbia and the Yukon Territory (Monger, 1977; Monger and Price, 1979). The Stikine terrane probably originated as a late Paleozoic volcanic arc; its key stratigraphic sequence (in British Columbia) is a thick pile of Lower and Middle Jurassic andesitic volcanic rocks that are unknown in any of the terranes to the west. In the Ketchikan-Prince Rupert study area, we interpret the southwest boundary of the Stikine terrane as a northeast-dipping thrust zone that has been mostly obliterated by the Eocene plutons.

MINES, PROSPECTS, AND MINERAL OCCURRENCES (Open-File Report 78-73-B)

The map and accompanying table (Elliott and others, 1978) briefly describe 174 metalliferous mines, prospects, and mineral (including barite) occurrences, as well as nine occurrences of nonmetallic minerals, publicly known in the Ketchikan-Prince Rupert study area when the report was published early in 1978. Since then, several private companies have conducted extensive mineral explorations in the area, but except for the porphyry molybdenum deposit at Quartz Hill (Randolph, 1979), results of these explorations have not been made public.

Our own investigations consisted of examining as many of the known mineral deposits as possible to determine their age, origin, classification, geologic setting, and extent, and of collecting and analyzing representative samples of ore minerals and host rocks. We did not enter or remap any abandoned underground mine workings because all of them are caved, flooded, or otherwise inaccessible or hazardous. There are no active mines in the study area.

Our report (Elliott and others, 1978) shows the locations of the known deposits plotted on a combined topographic and generalized geologic map, alphabetically lists the commodities contained in them, classifies them by form and extent of development, and briefly describes each with appropriate references. The geologic settings of the deposits and our interpretations of their age, origin, history, and resources were summarized in our report describing the mineral resources of the study area (Berg and others, 1978a).

METALLIFEROUS DEPOSITS

Between about 1900 and the early 1950's, the study area was the hub of what were formerly known as the Ketchikan and Hyder mining districts (Brooks, 1902; Wright and Wright, 1908; Berg and Cobb, 1967), which comprised numerous active small lode mines that shipped ores containing gold, silver, copper, lead, zinc, and tungsten (Byers and Sainsbury, 1956; Cobb, 1972a, b). The gold and (byproduct) silver mines were mainly on Gravina Island, at Helm Bay on the Cleveland Peninsula, along Tongass Narrows and at the Thorne Arm on Revillagigedo Island, and near Hyder, where some of the lodes were worked mainly for silver. In addition to gold and silver, the mines on Gravina Island also shipped small amounts of copper ore, and those near Hyder shipped or stockpiled a few hundred tons of ore or concentrates containing tungsten, copper, lead, and zinc. Mines that produced small amounts of zinc concentrates containing subordinate copper and lead were worked at George Inlet and Moth Bay (Robinson and Twenhofel, 1953).

In addition to the productive mines, several metalliferous deposits were more or less extensively explored by drilling or underground workings, but there is no record of any production from them (Berg and Cobb, 1967). These include deposits prospected for gold and silver on Annette Island; for copper at Walker Cove and near Smeaton Bay and Humpback Lake; for gold, silver, tungsten, and molybdenum near Hyder; for titaniferous magnetite on and near Duke Island; and for antimony near Caamano Point on the Cleveland Peninsula. Extensive drilling and other exploration is currently (1980) underway by private interests at a prospect locally known as Quartz Hill, about 65 km east of Ketchikan, where about 1.5 billion t of low-grade molybdenum ore reportedly have been blocked out (Randolph, 1979; Juneau *Empire*, March 25, 1981).

In addition to the mines and prospects, the study area contains hundreds of occurrences of metalliferous minerals that have at most been only cursorily prospected. Our report (Elliott and others, 1978) includes only occurrences that we could confirm from published reports, from U.S. Bureau of Mines claim maps (U.S. Bureau of Mines, 1974, 1977), or by our own field studies. We did not include unconfirmed reports of metallic minerals, nor did we consider anomalous amounts of metals in our rock or mineral geochemical samples as mineral occurrences, unless subsequent followup revealed metalliferous minerals at the geochemical-anomaly site.

Numerous such mineral occurrences containing traces to potentially significant amounts of gold, silver, copper, lead, zinc, and barite occur on Annette (Berg, 1972a; Hawley, 1975), Gravina, and southwestern Revillagigedo Islands; of gold, silver, copper, and molybdenum on the Portland peninsula; of gold, silver, tungsten, and molybdenum near Hyder; and traces of an unidentified radioactive mineral on southern Gravina Island (Williams, 1956).

NONMETALLIC MINERALS

Several occurrences of mica, feldspar, and garnet near the south tip of the Portland peninsula have been prospected for their value as industrial minerals, but none has proved to be of commercial size or grade (Sainsbury, 1957b).

A small amount of short-fiber chrysotile(?) asbestos occurs at Yellow Hill, south of Metlakatla on Annette Island.

GEOCHEMISTRY

(Open-File Reports 78-73-C through 78-73-J and 78-156-A through 78-156-C)

We conducted systematic geochemical investigations in the Ketchikan-Prince Rupert study area to identify areas of anomalous concentrations of metallic elements. We collected and analyzed two relatively easily obtainable types of geochemical samples: stream sediment and rocks. Our reports describe the results of these geochemical investigations in three ways: (1) the sample-locality maps and accompanying tables list complete analytical data for all samples (Koch and Elliott, 1978a, b, c); (2) the analytical data on all U.S. Geological Survey geochemical samples collected for resource assessment in the study area also are available on magnetic computer tape (Koch and others, 1978i); and (3) a set of eight maps shows the distribution of stream-sediment samples containing anomalous amounts of nine metals (Koch and others, 1978a, b, c, d, e, f, g, h). We selected these particular metals because the existing information on mineral deposits in the study area indicated that they would be useful as pathfinders either to additional mineral deposits or to geologic tracts with potential for mineral resources.

Analyses were performed by the U.S. Geological Survey for many as 30 elements by six-step semiquantitative emission spectrography (Grimes and Marranzino, 1968), and for gold, copper, lead, and zinc by atomic-absorption spectrophotometry (Ward and others, 1969). Samples collected in 1972 and 1973 were analyzed for mercury by a flameless atomic-absorption mercury-vapor-detection technique (Vaughn and McCarthy, 1964). Some analyses were not performed on all samples.

STREAM-SEDIMENT GEOCHEMICAL INVESTIGATIONS

We collected most of the 2,602 stream-sediment samples used in our resource assessment during 1975 through 1977; this total also includes samples collected during other U.S. Geological Survey geologic mapping and mineral-resource investigations in the study area between 1968 and 1977 (for example, Berg, 1972a, 1973; Elliott and others, 1976; Berg and others, 1977a; Smith, 1977). The total includes only "normal" samples collected specifically for resource assessment and does not include certain samples collected for quality control, or for special studies of sample-site density and for geochemical tests of different sample-size fractions (A. L. Clark, unpub. data, 1972-74).

We followed standard procedures in collecting and preparing the stream-sediment samples. We generally collected samples from the finest sediment freest of organic material in the active stream channel. In a few places where this procedure was not possible, we sampled bank or terrace deposits adjacent to the channel. At sites between sea level and timberline, we were not always able to collect a sample completely free of organic material, and a few samples have low to high organic content.

We obtained stream-sediment samples at shoreline sites above highest tide level wherever possible. Most of the study area is steep, and the sediment in the resulting swift streams is almost all detritus formed by mechanical, not chemical, weathering. Most stream-sediment samples are composed of material ranging in size from very fine sand to pebbles. Samples containing large amounts of silt- and clay-size material are rare and generally from areas of low elevation and gentle gradient. Samples were dried and sieved; the minus-80-mesh (minus 0.2 mm) fraction was pulverized, and a split analyzed.

GEOCHEMICAL DATA AND INTERPRETATION

Data from our stream-sediment geochemical program are presented in two reports (Koch and Elliott, 1978a, c), in which the sample locations are plotted on 1:125,000-scale topographic maps, accompanied by tables of all analytical values, statistical summaries, and brief discussions of analytical precision and of the bias and variability affecting interpretation. A second set of eight reports (Koch and others, 1978a, b, c, d, e, f, g, h) graphically presents data for selected elements to aid in mineral-resource assessment. These reports consist of 1:250,000-scale combined topographic and generalized geologic maps showing the distribution of gold, silver, copper, lead, zinc, molybdenum, chromium, cobalt, and nickel in stream-sediment samples in the study area. Because geochemical background levels vary for different rock types and different areas, and because of other variables inherent in geochemical sampling practice and conditions, each map (other than the one for gold and silver) suggests background, threshold, and anomalous levels for a particular element by grouping its analytical values into four ranges, each represented by a different symbol on the map. Although higher values may indicate a greater likelihood of bedrock mineralization in the relevant drainage basin, confidence levels are low for single-element "anomalies" and for high values that are not supported by neighboring values. Because only 2.2 percent of the stream-sediment samples analyzed for silver and only 0.8 percent of those analyzed for gold yielded measurable values, all such samples and their values are plotted on the map showing the distribution of gold and silver.

ROCK GEOCHEMICAL INVESTIGATIONS

To complement our regional reconnaissance of stream-sediment geochemistry, we collected representative grab samples of the main geologic units in most of the study area and analyzed them for the same metals as the stream-sediment samples. We also collected and analyzed grab samples of rocks containing visible metallic minerals (most commonly pyrite, magnetite, and hematite), and of hydrothermally altered rocks (mainly from bleached or iron-stained zones). The objectives of these investigations were: (1) to establish background levels of approximately two dozen "ore" and pathfinder metals in the main geologic units, as an aid in interpreting data from the stream-sediment samples collected from streams draining those units; (2) to determine whether parts of any rock units have intrinsic value as potentially economic mineral resources; (3) to detect potentially valuable metals not visible in hand specimens; and (4) to provide rough assays of samples containing visible metallic minerals. Whenever possible, we revisited sites from which we had collected rock geochemical samples containing very high values of potentially economic metals, to evaluate them as mineral occurrences (see section entitled "Mines, Prospects, and Mineral Occurrences").

We collected a total of 1,708 samples, most (about 85 percent) of which were apparently barren background samples of rock units. This total comprises all normal rock geochemical samples collected during U.S. Geological Survey geologic mapping and mineral-resource investigations in the study area from 1968 through 1977. Rock geochemical data from these investigations are presented in two reports (Koch and Elliott, 1978a, b) that plot the sample locations on 1:125,000-scale topographic maps, accompanied by tables of all analytical values, sample descriptions, and statistical summaries; describe the sampling procedures, sample preparation, and methods of analysis; and briefly discuss analytical precision and the bias and variability affecting interpretation. Analytical data for rock and ore samples collected in the study area by U.S. Bureau of Mines engineers for mineral appraisal of the Granite Fiords Wilderness study area (Berg and others, 1977a) are presented in a separate similar report (Koch and others, 1976).

INTERPRETATION OF LANDSAT IMAGERY
(Open-File Report 78-73-K)

To aid in the mineral-resource assessment of the Ketchikan and Prince Rupert quadrangles, we analyzed Landsat images of the study area for color anomalies, lineaments, circular and arcuate features, and regional fracture patterns that might be related to known mineral occurrences (Elliott and others, 1978) or to areas of mineral resource potential (Berg and others, 1978a). To complement this comparison of Landsat data with the distribution of known or potential mineral resources, we also correlated features identified on Landsat imagery with faults, contacts, foliation, and lithologic trends identified during geologic mapping (Berg and others, 1978b), with trends or deflections of aeromagnetic contours (U.S. Geological Survey, 1977), with interpreted aeromagnetic anomalies (Griscom, 1981), and with rock geochemical anomalies (Koch and Elliott, 1978a, b).

Our report (Steele and Albert, 1978) consists of two 1:250,000-scale combined topographic and generalized geologic maps overprinted with our interpreted Landsat data. One map highlights linear, arcuate, and circular features and iron-oxide-colored areas, and is accompanied by histograms of trends, cumulative lengths, and relative intensities of lineaments. The other map relates the Landsat data to geology, geophysics, and rock geochemistry, and is accompanied by indexes of the Landsat imagery used in our analyses of the Ketchikan and Prince Rupert quadrangles.

Preliminary results of our Landsat studies of the Ketchikan and Prince Rupert quadrangles and neighboring areas of southeastern Alaska indicate that intersections of east-northeast-trending (azimuth 059°-072°) and east-west-trending (azimuth 083°-094°) lineaments coincide with sites of significant or potentially significant porphyry molybdenum deposits (Hudson and others, 1979; R. L. Elliott, oral commun., 1980). The porphyry-molybdenum deposits in the study area occur in relatively small granite porphyry stocks and in quartz porphyry dikes of Oligocene or Miocene age (Hudson and others, 1979). Mapped porphyry-molybdenum-bearing plutons that coincide with these intersections are exposed at Quartz Hill and Burroughs Bay in the Ketchikan quadrangle (Berg and others, 1978b; Elliott and others, 1978). Molybdenite-bearing quartz veins at Walker Cove in the central part of the Ketchikan quadrangle also coincide with one such intersection, although these deposits are not known to be associated with an Oligocene granitic body. Porphyry molybdenum deposits in Oligocene(?) felsic plutons also coincide with the intersections of similarly oriented Landsat lineaments at Groundhog Basin in the Petersburg quadrangle (Twenhofel and others, 1946; J. R. LeCompte and W. C. Steele, unpub. data, 1979; D. A. Brew, oral commun., 1980), immediately northwest of the Ketchikan quadrangle.

The coincidence of molybdenum deposits with zones of intersecting Landsat lineaments in the Ketchikan and adjancent quadrangles (J. R. LeCompte and W. C. Steele, unpub. data, 1979) suggests a spatial relation that can be used for future molybdenum exploration in this region, even though their genetic relations remain uncertain.

GEOPHYSICS

AEROMAGNETIC INTERPRETATION
(Open-File Reports 77-359 and 78-73-L)

The 1:250,000-scale aeromagnetic-contour map used for our resource assessment of the Ketchikan-Prince Rupert study area was compiled from aeromagnetic surveys flown in 1972 (U.S. Geological Survey, 1976; Berg and others, 1977a) and 1976 (U.S. Geological Survey, 1979), and released as an Open-File Report (U.S. Geological Survey, 1977). This aeromagnetic-contour map was republished in Open-File Report 78-73-L (Griscom, 1981, pl. 1). The magnetic-field variations on such maps as these provide units containing varying amounts of magnetic minerals, commonly magnetite. Therefore, aeromagnetic maps are a most useful adjunct to geologic mapping, as well as for mineral-resource assessment.

An interpretive map (Griscom, 1981, pl. 2), drawn on a 1:250,000-scale combined topographic and generalized geologic base map, identifies various rock units in the Ketchikan-Prince Rupert study area that possess characteristic magnetic intensities, and enables the interpreter to extrapolate geologic information from known areas into covered or inaccessible regions. This interpretive map features prominent magnetic anomalies related to several zoned ultramafic plutons and to several volcanic and metamorphic units. It also shows several major magnetic boundaries marked by differences in the magnetic properties of the rocks on either side. The most conspicuous such boundaries coincide with mapped or inferred major faults that separate tectonostratigraphic terranes in the study area (fig. 5; Berg and others, 1978d). These boundaries lie along the Clarence Strait fault, which separates the Craig and Annette subterranes of the Alexander terrane; along and near an inferred northwest-trending thrust zone that separates the Gravina-Nutzotin belt from the Taku terrane; and along the (east) Behm Canal, which coincides approximately with the contact between the Taku and Tracy Arm terranes. The magnetic boundary along the (east) Behm Canal is the most prominent feature on the magnetic map; it represents the west limit of exposed magnetic rocks of the Coast Plutonic Complex, which are much more strongly magnetic than rocks of the terrane to the west, and also coincides with a major north-south-trending lineament that has been traced the length of southeastern Alaska (Andrew Griscom, in Berg and others, 1977a, p. 33-34; Brew and Ford, 1978).

BOUGUER GRAVITY MAPS AND INTERPRETATION

By David F. Barnes

A set of 16 Bouguer gravity maps at 1:250,000 scale of southeastern Alaska (Barnes, 1972) includes maps of the Ketchikan and Prince Rupert quadrangles. Although these maps were published before our AMRAP mineral-resource assessment of the study area, additional gravimetric studies were conducted under AMRAP, and the results of some of these studies were incorporated into the resource assessment.

The Bouguer gravity maps of the Ketchikan and Prince Rupert quadrangles were compiled from more than 550 shoreline gravity measurements, supplemented by about 70 measurements established by floatplane and helicopter to the interior, as well as a few hundred kilometers of marine gravity traverses (Dehlinger and others, 1966). The resulting maps show a regional decrease in Bouguer gravity from about +30 mGal in the southwest corner of the study area to less than -120 mGal in the northeast corner. The empirical relations of Woollard and Strange (1962) suggest that most of this decrease probably represents a regional increase in crustal thickness from less than 30 km at the coastal corner to more than 45 km near the United States-Canadian border. Thus the gravity maps in part reflect deeper features of the crust than do most of the other maps described in this report (table 1).

However, some local variations in this regional decrease may be more closely correlated with the relatively shallow features depicted on the geologic (Berg and others, 1978b) and aeromagnetic (Griscom, 1981) maps. Most of the decrease occurs in two steep-gradient steps that approximately coincide with recognized geologic and aeromagnetic lineaments. One of these steps is evident along Clarence Strait and Revillagigedo Channel, which are also the approximate west and east boundaries, respectively, of the Annette subterrane of the Alexander terrane (fig. 5). The second steep gradient was measured across the (east) Behm Canal, which follows the Coast Range megalineament (Brew and Ford, 1978) and approximately concides with the boundary between the Taku and Tracy Arm terranes. Both of these features in part probably represent significant increases in crustal thickness as well as lithologic changes.

Local anomalies associated with intrustions have greater economic importance. These local anomalies are best recognized where the gravity field flattens between these steep-gradient steps and thus are most evident in the broad zone of gentle gradient in the southwest corner of the study area. The largest of these anomalies is the 30-mGal high associated with the ultramafic body on Duke Island, where the data suggest a complex field and the desirability of more detailed surveys. Smaller gravity highs are associated with other mafic bodies near Humpy Point about 9 km northwest of Cape Fox, on the Percy Islands, and on the Cleveland Peninsula. More silicic intrusions are associated with gravity lows, as on Annette Island, George Inlet, Francis Cove, and Bell Island. The larger silicic intrusions, such as the Coast Plutonic Complex, also contribute to low gravity values, although their anomalies are difficult to distinguish from the regional changes associated with crustal thickening. The marine data suggest that other gravity lows may be caused by thick sequences of Holocene sediment underlying some of the fiords and passages.

MINERAL-RESOURCE ASSESSMENT (Open-File Report 78-73-M)

The map and accompanying tables (Berg and others, 1978a), which describe the metallic-mineral potential of the Ketchikan-Prince Rupert study area, consist of a 1:250,000-scale combined topographic and generalized geologic map showing 16 areas[1] favorable for metal resoures in eight specific types of mineral deposits and the commodities likely to be contained in them. The map also shows the locations of mines, prospects, and mineral occurrences known in the study area, and lists the commodities in each locality. We determined the mineral-deposit types and identified the favorable areas mainly from the type and distribution of known deposits and from geologic, geochemical, and geophysical evidence that favors the occurrence of mineral deposits (fig. 6).

The map is accompanied by a 48-page pamphlet that describes the favorable areas shown on the map, lists the criteria we used to select each area, and, where data permit, predicts at three confidence levels the number of undiscovered deposits of the specific types and the mineral resources that they contain. The pamphlet also describes the method we used for our resource assessment and includes three tables that essentially constitute the assessment. One table lists the known and inferred types of deposits in each area; summarizes the available data on geology, geochemistry, and geophysics and on production,

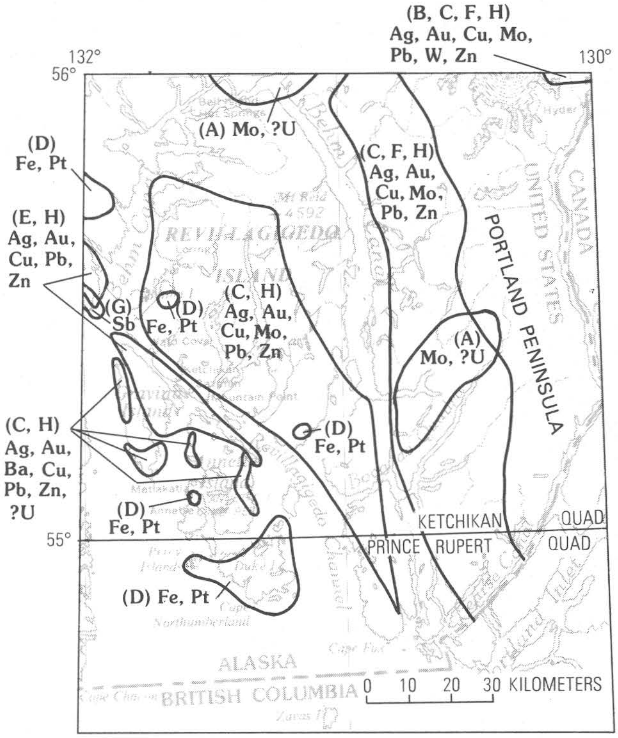

FIGURE 6.—Ketchikan-Prince Rupert study area, showing 17 areas favorable for occurrence of mineral resources and types of mineral deposits known or predicted in those areas (letters in parentheses followed by chemical symbols of relevant commodities). (A), porphyry molybdenum deposits in Oligocene or Miocene plutons; (B), porphyry copper deposits in Triassic or Jurassic plutons; (C), stratabound massive and disseminated volcanogenic base- and precious-metal deposits in diverse host rocks (see text); (D), stratiform titaniferous magnetite deposits in Cretaceous zoned ultramafic complexes; (E), disseminated lode-gold deposits in pyritic late Paleozoic or Mesozoic greenschist and phyllite; (F), copper-iron skarn deposits in Paleozoic or Mesozoic metacarbonate, and tungsten skarn deposits in Triassic or Jurassic plutonic and bedded rocks; (G), stibnite-bearing epithermal replacement veins in late Paleozoic or Mesozoic metacarbonate and phyllite; (H), auriferous and polymetallic quartz (-carbonate) veins in diverse host rocks. Chemical symbols: Ag, silver; Au, gold; Cu, copper; Mo, molybdenum; Pb, lead; W, tungsten, Zn, zinc, Fe, iron; Pt, platinum, Sb, antimony; Ba, barium; U, uranium. Base from National Atlas of the United States of America, 1970.

[1]A seventeenth area (at Yellow Hill on southwestern Annette Island) has been since Open-File Report 78-73-M was published.

resources, and the status of geologic knowledge; and provides the numerical resource estimates. The second table summarizes the criteria we used to define the areas of metalliferous mineral-resource potential. The third table shows the statistical grade-and-tonnage models we used to estimate the resources contained in four of the eight types of mineral deposits in the study area.

MINERAL-DEPOSIT TYPES, MINERAL-RESOURCE AREAS, AND METALLOGENESIS

The eight types of mineral deposits that we have identified or inferred in the study area occur in 16 partly overlapping areas characterized by several rock units containing potentially valuable metallic-mineral resources. These units, in turn, impart metallogenic significance to their host tectonostratigraphic terranes (Berg and others, 1978d), which then become the framework for interpreting regional metallogenesis, and for resource appraisal and mineral exploration (Berg, 1979, 1981). The eight types of mineral deposits are: (1) porphyry molybdenum deposits in Oligocene and possible Miocene granite porphyry stocks and peripheral swarms of quartz porphyry dikes in the Tracy Arm and Taku terranes (two areas); (2) porphyry copper deposits in the Triassic or Jurassic Texas Creek Granodiorite of the Stikine terrane (one area); (3) stratabound massive and disseminated volcanogenic base- and precious-metal deposits (eight areas): (a) in Paleozoic or Mesozoic paragneiss of the Tracy Arm terrane, (b) in late Paleozoic or Mesozoic metamorphosed sedimentary and volcanic rocks of the Taku terrane, (c) in Late Jurassic or Early Cretaceous metamorphosed andesitic volcanic and vocaniclastic rocks of the Gravina-Nutzotin belt, (d) with barite in Late Triassic felsic metavolcanic rocks of the Jurassic or older Hazelton(?) Group of the Stikine terrane; (4) stratiform titaniferous iron deposits (with traces of platinum-group metals) in Cretaceous zoned ultramafic complexes that intrude the Annette subterrane, the Taku terrane, and possibly the Gravina-Nutzotin belt (four areas); (5) disseminated lode-gold deposits in pyrite- and arsenopyrite-bearing greenschist and phyllite of the Taku(?) terrane and the Gravina-Nutzotin belt (two areas); (6) copper- and iron-bearing skarn deposits in Paleozoic or Mesozoic metacarbonate near the contacts of Cretaceous or Tertiary granodiorite and quartz diorite plutons in the Tracy Arm terrane, and tungsten skarn in the Hazelton(?) Group near the contacts of the Texas Creek Granodiorite and possibly of Eocene granodiorite and quartz monzonite plutons in the Stikine terrane; (7) a stibnite-bearing epithermal replacement vein in late Paleozoic or Mesozoic metacarbonate and phyllite of the Taku(?) terrane (one area); and (8) auriferous and polymetallic quartz fissure veins, stockworks, and breccia that occur in diverse host rocks throughout all the tectonostratigraphic terranes.

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