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Accomplishments During 1976

The United States Geological Survey in Alaska: Accomplishments During 1976

Kathleen M. Blean, Editor

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The United States Geological Survey in Alaska: Accomplishments during 1976

Kathleen M. Blean, Editor

ABSTRACT

United States Geological Survey projects in Alaska study a wide range of topics of economic and scientific interest. Work done in 1976 includes contributions to economic geology, regional geology, stratigraphy, environmental geology, engineering geology, hydrology, and marine geology. In addition, many reports and maps covering various aspects of the geology and mineral and water resources of the State were published.

SUMMARY OF IMPORTANT RESULTS

INTRODUCTION

Significant new scientific and economic geologic information has resulted from many topical and field investigations of the Geological Survey in Alaska during the past year. Discussions of the findings or, in some instances, narratives of the course of the investigations are grouped in eight subdivisions corresponding to the six major onshore geographic regions (fig. 1), the offshore projects, and projects that are statewide in scope. Locations of the study areas are shown in figure 2.

STATEWIDE PROJECTS

Preliminary geologic map of Alaska
By Helen M. Beikman

A new preliminary geologic map of Alaska at a scale of 1:1,000,000 (1 inch equals about 16 miles) has been completed. This preliminary map, which has been published in five parts (fig. 3), incorporates and summarizes all available geologic mapping. Each of the five geologic maps is accompanied by a second sheet on which correlation of map units is shown, together with a brief description of the map units, an index map showing principal sources of geologic data, and references to the source data.

These five preliminary geologic maps have been published as they were completed and together constitute an interim map from which a single multicolored geologic wall map of the entire State is being prepared. Each of these preliminary maps has been hand colored, color coordinated, and pieced together forming one map, which is on display on the wall of Room 223, Building 1, at the U.S. Geological Survey Center in Menlo Park.

REFERENCES CITED

Beikman, H. M., 1974a, Preliminary geologic map of the southwest quadrant of Alaska: U. S. Geol. Survey Misc. Field Studies Map MF-611, 2 sheets, scale 1:1,000,000.

——1974b, Preliminary geologic map of the southeast quadrant of Alaska: U.S. Geol. Survey Misc. Field Studies Map MF-612, 2 sheets, scale 1:1,000,000.

——1975a, Preliminary geologic map of southeastern Alaska: U.S. Geol. Survey Misc. Field Studies Map MF-673, 2 sheets, scale 1:1,000,000.

——1975b, Preliminary geologic map of the Alaska Peninsula and the Aleutian Islands: U.S. Geol. Survey Misc. Field Studies Map MF-674, 2 sheets, scale 1:1,000,000.

Beikman, H. M., and Lathram, E. H., 1976, Preliminary geologic map of northern Alaska: U.S. Geol. Survey Misc. Field Studies Map MF-789, 2 sheets, scale 1:1,000,000.

Mineral resources of Alaska
By Edward H. Cobb

Products of this office project during 1976 included open-filed summaries of references to mineral occurrence (other than organic fuels and construction materials) in 16 quadrangles (scale 1:250,000) in Alaska and an open-filed list of recent Federal and State reports on the geology and mineral resources of Alaska, indexed by quadrangle. Current bibliographic and mineral-resource reference material was made available to the Alaskan Branch information processing project for entry into computerized storage and retrieval banks.

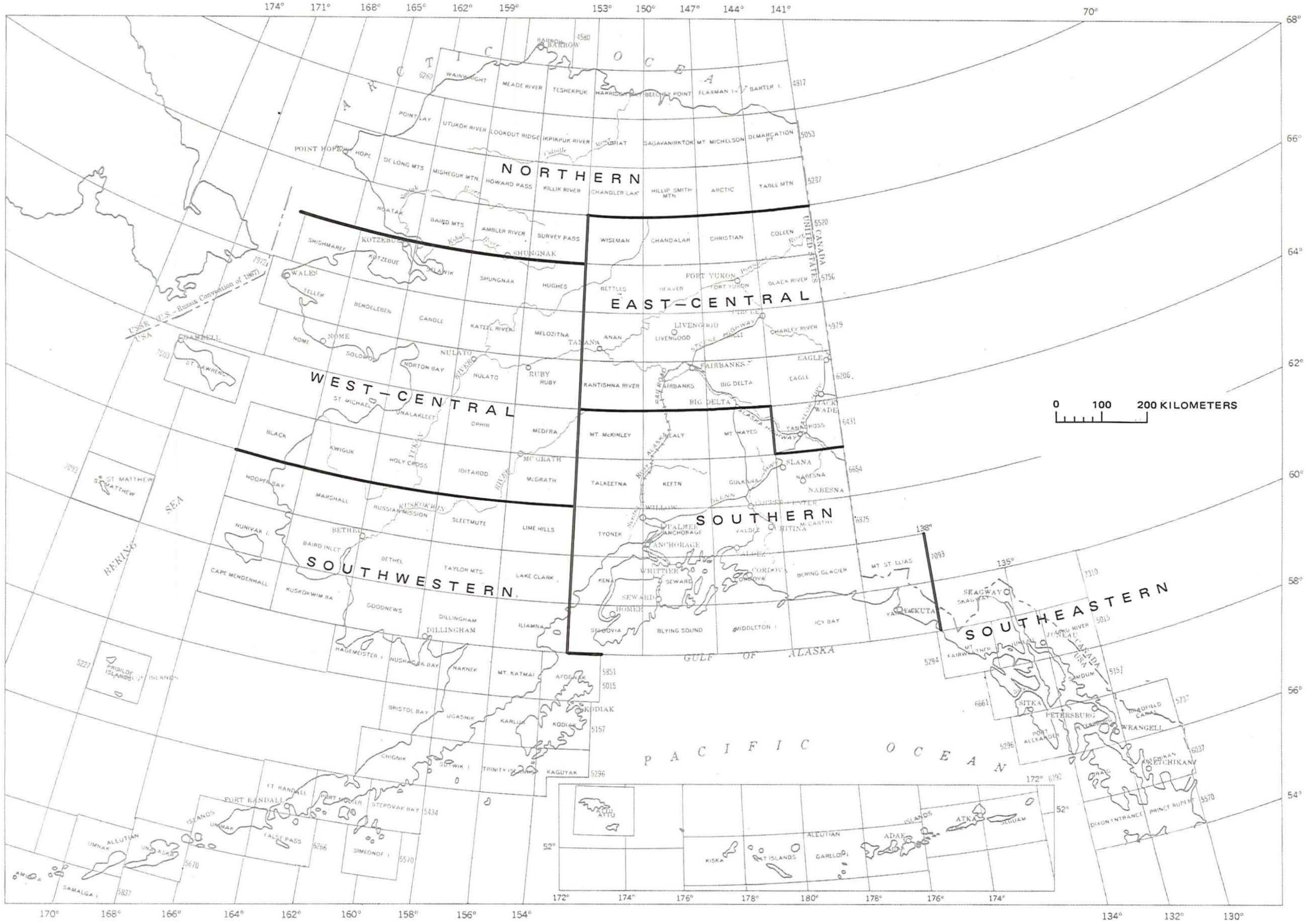

FIGURE 1.—Regions of Alaska used in this report.

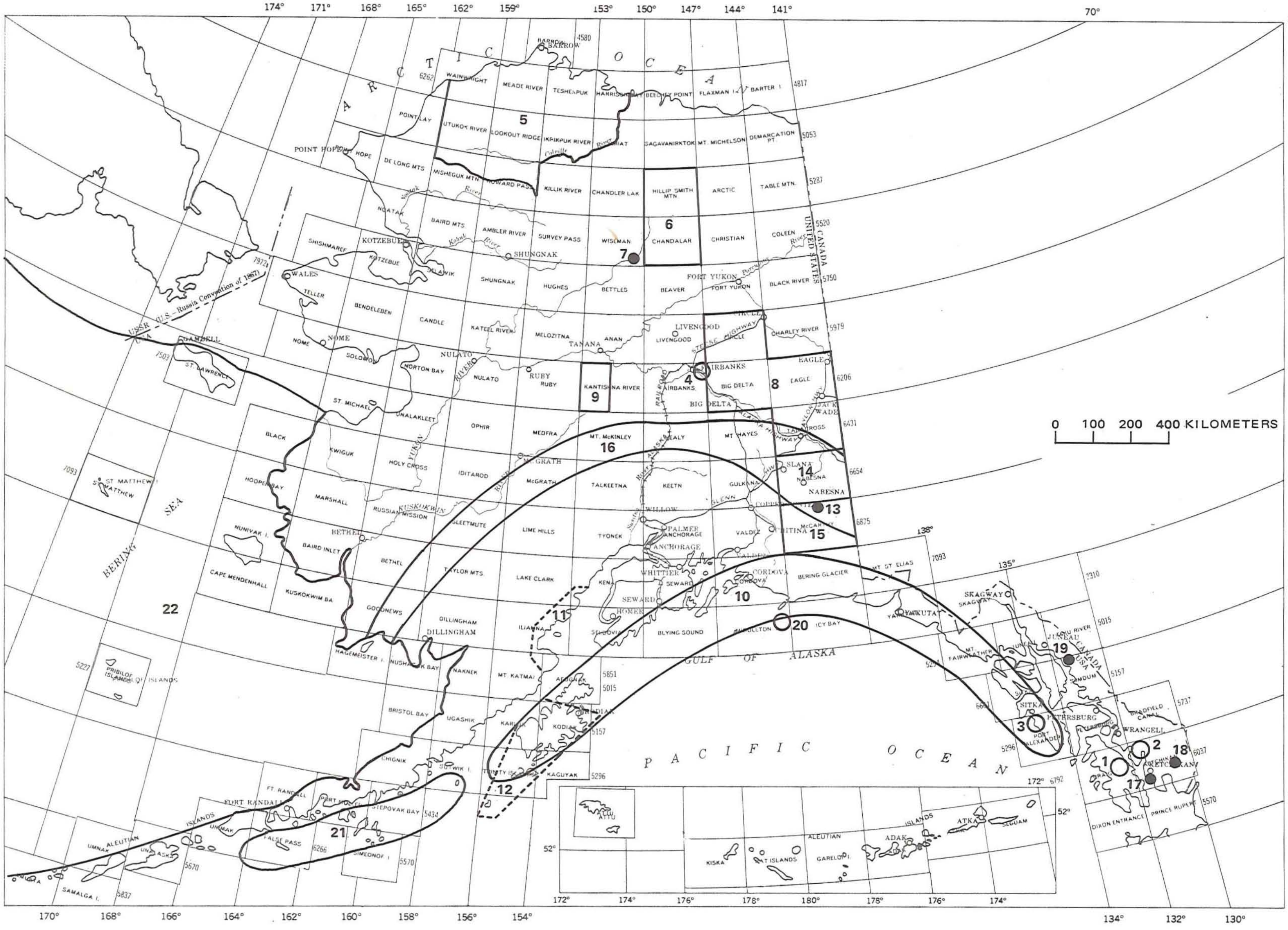

FIGURE 2.—Location of studies discussed in summary of important results, 1976. Numbers key to project discussions in text.

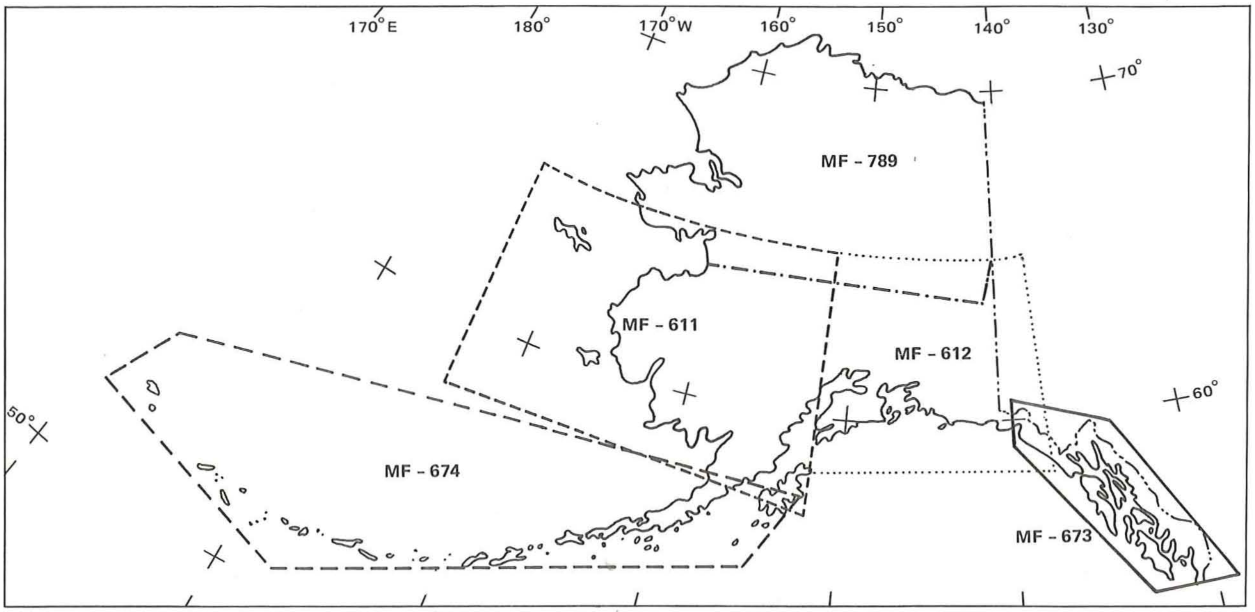

FIGURE 3.—Index map of Alaska showing areas covered by five preliminary geologic maps at a scale of 1:1,000,000 (Beikman, 1974a, 1974b, 1975a, 1975b; Beikman and Lathram, 1976).

A new radiometric date for the Ordovician-Silurian boundary

By M. A. Lanphere, Michael Churkin, Jr., and G. D. Eberlein

The first discovery in North America of a continuous succession of graptolite faunas across the Ordovician-Silurian boundary was described from Esquibel Island in 1970 (Churkin and others, 1970). Since then, Marvin A. Lanphere has separated and analyzed hornblende suitable for potassium-argon dating from two rock units on Esquibel Island that can be related to the graptolite shale. One of the datable rocks is a sedimentary breccia that lies at the top of the graptolite shale sequence (fig. 4).

A potassium-argon date of 432 ± 3.3 m.y. was obtained on the breccia. The second datable rock, not shown on figure 4, is a porphyritic hornblende diorite, approximately 2.4 km south of the section shown on figure 4, that intrudes the upper part of the stratigraphic section containing the graptolites. A potassium-argon date of 427 ± 3.5 m.y. was obtained on the diorite. These dates provide a minimum age of 433 ± 3.3 m.y. for the zone of *Monograptus cyphus* and an extrapolated age for the Ordovician-Silurian boundary of between 435 and 437 m.y., assuming a constant rate of sediment accumulation.

REFERENCE CITED

Churkin, Michael, Jr., Carter, Claire, and Eberlein, G. D., 1970, Graptolite succession across the Ordovician-Silurian boundary in southeastern Alaska (abs.): London Geol. Soc. Proc., no. 1663, p. 194.

A new Ordovician time scale based on accumulation rates of graptolite shale

By Michael Churkin, Jr., Claire Carter, and Bruce R. Johnson

The radiometric dating of graptolite zones in the Esquibel Island section (Lanphere and others, 1977) was expanded to provide a preliminary dating of Middle and Upper Ordovician graptolite zones. Our stratigraphic studies of graptolite shales in various parts of the Cordillera, including an unusually complete succession of graptolite zones at Trail Creek, Idaho, indicate an average accumulation rate of 4 ± 1 m/m.y. This rate, based on careful measurements of the thickness of graptolite zones, falls within the range of 2-5 m/m.y. for modern abyssal clays and siliceous oozes, which we believe are the closest analogs to ancient black siliceous shale and chert sequences rich in graptolites.

The Deep Sea Drilling Project has shown that once an age is determined for a stratigraphic horizon within a pelagic section, it is possible to estimate the ages of other stratigraphic horizons by assuming constant rates of sediment accumulation. Preliminary findings, using this method on rocks in the Cordillera, suggest that the time span represented by a

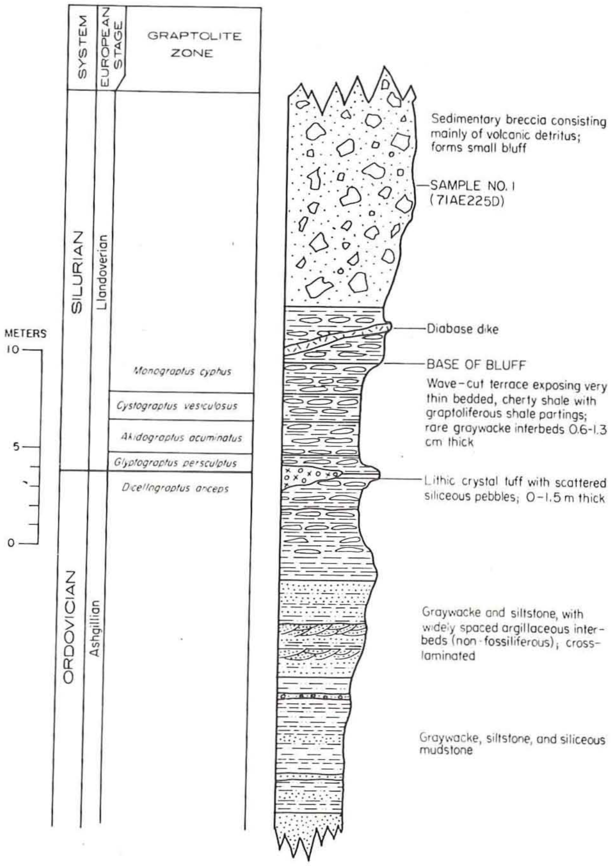

FIGURE 4.—Columnar section across the Ordovician-Silurian boundary in the Descon Formation, east shore Esquibel Island, southeastern Alaska.

graptolite zone is proportional to its thickness. The thickest zone, *Nemagraptus gracilis,* is calculated to span 8 m.y., whereas the thinnest zone, *Glyptograptus persculptus,* accumulated in less than a million years.

Preliminary subdivision of the Middle and Late Ordovician and Early Silurian time scale is (fig. 5): about 433 ± 3 m.y. for the base of the *Monograptus cyphus* zone, 435–437 m.y. for the base of the *Glyptograptus persculptus* zone (Ordovician-Silurian boundary), 438 m.y. for the base of the *Dicellograptus ornatus* zone (base of the Ashgillian), 439 m.y. for the base of the *Pleurograptus linearis* zone, 445 m.y. for the base of the *Dicranograptus clingani* zone, 448 m.y. for the base of the *Diplograptus multidens* zone, 456 m.y. for the base of the *Nemagraptus gracilis* zone (base of the Caradocian), 458 m.y. for the base of the *Glyptograptus teretiusculus* zone (base of the Llandeilian), 463 m.y. for the base of the *Didymograptus murchisoni* zone, and about 470 m.y. for the base of the *Isograptus gibberulus* zone (upper Arenigian).

REFERENCE CITED

Lanphere, M. A., Churkin, Michael, Jr., and Eberlein, G. D., 1977, A new radiometric date for the Ordovician-Silurian boundary, *in* Blean, K. M., ed., United States Geological Survey in Alaska; accomplishments during 1976: U.S. Geol. Survey Circ. 751-B, p. 4.

Glacier research

By L. R. Mayo

The activity of three glaciers in Alaska is being studied because present or planned developments near these glaciers may be affected. Black Rapids Glacier in the Alaska Range may affect the Richardson Highway and the TAPS pipeline and could block the Delta River. The Columbia Glacier is discharging icebergs into the tanker shipping lanes south of Valdez. Portage Glacier is retreating from view at the Portage Visitor Center.

Radar soundings at Black Rapids Glacier were made in March 1976 to determine the amount of ice that may surge into the Delta River valley. The glacier has eroded the Denali fault trench to a level lower than the Delta River valley. The ice in the fault trench is 550 m thick near the glacier terminus and thicker upglacier. Assuming that the glacier will move 8.5 km in the fault trench as it did during the previous three surges, 6.7 km^3 of ice will surge into the Delta River valley within the next one or two decades.

In 1976, 12 locations on the lower 30 km of Columbia Glacier were resurveyed to determine whether the glacier is becoming unstable as proposed by Post (1975). Since 1974, the time of the previous survey, the glacier thinned 0.2 to 2.0 m from 30 to 5 km above the terminus and thinned 2.0 to 12.5 m from 5 km to the terminus. Therefore, Columbia Glacier is less stable in 1976 than in 1974, and the probability is greater that iceberg discharge will increase in the future.

A prediction to approximately the year 2020 for Portage Glacier indicates that this glacier with "visitor appeal" will continue calving so rapidly that the terminus will recede out of view of the present visitor center. Even a substantial change in climate is unlikely to change the direction of movement because the rapid cal-

SYSTEM	STAGE	RADIOMETRIC DATE, IN M.Y., AND LOCALITY	GRAPTOLITE ZONE, AND CALCULATED AGE, IN M.Y., OF BASE	
SILURIAN	Llandoverian			
		433 ± 3 Volcanic breccia, Esquibel Island, Alaska	433	*Monograptus cyphus*
ORDOVICIAN		435 m.y.	435-437	*Glyptograptus persculptus*
	Ashgillian		438	*Dicellograptus ornatus*
	Caradocian		439	*Pleurograptus linearis*
		445 m.y.	445	*Dicranograptus clingani*
			448	*Diplograptus multidens*
		452 ± 10 Bentonites in Sweden		
		455 m.y.	456	*Nemagraptus gracilis*
	Llandeilian		458	*Glyptograptus teretiusculus*
	Llanvirnian		463	*Didymograptus murchisoni*
		465 m.y.		
	Arenigian	469 ± 5 Metamorphic aureole, Bay of Islands ophiolite, Newfoundland	470	*Isograptus gibberulus*
		475 m.y.		
		484 Ballantrae Igneous Complex, Scotland		
		485 m.y.		

FIGURE 5.—Preliminary time scale using accumulation rates of graptolite zones.

ving of icebergs from the glacier terminus is controlled by the 170-m-deep water of Portage Lake rather than by the flow of ice down the glacier.

REFERENCE CITED

Post, Austin, 1975, Preliminary hydrography and historic terminal changes of Columbia Glacier, Alaska: U.S. Geol. Survey Hydrol. Inv. Atlas HA-559, 3 sheets, scale 1:10,000 [1976].

Investigations of impact on hydrologic features by construction and operation of TAPS

By C. E. Sloan and J. W. Nauman

Ditching and backfilling operations for the buried pipeline crossing of the Salcha River between Fairbanks and Big Delta occurred during March 1976. Turbidity values upstream from the crossing during this period ranged from 2 to 4 JTU. Downstream measured turbidity ranged from 29 to 95 JTU during ditching, and during backfilling turbidity reached a high of 200 JTU. Streamflow discharge during the period was fairly steady at about 2.8 m^3/s.

Forty-two benthic invertebrate drift samples were collected at three sites located 143 m upstream from the pipe crossing and 137 m and 442 m downstream from the pipe crossing, respectively, during the period March 14-27, 1976. Fewer drifting invertebrates were collected immediately downstream from the pipeline than upstream, and the station farthest downstream retained many more invertebrates than either of the other stations. The numbers of drifting invertebrates under ice were substantially greater at night than during daytime at all stations.

Streamflow and channel erosion along the TAPS route
By P. F. Doyle

Operation of ten gaging stations established along the TAPS route in the early 1970's provided another year of hydrologic data in data-scarce areas. Surveillance of 28 specific channel erosion sites along the TAPS route continued. A well-documented broad base of channel behavior information is being compiled for these pipeline stream-crossing sites, most of which have been monitored for several years. Relatively little erosion has occurred at most of the channel erosion sites since the 1975 surveys. Channel changes were due mainly to construction of the pipeline. Methods of surveillance include on-the-ground surveys, photogrammetric surveys, photographic comparisons, and site visits. Evaluation of suitability of photogrammetric techniques in channel erosion study continues. Photogrammetry appears to be a useful method in many instances, and ways to improve its accuracy in this erosion study will be tested in 1977.

A break-out flood from a glacier-dammed lake was observed at the Tazlina River pipeline crossing site and the effects noted. The Tsina River also had a similar break-out flood in 1976. Project personnel studied particularly severe icings on the Gulkana River in the vicinity of the TAPS crossing.

Effects of fuel oil leaks on water quality in three streams along the trans-Alaska pipeline
By J. W. Nauman, C. E. Sloan, and D. R. Kernodle

Studies were conducted on three streams along the trans-Alaska pipeline corridor to evaluate the effects of fuel oil leaks on water quality and benthic invertebrates. Streams affected by leaks are the Jim River at Prospect Camp, Unnamed Creek at Galbraith Lake Camp, and Happy Creek at Happy Valley Camp.

Drifting benthic invertebrates were collected with drift nets installed for one hour above and below the oil spill sites. Species diversity was lower at the downstream site in each of the three streams. The diversity reductions were from 2.96 to 2.39 at Jim River, from 1.26 to 1.06 at Unnamed Creek, and from 2.43 to 1.86 at Happy Creek. There was also a reduction in total number of taxa collected at each of the lower downstream sites. However, little difference was apparent in the composition of the benthic community.

Although a surface oil sheen was visible at each of the downstream sites, no oil was detected from samples collected below the surface using the Freon extraction method for oil and grease. However, oil and grease were detected in the stream bed material. Values ranged from 0.1 to 1.6 mg/kg in Jim River, from 0.1 to 9.7 mg/kg at Unnamed Creek and from 0.1 to 24.7 mg/kg in Happy Creek. Although these concentrations of oil in sediment are relatively low, they suggest that fuel oil contamination from the initial leak and continued seepage into these streams have reduced the benthic invertebrate population immediately downstream from the area of fuel oil leaks in these three streams. Furthermore, the diversity of benthic organisms below the seep area has not reached its pre-seepage level, suggesting that the oil is a continuing detriment to the benthic community.

Fisheries enhancement studies: Limnological studies in southeastern Alaska and water quality measurements along the TAPS route during pipeline construction
By G. A. McCoy

Limnological investigations were completed at Salmon Lake near Kasaan (fig. 2(1)), and Patching, Klawak and Heckman Lakes near Ketchikan (fig. 2(2)) to determine their suitability for restocking with fish. The water quality of these lakes is excellent for the intended uses; the water is dilute and low in nutrients (nitrogen and phosphorus).

A report on the limnology of six lakes in southeastern Alaska (Spurt Point, Osprey, Blue, Green, Swan and Redoubt Lakes) and another on meromixis in Redoubt Lake (fig. 2(3)) near Sitka were completed and will be published in 1977. With the exception of Redoubt, these lakes are oligotrophic, exhibit a temperature stratification between turnovers, and are dimictic. Water quality is excellent for use as a fishery resource, and primary productivity is low. Redoubt Lake, a relic fiord, is one of the largest documented meromictic lakes on this continent. Salt water intrusion probably ceased because of regional uplift about 650-800 years B.P.

Chemical-quality and sediment-transport data were collected downstream from a trans-Alaska pipeline crossing on the Salcha River

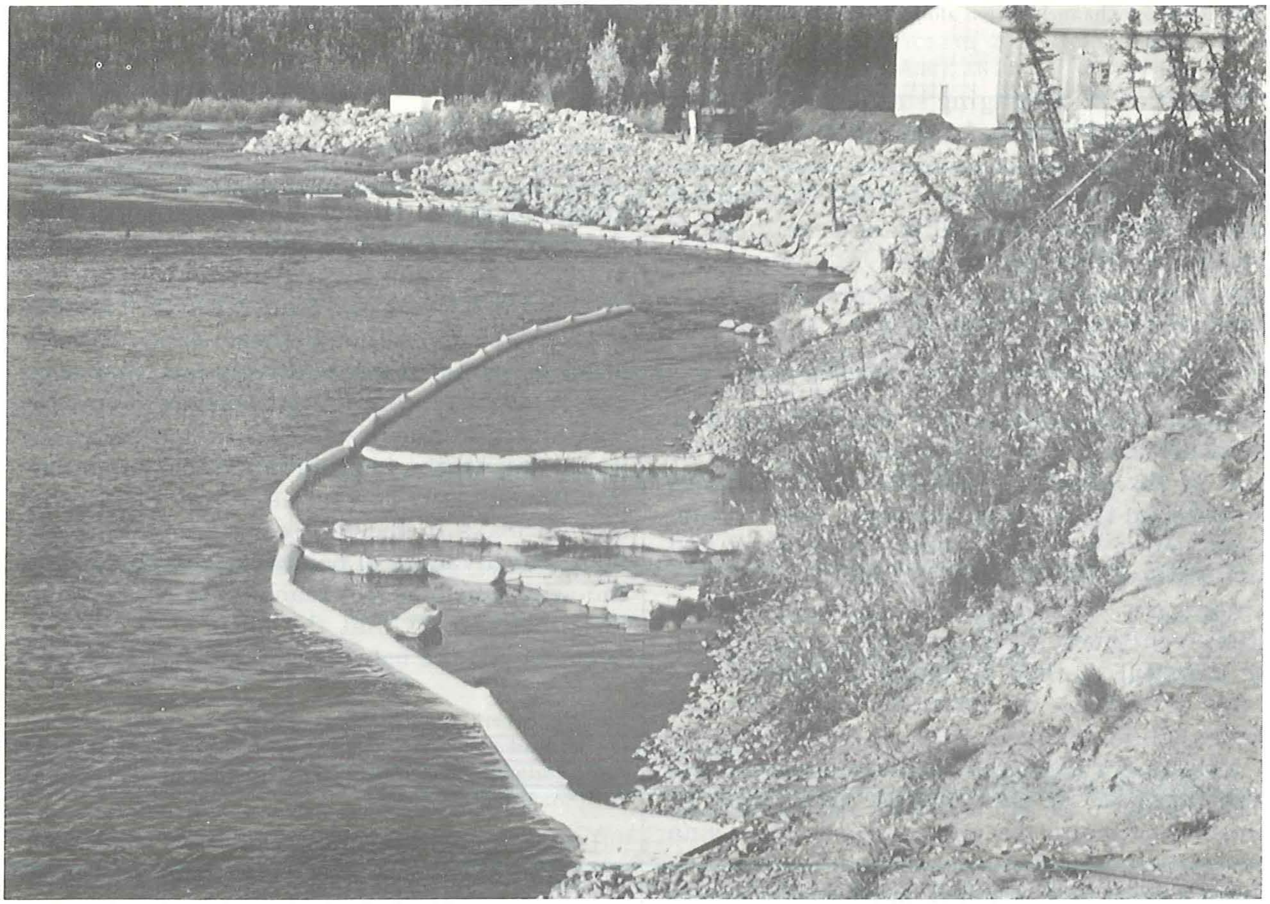

FIGURE 6.—Containment shield and absorbents for oil seeps into the Jim River at Prospect Camp, September 1976.

(fig. 2(4)) near Fairbanks. Measurements were made during and after construction of the crossing. During construction the sediment load increased downstream from the crossing. Some fine sediment was carried at least 13 km downstream.

NORTHERN ALASKA

Lead-zinc mineralization at Bear Mountain, southeastern Brooks Range

By William P. Brosgé and Hillard N. Reiser

The sparse data available on occurrences of non-hydrocarbon mineral resources and geochemical anomalies in the Arctic National Wildlife Range have been summarized and interpreted in a series of maps which show that the Wildlife Range has some potential for base metals, uranium, phosphate rock, barite, gold, and possibly coal (Brosgé and Reiser, 1976). One of the most conspicuous favorable areas shown on these maps is indicated by the cluster of mineral occurrences and high geochemical concentrations of lead and zinc near Galena Creek in the southeastern part of the Wildlife Range. A helicopter-supported investigation of the area south of the Wildlife Range by the Bureau of Mines in 1976 made it possible for Brosgé and James Barker, U.S. Bureau of Mines to have a closer look at a small part of this mineralized area.

Galena Creek is in the Table Mountain quadrangle on the south flank of Bear Mountain, an anticlinal dome of lower Paleozoic and possibly older rocks that are intruded by small bodies of rhyolite. Gray-green phyllite, phyllitic sandstone and greenstone, and fine-grained quartzite in the core of the dome are overlain by a thick conglomerate of probable Devonian age which forms most of the mountain. The rhyolite occurs mainly in the older rocks, but one dike intrudes probable Devonian conglomerate on the west flank of the mountain, and another intrudes the

FIGURE 7.—Backfilling over the pipeline in the Salcha River, March 1976.

overlying Mississippian shale on the east flank. Reconnaissance mapping and sampling done 10 years ago revealed anomalous amounts of lead and zinc in the streams draining the south flank of Bear Mountain, as well as abundant galena in quartz veins at the contacts of some rhyolite dikes. Concentrations were highest in Galena Creek and its two neighboring streams, where as much as 500 ppm lead and 380 ppm zinc were found in sediments in the main valleys, and 1,500 ppm lead and 360 ppm zinc in one small tributary. These streams drain the core of the anticline where most of the rhyolite occurs and where it invades only the oldest rocks. Because of limited observations it was previously thought that mineralization was restricted to large veins at the rhyolite contacts. However, a traverse was made in 1976 along one of the phyllitic sandstone ridges that has a longitudinal dike about 30 m thick along its west face. Close examination showed that mineralization is pervasive in the country rock across the ridge crest in a zone east of the dike at least 200 m wide and 750 m long and continues downhill west of the dike. Galena occurs in tiny veinlets, with and without quartz, along foliation and small fractures in the fine-grained phyllitic sandstone, and in the minor amounts of intercalated greenstone. No galena was seen in the rhyolite, nor have anomalous amounts of lead been found in analyses of the other rhyolites, so it is not certain that the lead at Bear Mountain was introduced by the rhyolite. It may be indigenous to the phyllitic host rocks. The fact that lead anomalies do occur in gossan soil on the dike in the probable Devonian conglomerate on the west flank of the dome and in soil on a fault zone within the probable Devonian conglomerate on the north flank indicates that the mineralization is younger than the lower Paleozoic phyllite. No matter what the source, the new field observations suggest that galena is distributed through a large volume of the phyllitic rocks.

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Depositional environment and fauna for a section of the Sadlerochit Group, northeastern Alaska

By R. L. Detterman and J. T. Dutro, Jr.

As part of a continuing study of the Sadlerochit Group (Lower Permian to Lower Triassic) a section east of the Ivishak River in sections 10, 11 and 12, T. 4 S., R. 18 E. of the Sagavanirktok A-2 quadrangle was measured in 1976. This section, which is more than 535 m thick, is well exposed and is one of the thickest measured in northeastern Alaska. It provides good faunal control and supplies much stratigraphic information for the transition between the southern facies of the Sadlerochit group exposed in the Philip Smith Mountains quadrangle and the northern facies in the Mt. Michelson and Demarcation Point quadrangles.

The lower 122 m of the measured section (fig. 8) comprises the Joe Creek Member of the Echooka Formation (Detterman and others, 1975). This unit is mainly a carbonate, siltstone, and sandstone sequence that was deposited by a northward marine transgression that overlapped a subaerially eroded surface of the Lisburne Group. The depositional environment for the basal 43 m is interpreted as being a shallow marine embayment or carbonate-rich lagoon with a nearby stream delta. This interpretation is based on thin, shaly-bedded, bioturbated silty and sandy limestone (Erxleben, 1973) and bioturbated calcareous siltstone. Overlying this is a crossbedded, cross-laminated, bioturbated sandstone, 12 m thick, with numerous scour marks and cut-and-fill structures interpreted as a distributary mouth bar. The top meter contains numerous broken brachiopod and coral fragments. The next 15 m is calcareous siltstone representing tidal flat deposition. The overlying section is mainly a massive-bedded shelf carbonate and reworked shelf mud and sand sequence, 52 m thick, deposited in deeper water.

The Joe Creek Member is fossiliferous throughout. The main faunal elements present in the five collections include *Yakovlevia, Waagenoconcha, Linoproductus, Cancrinella, Thamnosia, Timaniella, Spiriferella,* and *Attenuatella*; these fossils represent a part of Zone F of Bamber and Waterhouse (1971) and are correlated with the upper Leonard and Road Canyon of west Texas. The fossils from this section are younger than the ones found in the lower part of the Joe Creek Member at Flood Creek, 15 km southwest, which are correlated with the Wolfcamp (Detterman and others, 1975).

The Ikiakpaurak Member of the Echooka Formation is about 150 m thick but contains one break that, on the basis of lithology of nearby sections, probably represents no more than 30 m. The basal 38 m is interpreted as a littoral sand that disconformably overlies the shelf carbonate sequence. This interpretation is based on bed form, segregated lenses of pebbles, and fossils (Clifton, 1973). This basal unit is overlain by 6 m of gray calcareous shaly siltstone deposited in tidal flats and 76 m of black massive siltstone that represent a protected lagoon with low clastic contribution. The upper 30 m of well-sorted, bioturbated sand is interpreted as an offshore bar.

Fossils were collected only from the base of the lowest unit and include *Kuvelousia, Stenoscisma, Punctospirifer,* and *Spiriferella.* The trace fossil *Zoophycos* is also present; it is common throughout Permian strata in northeastern Alaska. These fossils are correlated with the Kazanian, Late Permian Arctic fauna (basal Word equivalent) and are characteristic of the basal Sadlerochit beds in the Mount Michelson and Demarcation Point quadrangles.

The shallow-water Permian sequence is disconformably overlain by deeper water Early Triassic beds that reflect a major marine transgression. These rocks, mapped as Kavik Member of the Ivishak Formation, are dark-gray to black pyritic fissile siltstone about 245 m thick. The rocks are commonly laminated and locally cross-laminated. Large limestone concretions and limy septarian nodules are common. The depositional environment is interpreted as prodeltiac bottom-set beds (Matthews, 1974). The few fossils found support a deep-water depositional site as they are mainly ammonites, which were free-swimming organisms. Included are *Otoceras* and *Ophiceras,* which indicate an Early Triassic Griesbachian age.

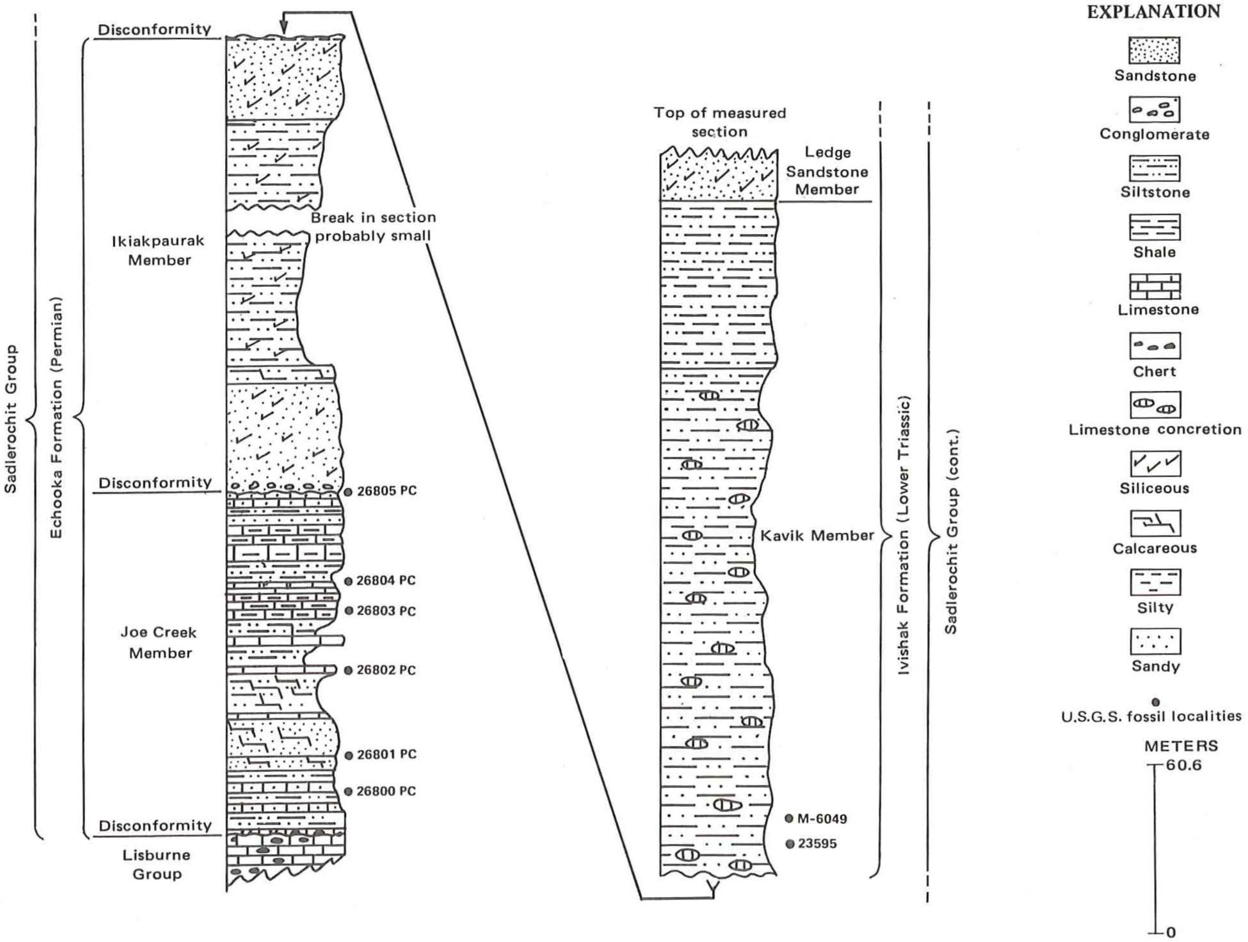

FIGURE 8.—Stratigraphic column, Sadlerochit Group.

Overlying the siltstone prodeltaic deposits is about 15 m of clean quartzitic sand mapped as part of the Ledge Sandstone Member and interpreted as a deep-water fan deposit. This sandstone is the top of the measured section. Previous work in the area (Keller and others, 1961) suggests that another 100 m of mainly siltstone and shale lies between the sandstone and the base of the Shublik Formation. A pebble zone at the base of the Shublik Formation suggests the contact is disconformable.

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Gubik and pre-Gubik Cenozoic deposits along the Colville River near Ocean Point, North Slope, Alaska

By L. D. Carter, C. A. Repenning, L. N. Marincovich, J. E. Hazel, D. M. Hopkins, Kristin McDougall, and C. W. Naeser

Fossiliferous marine siltstone, shale, and sandstone are exposed in bluffs along the Colville River from Big Bend Benchmark (near Ocean Point, Harrison Bay A-3 quadrangle, Alaska, 1955 ed.) northwest for about 2.3 km. The rocks interfinger to the west with nonmarine coal-bearing beds and are unconformably overlain by fossiliferous unconsolidated deposits of the Gubik Formation. The nonmarine beds extend up the Colville River 65.5 km to about the mouth of the Anaktuvuk River and have been designated as the type section of the Kogosukruk Tongue of the Prince Creek Formation (Brosgé and Whittington, 1966) and assigned a Late Cretaceous age (Gryc and others, 1951). Macbeth and Schmidt (1973) first reported the marine rocks near Ocean Point and examined the foraminifers contained in them. They assigned the beds a late Campanian age and referred them to the Sentinel Hill Member of the Schrader Bluff Formation, which intertongues with the nonmarine Prince Creek Formation in other areas.

Recent faunal collections indicate that the pre-Gubik marine beds near Ocean Point are no older than Miocene and are probably Pliocene and that the Gubik deposits may be as old as late Pliocene but are most likely middle Pleistocene. Fission-track dating of zircons from an ash bed in the Prince Creek Formation, 10 km upstream from Ocean Point, indicates that the rocks exposed there also are Cenozoic. Four zircon grains separated from the ash have fission-track ages that are indistinguishable within the analytical uncertainties of the method. The age of these grains is 50.9 ± 7.7 m.y. ($\pm 2\sigma$), or Eocene, and this age is considered a reliable maximum for the ash. Some of the zircons separated from the ash, however, were nearly destroyed during the etching process, which indicates the presence of damaged detrital grains of greater age. Thus it is possible that the Eocene zircons are also detrital, and that the ash is younger than Eocene.

The Gubik and pre-Gubik marine deposits near Ocean Point were sampled extensively at two localities; about 80 m northwest (downstream locality) and 2,300 m northwest (upstream locality) from the Big Bend Benchmark. The upstream locality is the same as that described by Macbeth and Schmidt (1973). At the downstream locality, about 8 m of pre-Gubik marine strata is exposed beneath about 18 m of unconsolidated Gubik sand and gravel. Sets of samples were taken at 30-cm intervals for foraminifers and ostracodes. At the upstream site, about 14 m of marine beds are exposed beneath about 15 m of Gubik sediments. Samples were collected at 60-cm intervals. Mollusks are present at both localities in the pre-Gubik beds but are abundant only in the Gubik deposits at the upstream locality.

The known stratigraphic ranges of several species of the 11 molluscan taxa present in the pre-Gubik deposits strongly suggest a Pliocene or younger age assignment for this collection. One of the important age indicators is the gastropod *Amauropsis islandica* (Gmelin), which is known thus far only in Pleistocene and Holocene faunas of the arctic region. The bivalve *Cyrtodaria kurriana* (Dunker) is also known, thus far, only in arctic Pleistocene and Holocene faunas. The extinct scallop *Chlamys lioica* (Dall) has been found previously only in Pliocene or early Pleistocene deposits at Nome and in the Chaix Hills in the Gulf of Alaska region (MacNeil, 1967). Thus, the mollusk fauna indicates that the pre-Gubik deposits near Ocean Point are no younger than early Pleistocene and possibly as old as Pliocene.

The microfauna of the pre-Gubik beds consists of a mixture of indigenous late Cenozoic and a few redeposited Cretaceous specimens. The ostracode *Brachcythere* sp. and pollen of *Aquilapollenites* are evidently redeposited from Cretaceous strata. An ostracode of new species of the genus *Heterocyprideis* is suggestive of a Neogene age, since the genus is previously known only to contain the two Pleistocene to Holocene species *H. sorbyana* and *H. fascis*, neither of which is represented here. The other several ostracode species present also are apparently new and not known from the Gubik. The overall generic and familial composition of the fauna, with the exception of the *Brachycythere* mentioned above, suggests a Neogene age. Foraminifers of the genera *Buliminella, Nonionella,* and *Pseudopolymorphina* are represented by the same species in the Gubik Formation and in the underlying pre-Gubik beds and exhibit morphological traits that indicate a Neogene or younger age.

A minimum age for the pre-Gubik beds is established by the presence of a toothless ramus of the lower jaw of *Enhydra* sp., a sea otter, which was collected from the basal gravels of the Gubik Formation. In nearly all features it is identical to the living *Enhydra lutris,* but the alveoli for the lower carnassial (first lower molar) differ markedly from those of the living species, which are highly modified to adapt to the crushing mastication of sea otters. Fossil sea otters with modern adaptation of the first lower molar roots are known from Moonstone Beach, California, in association with Irvingtonian land mammals (Repenning, 1976) and are correlated, in that area, to exposures containing planktonic foraminifers indicating zone N22 of Blow (Ingle, 1976). They are also known from the Timms Point Silt Member of the San Pedro Formation in the Los Angeles area in association with planktonic foraminifers indicating N22-N23 zones of Blow (Poore in Repenning, 1976).

The alveoli of the mandibular ramus from the base of the Gubik Formation, on the other hand, shows nothing of the root adaptation of the first lower molar of living *Enhydra lutris* or the one named, closely related fossil species. In contrast, it shows the root pattern of the ancestral genus *Enhydriodon,* the youngest record of which, in North America, is about 3 m.y. old (somewhat younger than believed by Repenning, 1976). Despite the fact that this specimen is the only record of a sea otter of this stage of evolution, the basal part of the Gubik Formation at Ocean Point, and its contained fauna, might be between 2 and 3 m.y. old and best considered as late Pliocene.

An alternate interpretation, however, is that the sea otter remains were incorporated into the basal gravels of the Gubik from the underlying deposits, and that the underlying deposits are 2 to 3 m.y. old. This interpretation is more in keeping with the faunal aspects of both the pre-Gubik and Gubik deposits but is questioned, in part, as the ramus shows no signs of abrasion.

The faunal collection from the Gubik deposits in the area where the sea otter was found includes about 65 molluscan taxa. Several of the species present are helpful in age assignment and suggest a Kotzebuan (middle Pleistocene) age for the deposits. *Neptunea lyrata leffingwelli* and *Neptunea heros heros* are both present and are known to occur together only in Kotzebuan deposits. *Axinopsida orbiculata* is not known from deposits older than Kotzebuan, and the occurrence together of *Trichotropis borealis* and *Neptunea lyrata leffingwelli* suggests deposition during the Kotzebuan transgression. Additionally, the Gubik ostracode fauna, which is significantly different from the pre-Gubik fauna, indicates a Quaternary, rather than Tertiary age for the deposits. The Gubik foraminiferal fauna is also quite different from the pre-Gubik fauna, despite the occurrence of some forms in both the Gubik and pre-Gubik deposits.

The conclusions tentatively drawn here are that, in the vicinity of Ocean Point, rocks previously mistaken for the Schrader Bluff Formation are Pliocene, the Gubik Formation is middle Pleistocene, and, 10 km upstream, rocks previously misidentified as the Prince Creek Formation are Eocene or younger. It is interesting that a Pliocene age was originally assigned to pre-Gubik deposits along this part of the Colville River by Schrader (1904, p. 83) on the basis of mollusks collected from the bluffs about 16 km upstream from Ocean Point. Later, on the basis of microfaunal and macrofaunal evidence, all of the rocks exposed along the Colville River from the mouth of the Anaktuvuk River to Ocean Point were assigned Late Cretaceous age (Gryc and others, 1951). Since then, the fossils collected by Schrader have been described as part of the Gubik fauna (MacNeil, 1957).

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Any Prudhoe Bays in Naval Petroleum Reserve No. 4?

By Robert D. Carter, C. G. Mull, and Kenneth J. Bird

From results of the 1944-53 Pet-4 exploration program, recent investigations, and the extension of eastern North Slope (primarily Prudhoe Bay) data westward, a preliminary judgment can be made of the probability of the occurrence of Prudhoe Bay-type hydrocarbon accumulations in Naval Petroleum Reserve No. 4 (see fig. 2(5) for location).

The Prudhoe Bay field is the result of a fortuitous combination of structural, stratigraphic, and geochemical factors. The most critical relationship derives from a Lower Cretaceous unconformity which superimposes rich Cretaceous hydrocarbon source beds on the truncated surfaces of upper Paleozoic and Mesozoic reservoir rocks (Morgridge and Smith, 1972; Jones and Speers, 1976). Evaluation of the regional geology of northern Alaska suggests that the unique combination of geologic and geochemical elements resulting in the Prudhoe Bay field is not likely to be repeated in NPR-4.

The zone of truncation apparently extends northward from the Prudhoe Bay area along the north flank of the Barrow arch. However, the northern limit of the most important reservoirs, the Sadlerochit and Lisburne Groups, apparently trends generally westward from the area of the Colville River delta (fig. 9). Well information in central NPR-4 indicates that both groups pinch out down the south flank of the Barrow arch (Collins and Robinson, 1967; Alaska Geological Society, 1970-71). As a result, the best potential reservoir beds are probably not present in the northern parts of NPR-4 or in most of the area of the truncation zone on the north flank of the Barrow arch. Relatively thick Jurassic shales south and west of Prudhoe Bay

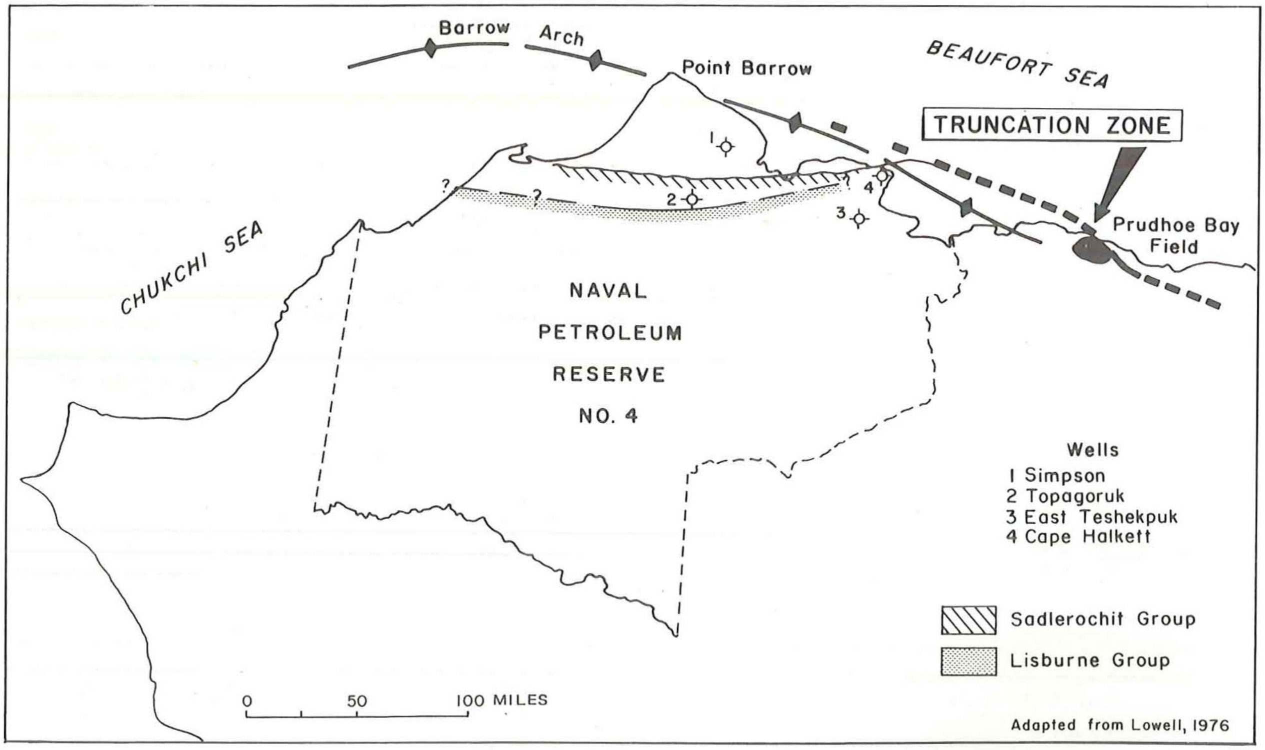

FIGURE 9.—Approximate northern limits, Lisburne and Sadlerochit Groups.

intervene between the best potential reservoirs and the rich Cretaceous source beds. Data from organic geochemical analyses (Morgridge and Smith, 1972) indicate that the indigenous hydrocarbon source potential of the pre-Cretaceous section is much lower than that of the Cretaceous rocks. These data diminish the possibility of finding giant hydrocarbon accumulations in the Sadlerochit or Lisburne Groups over much of NPR-4 south of the Barrow arch.

Recent figures developed by the Federal Energy Administration (1976) estimate that NPR-4 may contain recoverable resources of 5 billion barrels of liquid hydrocarbons and 14.3 trillion cubic feet of natural gas. Assessment of the critical geological-geochemical factors discussed above suggests that the recoverable resource may be even smaller than estimated by the FEA and are likely to be distributed in a number of small accumulations rather than a few giant fields.

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Surficial geology of the east-central Brooks Range

By Thomas D. Hamilton

Mapping of the Philip Smith Mountains and Chandalar quadrangles (see fig. 2(6)) was completed during the summer of 1976, and 1:250,000-scale surficial geologic maps of both quadrangles currently are being prepared for publication. The two maps together provide a transect across the Brooks Range from its northern foothills to the valleys and uplands that lie beyond its southern flank. This transect includes (1) massive piedmont drift sheets at and beyond the north flank of the range, (2) a belt of active alpine glaciers and alpine mass wastage processes along the Continental Divide at the crest of the range, (3) piedmont glacial deposits in the Koyukuk and Chandalar troughs at and beyond the south flank of the range, and (4) glacial valley systems that extend north and south from the Continental Divide to the piedmont zones.

Coalescing piedmont drift sheets dominate the surficial geology of the northwest half of the Philip Smith Mountains quadrangle. Assignment of these drifts to the Anaktuvuk River and Sagavanirktok River Glaciations and stades I, II, and "III" of the Itkillik Glaciation (Hamilton and Porter, 1975; Hamilton and Thorson, 1976) has been confirmed by tracing the older drift limits into the Anaktuvuk River and Sagavanirktok River type localities and by interrelating the less coalescent Itkillik deposits through distributions and crosscutting relationships of meltwater drainage channels. A previously unrecognized drift intermediate in age between Sagavanirktok River and Itkillik I occurs in some areas but elsewhere has been overridden and obliterated by Itkillik-age glaciers. Persistence of deep kettles beneath overlapping Itkillik deposits suggests that stagnant glacier ice dating from this earlier advance was still present during Itkillik I time.

The major valley systems that trend north and south from the Continental Divide to the flanks of the Brooks Range are dominated by (1) glacial deposits of Itkillik age, (2) alluvial and lacustrine sediments of moraine-dammed basins, and (3) landslides, solifluction aprons, and other products of postglacial mass wastage. Glacial valleys north of the divide are relatively short and steep. Most of their tributaries originate in cirques that were active during Itkillik time, hence these valley systems tend to be well integrated conduits for the passage of glacier ice from source areas northward to the range front. Glacial deposits tend to be sparse and discontinuous, in contrast to the more widespread sandy sediments that accumulated behind moraines near the range front. Large, active boulder-littered alluvial fans in the upper courses of most valleys attest to continued high rates of sediment yield to tributary streams and to frequent slushflows during the spring thaw season. Glacial valleys south of the divide typically are longer and lie at gentler gradients than valleys farther north. Many of their tributaries were unglaciated during Itkillik time, leading to complex flow patterns in which main valley glaciers extended varying distances up some tributary valleys and in places flowed across low divides at their heads. Because of complex patterns of ice flow, glacial lakes in the Chandalar and Koyukuk drainages were more numerous and more varied in character than in valleys farther north. Because of their gentler gradients, these two southern valley systems contain relatively long (up to 50 km) lake basins in which clay and silt tend to predominate. Active mass-wasting processes occur along the flanks of most of the southern valleys. Till aprons and embankments occur along most lower valley walls, promoting widespread solifluction and more localized rapid slope movements. Highly sheared metamorphic and igneous rocks exposed higher on valley sides are associated with numerous large landslides and debris flows.

Beyond the southern flank of the Brooks Range, glacier tongues remained confined within the Chandalar and Koyukuk troughs. Drift sheets that are mappable as surface units in this region are fewer in number than those that spread broadly across the northern piedmont zone. Three drifts correlative with Itkillik deposits of the northern Brooks Range are recognizable within the Chandalar quadrangle, and a widespread older drift appears comparable to deposits of Sagavanirktok River age. Very discontinuous, highly weathered till patches beyond Sagavanirktok River drift limits could be of Anakutvuk River age, but exposures are not adequate for firm correlation. Drift intermediate in age between Sagavanirktok River and Itkillik I has not been recognized within the Chandalar quadrangle, although it appears to be present farther west in the Koyukuk basin. Such drift presumably was buried by deposits of Itkillik I age within the Chandalar drainage system. Deep erosion along parts of the Chandalar and Koyukuk Rivers has exposed sections of stratified Quaternary deposits, which stand as high as 40–90 m and which commonly contain several superimposed tills separated by alluvium and lacustrine sediments and capped by peat, loess, and thaw-lake deposits. These bluffs have great promise for providing a dated stratigraphic framework for the region as well as detailed paleoecologic information for those horizons in which organic remains are abundant.

Upper Devonian depositional history, central Brooks Range, Alaska

By J. Thomas Dutro, Jr., William P. Brosgé, and Hillard N. Reiser

The Upper Devonian of the Philip Smith Mountains quadrangle is a tripartite sequence consisting of two marine formations, the Hunt Fork Shale and an underlying unnamed unit, capped by the thick nonmarine Kanayut Conglomerate (fig. 10).

A marine depositional cycle initiated in the early Frasnian produced more than 1,400 m of fine-grained clastic rocks and reefoid limestone. The basal formation, as yet unnamed, is about 500 m thick. Laminated dark fine-grained limestone and black shale, low in the formation, are succeeded by brown-weathering calcareous siltstone and fine-grained sandstone below a main reef horizon. Early Frasnian stromatoporoid reefs and biostromes as much as 50 m thick, at as many as four horizons within the formation, are spatially related to preexisting Silurian to Middle Devonian high areas. Reef-capping nodular limestones contain a rugose coral and brachiopod assemblage, including *Pachyphyllum*, *Macgeea*, and *Atrypa*. Chert and limestone-pebble conglomerates are locally developed beneath the limestone buildups.

In some places, the lower Frasnian includes volcaniclastic rocks and flows, including mafic pillow lavas, that appear related to an initial deeper-water depositional phase.

The unnamed formation contains several units that previously were mapped separately in the Chandalar, Arctic, and Wiseman quadrangles. Among these correlative units are: in the northern part of the Chandalar quadrangle (Brosgé and Reiser, 1964) parts of the "limestone and siltstone" unit, and the green

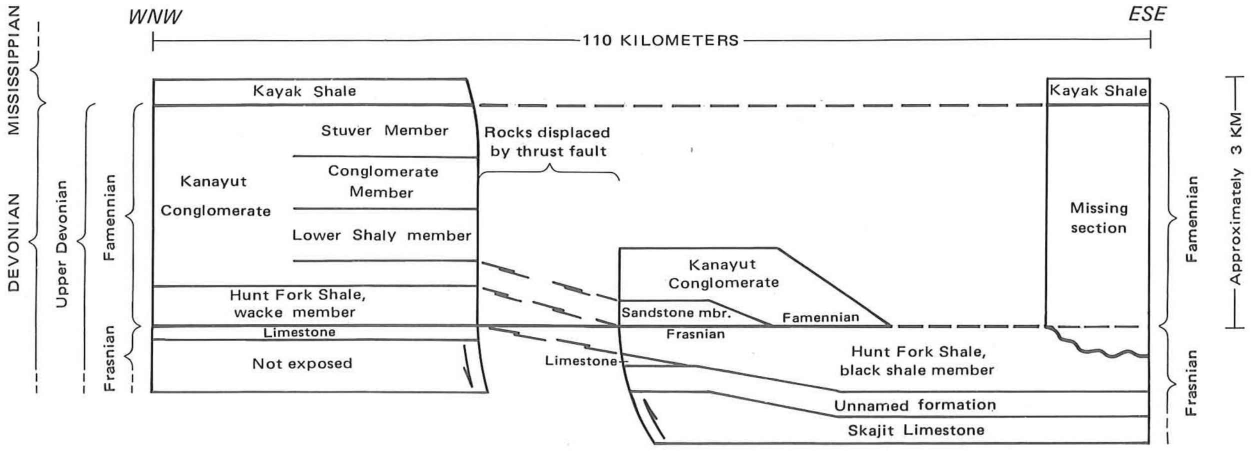

FIGURE 10.—Diagrammatic section across strike showing correlation of Upper Devonian rocks in the Philip Smith Mountains quadrangle.

phyllite, black siltstone, and basal conglomerate facies of the "slate and sandstone" unit; in the northeastern part of the Wiseman quadrangle (Brosgé and Reiser, 1971), parts of the "chloritic phyllite and quartzite" unit, the lower part of the Hunt Fork Shale, and the underlying limestone units; in the southwestern part of the Arctic quadrangle (Brosgé and Reiser, 1965) the "slate, conglomerate and limestone" unit and the "calcareous shale and limestone" unit. The recognition of the stratigraphic unity of this pre-Hunt Fork sequence in the southern part of the Philip Smith Mountains quadrangle clears up stratigraphic relations among most of these units.

The overlying Hunt Fork Shale, at least 900 m thick, is laminated noncalcareous dark siltshale that includes scattered fine-grained sandstone intervals and shelly limestones with Frasnian brachiopods, molluscs, and horn corals. Dominant faunal elements are *Atrypa, Nervostrophia, Schizophoria,* and *Macgeea.* The Hunt Fork coarsens in its upper 300 m and is, to the north, a quartz wacke containing an early Famennian shelly fauna, dominated by *Cyrtospirifer.* Mafic sills, up to 20 m thick, are intercalated locally in the middle part of the Hunt Fork.

The Kanayut Conglomerate, at least 2,000 m thick, is a nonmarine unit of coarse clastic rocks containing plant-bearing gray, green, and red shale. Four members are recognized. The lowest is a fine- to medium-grained clean quartz sandstone that is of probable littoral origin. This member is overlain by a fluviatile member of sandstone and pebble conglomerate that contains red shale intervals. The next higher member is predominantly conglomeratic and includes a 300-m-thick, massive-bedded pebble-cobble conglomerate marker unit that is very useful in mapping the Kanayut. The uppermost member, the Stuver Member, is much like the heterogeneous member except that it is more regularly cyclic. Cycles in the Stuver generally display upward coarsening of grain size that is characteristic of some nonmarine clastic sequences. It contains gray and green shales, as well as red shale intervals, and has yielded Famennian plant fossils, including *Archeopteris* and *Pseudobornia.*

The unnamed Frasnian formation represents marine deposition beginning in relatively deep water but becoming shallow in the reefoid part of the sequence. The lower Hunt Fork was also deposited in deeper water, but shallowing conditions are reflected in the upper Hunt Fork. The Kanayut is a clastic wedge, derived from the north, that thins southward across the Brooks Range and represents the end of Devonian deposition. The lower three members of the Kanayut display an offlap relationship, and the Stuver indicates a change to regional onlap that continued upward into Mississippian carbonates of the Kayak Shale and Lisburne Group. There is no major unconformity between the Devonian and the Mississippian in the central Brooks Range north of the main drainage divide.

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Carboniferous microfacies, microfossils, and corals, Lisburne Group, arctic Alaska

By Augustus K. Armstrong and Bernard L. Mamet[1]

Armstrong and Mamet (1976) have completed a detailed study of 16 measured sections of the Lisburne Group in the Brooks Range of arctic Alaska and 3 from the Yukon Territory, Canada. These sections contain microfossil assemblages assigned to zones of late Tournaisian (Osagean) through early Westphalian (Atokan) age. Representatives of both Eurasiatic and American cratonic microfaunas permit correlation with the original Carboniferous type sections in western Europe as well as with the standard Mississippian and Pennsylvanian sequences in the midcontinent region of North America.

The carbonates of the Lisburne Group are composed of predominantly bryozoan-pelmatozoan wackestones and packstones, with lesser amounts of mudstones, diagenetic dolomites, and pelmatozoan and ooid grainstones. The Lisburne Group of the Brooks Range was deposited on a slowly subsiding shallow-water carbonate shelf. The stratigraphic succession is commonly cyclic, alternating from open-marine to subtidal deposition. A carbonate platform depositional model for these carbonate rocks, illustrating the spatial distribution of the organic remains and microfacies to water depth and salinity, shows that the corals and Foraminifera are common near the shoaling-water facies, rare in the basinal and subtidal facies, and absent in the intertidal or supratidal facies. The pelmatozoan-bryozoan wackestone packstone facies, an open-marine facies, generally contains a very sparse foraminiferal fauna.

The microfauna belongs to the Alaska and Taimyr subrealms, and a temperate environment is indicated by low abundance, a very low specific diversity, high genus-species ratio, a high rate of cosmopolitanism, and very incomplete phylogenies.

Lithostrotionoid corals of the Lisburne Group are at the specific level, partly provincial to northern Canada and Alaska. The stratigraphic range of individual coral species and faunal assemblages generally extends throughout two to four microfossil zones. This, combined with their abundance only in the Alapah Limestone and general scarcity in the Wachsmuth and Wahoo Limestones, makes the coral less useful for regional correlation than the microfossils.

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Mississippian microfacies of the Lisburne Group, Endicott Mountains, arctic Alaska

By Augustus K. Armstrong and Bernard L. Mamet[2]

Limestone and spiculitic radiolarian chert facies of the Lisburne Group are exposed in a sequence of allochthonous thrust sheets in the Endicott Mountains, central Brooks Range. The Alapah Mountain section is north, near the headwaters of the Nanushuk River, and the John River and Rumbling Mountain sections are to the south. In the Alapah Mountain section (fig. 11), which is about 1,100 m thick, carbonate sedimentation began on a shallow marine platform, then subsidence outpaced carbonate production. Deeper water carbonates were deposited and were overlain again by shallow-water sediments. The shallow marine lower or basal limestones, about 300 m thick, are echinoderm-brachiopod-bryozoan wackestone and packstone. These are in contact with a slope facies, consisting of about 89 m of thin dark-gray argillaceous pellet-echinoderm-bryozoan wackestone and packstone. In gradational contact is the starved basin or deeper water facies, about 300 m thick, composed of dark-gray to black thin-bedded dolomite and black radiolarian-spiculitic argillaceous phosphatic cherts (fig. 12). These grade upward into shelf

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FIGURE 11.—View to the south, to the headwaters of Nanushuk River. The Kayak Shale forms the slope; the first set of cliffs are the massive limestone of the lower Lisburne Group. The spiculitic-radiolarian black shale beds are marked, as is the stratigraphic position of the specimen shown in figure 12. The overlying light-colored shelf carbonates cap the center ridge. Carbonate stratigraphy of the Lisburne in the south half of the photograph is structurally complex.

carbonate sediments about 400 m thick.

The John River section, which is 430 m thick, is composed of deeper water, starved basin sediments, black and brown shale and siltstone, thin-bedded argillaceous spiculitic lime mudstone, phosphatic packstone and radiolarian black chert. Semiquantitative spectrographic analysis of a dark-gray limestone sample from the upper part of this section shows the following metal concentrations in parts per million: manganese, 100; silver, 2; barium, 100; chromium, 30; copper, 150; nickel, 20; strontium, 1000; yttrium, 50; and zirconium, 30.

The incomplete Rumbling Mountain section, 545 m thick, is the lateral equivalent of the lower and middle parts of the Alapah Mountain section.

Foraminifers of Zones 7 (Middle Tournaisian), 9 (Late Tournaisian), 10 and 11 (Early Visean), 12 and 13 (Middle Visean), 16_{inf} and 16_{sup} (Late Visean), 17 and 18 (Early Namurian) have been identified. The base of the Rumbling Mountain section displays the *Chernyshinella* Zone, the oldest Carboniferous foraminiferal assemblage known from arctic Alaska. The zone has been previously reported in the upper part of the Banff Formation and the lowermost part of the Pekisko Formation in the Canadian Cordillera.

Late Paleozoic carbonates from the south-central Brooks Range

By Kenneth J. Bird

Limestone associated with shallow-seated mafic igneous rocks from the southern Brooks Range has been tentatively dated as Pennsylvanian. The foraminiferal oolitic grainstone texture of this limestone is similar to that of the Wahoo Limestone of the Lisburne Group in the northeastern Brooks Range.

Samples of the limestone were collected in 1975 by I. L. Tailleur and C. F. Mayfield from the south peak of Twelvemile Mountain, located west of the Middle Fork Koyukuk River (sec. 20, T. 27 N., R. 13 W., Wiseman quadrangle) (see fig. 2(7)). The limestone, locally cherty, is less than 10 m thick and is situated between steeply south-dipping mafic igneous sheets. Petrographic study of 12 samples reveals a uniformity of texture—a recrystallized foraminiferal grainstone. Most particles are recrystal-

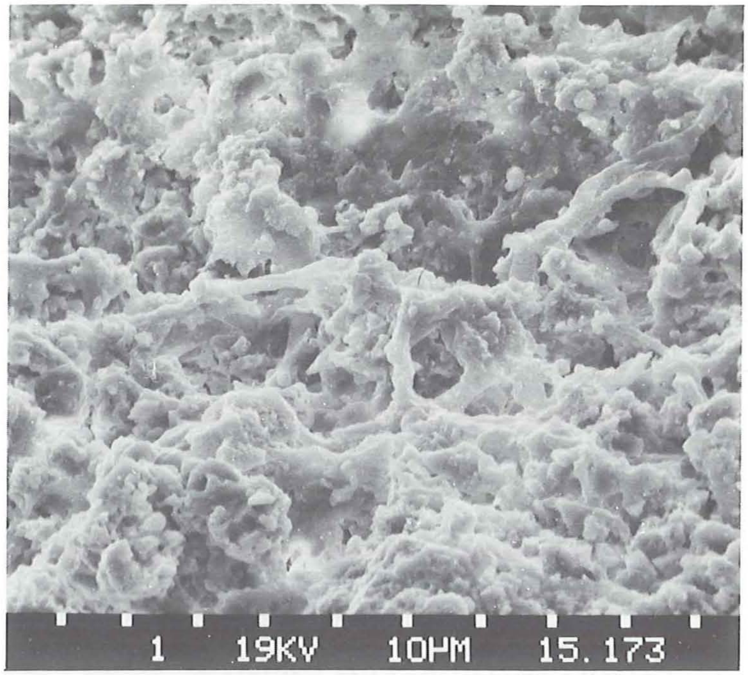

FIGURE 12.—Scanning electron microscope photomicrograph of a polished and HCl-etched surface of a calcareous spiculitic-radiolarian chert from 765 m above the base of the Alapah Mountain section. The silica in the original sponge spicules and radiolaria has been mobilized and the finer details of the spicules and radiolarian destroyed. The outlines of the linear spiculites are clear in the central part of the photograph. The silica of the radiolarian has formed amorphous globular masses. Small 2–3 µm-size subhedral to euhedral dolomite rhombs are present on the surface of the chert spicules and poorly preserved radiolarian. Scale between bars on bottom of photomicrograph is 10 µm.

lized to micrite; of those fragments identifiable, foraminifers and echinoderms are most common and ostracodes, calcareous algae, corals, bryozoans, and brachiopods are rare. Other minor components include oolites, macrodolomite (crystal size 50 µm), and replacement phosphate.

Foraminifers and algae identified to date include the following:

Archaediscus sp.
Biseriella sp.
Brunsia sp.
Calcisphaera sp.
Eotuberitina sp.
Globivalvulina sp.
Girvanella sp.
Priscella? sp.
Pseudoglomospira sp.
Radiosphaera sp.
Tetrataxis sp.

The presence of *Globivalvulina* sp. indicates a Pennsylvanian or Permian age. The other genera are longer ranging. The absence of representatives of the family Nodosariidae which are found in Permian (and younger) rocks in many places in Alaska suggests but does not prove a Pennsylvanian age for these rocks. The foraminiferal oolitic grainstone lithology is a common rock type in the Late Mississippian and Early and Middle Pennsylvanian Wahoo Limestone in the northeastern Brooks Range.

Hydrocarbon assessment of the Arctic National Wildlife Range, eastern Arctic Slope, Alaska

By C. G. Mull and B. A. Kososki

At the request of the U.S. Fish and Wildlife Service, field studies were carried out during the summer of 1976 in the Arctic National Wildlife Range (fig. 13). The studies were directed at an improved assessment of the hydrocarbon potential of the area; a similar assessment of the mineral potential has been carried out by Brosgé and Reiser (1976). The program included detailed mapping, facies studies, and an extensive sampling program for paleontologic and geochemical studies. Kososki obtained additional gravity readings, amplifying earlier gravity data by Barnes and others (1976), to compile a Bouguer gravity map of the northern part of the Wildlife Range at a 5-milligal contour interval. He has utilized these data, along with proprietary aeromagnetic data and regional outcrop mapping by Reiser and others (1971 and 1974), to compile a depth-to-basement map. A preliminary assessment of these data combined with the detailed mapping and facies studies has highlighted areas of major hydrocarbon potential in the Wildlife Range. The data suggest that a very highly prospective area underlies the Arctic Coastal Plain in the Niguanak River area, southeast of the village of Kaktovik (Barter Island). A regional structural high in this area of the Nuguanak River is indicated by the gravity, depth-to-basement, and surface mapping.

Regional facies studies in northern Alaska indicate that the reservoir potential of the Permian and Triassic Sadlerochit Group improves northward (Morgridge and Smith, 1972; Detterman and others, 1975; Jones and Spears, 1976). A similar northward improvement of reservoir potential in the underlying Mississippian and Pennsylvanian Lisburne Group is also indicated (Wood and Armstrong, 1973; Bird and Jordan, 1976). If similar trends prevail northward from the outcrop belt in the Wildlife Range, and if these horizons are present in the area of the structural high, favorable reservoir horizons may be present in the Niguanak River area.

Mapping along the north flank of the Sadlerochit Mountains indicates that the Kemik Sandstone Member of the Kongakut Formation, of probable Neocomian age (Detterman and others, 1975), rests unconformably upon the Sadlerochit Group along the mountain front east of the Katakturuk River. Along the south side of the Sadlerochit Mountains the Kemik overlies various horizons in the Jurassic Kingak Shale. The regional relations suggest that the depth of truncation increases northward and that the clastic detritus in the Kemik was derived from a northern source. In the Marsh Creek area at the mountain front, extensive outcrops of Kemik and the overlying Kingak are displaced northward by gliding off of the Sadlerochit Mountains uplift and emplaced over the in-place facies of the Kemik, which truncates the Sadlerochit Group. Abundant clasts and grains of white weathered chert (porcellanite or tripolitic chert) in the Kemik suggest that the basal Cretaceous regionally truncates at least as deep as the Lisburne Group, as similar cherts are found in the northernmost exposures of Lisburne in the Yukon Territory immediately east of the Wildlife Range.

Palinspastic restoration of the displaced glide sheets southward to a position near the crest of the Sadlerochit Mountains uplift makes it possible to draw a generalized facies distribution map for the Kemik Sandstone Member in the Sadlerochit Mountains area. Examination of sedimentary features in the Kemik and related rocks reveals two major parallel facies belts. The northern belt is a highly variable unit consisting of about 8 to 23 m of extensively burrowed pebbly siltstone, fine-grained sandstone, mudstone, and some conglomerate that can be interpreted as a fluvial to lagoonal facies. This facies unconformably overlies and truncates the Sadlerochit Group on the north side of the Sadlerochit Mountains. The southern belt is a clean quartzose sandy facies, as much as 30 m thick, that forms prominent ledges and cliffs. The lower half of the unit is characterized by large-scale festoon crossbedding and it contains a few pebble conglomerate beds. The upper half of the sandstone body is extensively burrowed and reveals little sign of internal bedding features. A few localities containing scattered pelecypods (*Astarte ignekensis* Imlay) lie north of the belt of thickest sandstone. The dominantly sandy facies of the Kemik can be broadly interpreted as representing a shoreface to beach environment. It unconformably overlies the Jurassic Kingak Shale. Regional relations suggest that the shoreface facies belt is gradational northward into the lagoonal and fluvial facies belt. To the south of the shoreface belt, a third facies was recognized in one locality near the Kavik River. It consists of mudstone and shale containing thin siltstone beds with convolute bedding; this facies probably represents an offshore environment. Because it is dominantly shale, this facies is not exposed in the Shublik Mountains area where nonresistant beds are commonly mantled by thick glacial alluvium. The mapping indicates that the facies belts occur in a long, narrow band trending N. 75° E. All three facies are conformably and apparently gradationally overlain by the highly organic pebble shale horizon recognized widely in the subsurface of the Prudhoe Bay area.

If the Kemik in the Sadlerochit Mountains area continues eastward, it projects into the Niguanak River area. However, the presence of a Jurassic outcrop on a tributary of the Niguanak River (NE ¼ sec. 10, T. 6 N., R. 36 E., UPM) (Brosgé and Reiser, 1976, sheet 1) suggests that the truncation of Sadlerochit and older rocks lies to the north, possibly on the north flank of the regional high. If so, the unconformity could juxtapose the rich organic pebble shale and associated Kemik facies and the Sadlerochit and Lisburne potential reservoir horizons. The apparently gradational relationship between the Kemik and overlying pebble shale, combined with the clean quartzose nature of the Kemik suggests that this unit may also be a major potential hydrocarbon reservoir. The combination of all these factors suggests that the potential for a Prudhoe Bay style stratigraphic-structural hydrocarbon accumulation southeast of Barter Island is high.

An area of moderate hydrocarbon potential underlies the coastal plain and foothills north of the Sadlerochit Mountains. Potential hydrocarbon source and reservoir beds may underlie the area. However, the basal Cretaceous truncation on the north side of the Sadlerochit Mountains suggests that the potential Sadlerochit and Lisburne Group reservoirs may not be present beneath the prominent Marsh Creek anticline, unless downfaulted blocks on the north preserve remnants of these rock units beneath the unconformity.

In order to assess the potential of helium geochemistry as a remote detection method for buried hydrocarbons in permafrost terrain, a limited soil sampling program was carried out in the Wildlife Range and in the area of the Prudhoe Bay oil field. Interpretation of the data by A. A. Roberts is not complete. However, apparently anomalous helium concentrations measured in most of the soil samples suggest that the method may be applicable in permafrost terrain.

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Southwestern Brooks Range-Ambler River quadrangle AMRAP

By I. L. Tailleur, I. F. Ellersieck, and C. F. Mayfield

Appropriations to the Alaska Mineral Resources Assessment Program (AMRAP) in 1976 permitted resumption of detailed-reconnaissance mapping and geochemical sampling of the southwestern Brooks Range. The Alaska Division of Geological and Geophysical Surveys began the southwestern Brooks Range program in 1971. They worked jointly with USGS personnel on the south side of the mountains in 1972-74. The 1976 geologic, geochemical, and gravity surveys joined the earlier work, extending the coverage to nearly 200 km along the axis of the Brooks Range, between the Endicott and Baird Mountains (fig. 13).

A large number of visitors joined the operations for special studies: Warren Hamilton, to assist in mapping; A. T. Ovenshine and R. Mast, Chiefs of Alaskan and Oil and Gas Branches, respectively, for a working tour; N. R. D. Albert, to correlate LANDSAT imagery with ground features; Claire Carter, to collect in

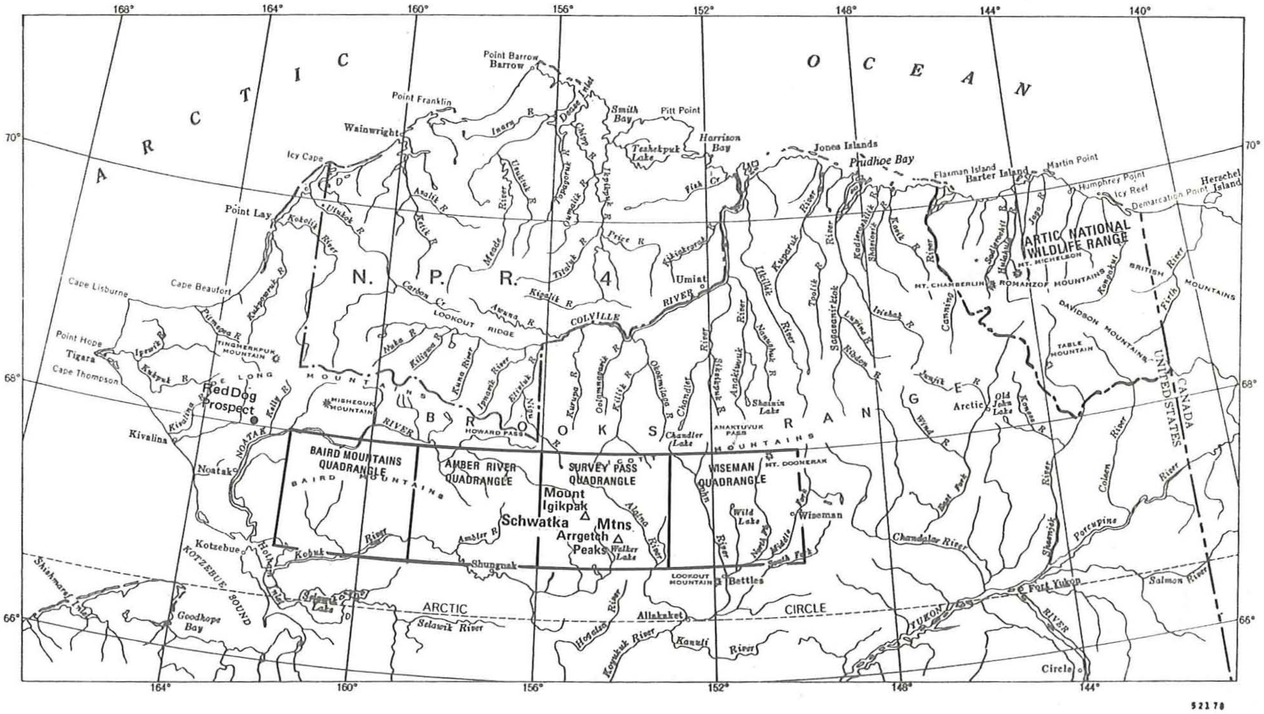

FIGURE 13.—Index map of northern Alaska showing location of 1976 field studies by Mull and Kososki and by Tailleur, Mayfield, and Ellersieck.

detail from a graptolite locality in the Baird Mountains (Tailleur and Carter, 1975); D. Grybeck, J. DeYoung, and D. Singer, for examination of mineral shows; B. L. Reed, for pan sampling of streams in areas with tin anomalies; S. Hackett (Alaska DGGS), to add 300 stations to the gravity net; and C. G. Mull, to continue regional tectonic and stratigraphic observations.

The survey added significantly to geologic knowledge of the belt transitional between the metamorphic-plutonic core of the Baird Mountains to the south and the strongly deformed but barely metamorphosed Endicott Mountains to the north. It failed, however, to sort out the complex structure and stratigraphy adequately. As a result, the geologic map being compiled by Mayfield and Tailleur does not advance as much as expected the portrayal of geology that Brosgé (Pessel and Brosgé, 1977) projected on photographs from 1966 fieldwork.

Interesting observations of surficial features are noted below. Separate reports outline preliminary results of bedrock and mineral resource studies (Tailleur, Mayfield, and Ellersieck, 1977; Tailleur, Ellersieck, and Mayfield, 1977).

1. Ground water flows abundantly through some terrains despite permafrost. Many springs occur within or peripheral to large carbonate masses. Where the springs emerge, perennial aufeis fields are common. The temperature of these nonthermal springs is usually 1.5°-5°C, though a few are as warm as 10°C. There are no unusual chemical qualities to these springs (Ivan Barnes, written commun., 1976). The springs, however, are a potential source for winter water supply.

2. Hikers in the Arrigetch Peaks area (oral commun., 1975) reported finding a hot pool beside the stream in the access valley to the Arrigetch Peaks. This spring is located at lat 67°24.83′ N., long 153°56.94′ W. Numerous game trails lead to the spring; sheep apparently use it as a salt lick. A minor flow of sulfurous-smelling water at 48°C issues among morainal boulders in the stream course.

A cool (14°C) thermal spring on the east bank of the Kugrak River at lat 67°37.52′ N., long 155°37.20′ W. is marked by travertine deposits and an anomalous stand of poplar trees. Unlike other thermal springs in the Brooks Range, it has a large flow (approximately 0.1 m^3/sec) and is 23 km from the nearest plutonic contact.

3. The upper Noatak Valley between long 156°30′ W. and 159° W. is a broad lowland separating igneous and metasedimentary rocks in the Baird Mountains from strongly deformed but barely metamorphosed sedimentary and mafic igneous rocks in the eastern De Long Mountains. The floor of the lowland is mantled with glacial drift. The few bedrock exposures consist of relatively soft, generally phyllitic rocks. It is possible that the course and shape of the Noatak Valley are controlled by these rocks.

4. The morphology of the divide between the Noatak Valley and streams tributary to the Ambler River demonstrates substantial alluvial erosion during latest Pleistocene and Holocene time. Glaciers flowed from an icefield near the crest of the range north or north-westward into the Noatak Valley at an altitude of 300–400 m, and southward into the Ambler River valley at an altitude near sea level. During or soon after the retreat of the glaciers, streams in the southern valleys eroded headward as much as 5 km, incising gorges up to 370 m deep into the formerly flat-floored valleys of the north-flowing glaciers, and pirating streams that formerly drained into the Noatak Valley.

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Mineral resources of the western Brooks Range

By I. L. Tailleur, I. F. Ellersieck, and C. F. Mayfield

In concept, the Brooks Range should contain mineral resources comparable to similar geologic settings elsewhere. Intense exploration in the schist belt on the south edge of the Baird Mountains and prospecting on the west end of the Brooks Range have verified the potential for those areas. The results of the 1976 investigation indicate that testing for mineral potential is warranted in the northern Baird Mountains and parts of the De Long Mountains. Geologic mapping showed that mineralized rocks to the south and west continue into the region. Mineral shows and geochemical anomalies indicate that potential mineral deposits may yet be found in the western Brooks Range.

The USGS field team briefly joined U.S. Bureau of Mines personnel to inspect the Red Dog prospect (fig. 13) and other localities in the western De Long Mountains. Detailed examination of the Red Dog prospect revealed impressive base-metal and barite mineralization, as reported by the Bureau of Mines contractor (Tailleur and others, 1976). Veins and disseminated sulfides and barite occur in partly altered carbonaceous black shale and chert of probable late Paleozoic age. Part of the stream bed displays massive sphalerite-galena-chalcopyrite veins more than a meter thick.

A second area of barite and sulfide mineralization, mapped by the contractors about 5 km to the south, contains several thin linear zones of rubbly bedrock containing weathered dacite(?) with quartz phenocrysts in a plagioclase-rich glassy matrix. This assemblage suggests that the mineralization in the Red Dog area may be the result of hydrothermal activity related to sporadic volcanism. Stream sediment samples from the two areas mentioned above show anomalously large amounts of barium, lead, and zinc, and moderate enrichment in copper. The South Red Dog area also has some gold anomalies.

Conditions similar to those at Red Dog occur in the headwaters of Kagvik Creek, 60 km north and east along the trend of the host rocks of the Red Dog. Samples from limonite-colored drainages in an area of brightly stained rubble contain anomalous amounts of zinc and barium. Hasty ground inspection found no conspicuous mineralization.

Similar bedrock and surficial conditions occur again along the north edge of the De Long Mountains in the upper Chertchip-Drenchwater Creeks area, 140 km to the east-northeast of Red

Dog. Anomalously bright iron-staining on banks and ridges accompanies Carboniferous black mudstone and chert bedrock. In the Drenchwater Creek basin, there is a suite of aphanitic rhyolite or other felsic igneous rocks with a biotite potassium-argon date of 319 ± 10 m.y.; this suite is possibly similar to the igneous rocks at Red Dog. As at Red Dog and Kagvik Creek, the Drenchwater Creek rocks are in the structurally lowest of several stacked thrust sheets.

Systematic exploration geochemistry consisted of collecting about 750 stream sediment samples from tributaries to the Noatak drainage, including those needed to complete the survey of the Ambler River quadrangle (Fritts, 1970; Garland and others, 1973; Pessel, 1976), 400 soil and rock samples of mineral shows, and 25 panned sediment samples from streams draining ultramafic and granitic plutons. All samples have been analyzed, either by the Alaska Division of Mines and Geology or by the USGS Branch of Exploration Research, and results are being compiled for release.

Several general or preliminary observations warrant mention. Streams draining the serpentinite body in the Siniktanneyak Mountain allochthon, Howard Pass quadrangle, contain chromium and nickel anomalies of 5,000 ppm or more. Streams draining the Kaluich, Shishakshinovik, Igikpak, and Arrigetch granite plutons have tin anomalies. Streams draining country rocks around the Shishakshinovik pluton are enriched in copper by 30–150 ppm over background levels. Black siliceous siltstone units that extend along the north side of the Baird Mountains across the Ambler River quadrangle contain red streams and chemical anomalies at several localities; a limonitic stream west of the Igning River had a copper anomaly of 700 ppm; a limonitic area on Kaluich Creek and another locality east of Nanelik Creek in the western part of the Ambler River quadrangle both yielded silver anomalies. Anomalies of 100–1,000 ppm zinc or lead are scattered across the north half of the Ambler River quadrangle.

Observed mineralized rocks and mineralization inferred from geochemical sampling have at least two modes or settings. One is epigenetic concentration by processes related in some way to igneous activity. The other is syngenetic concentration within stratiform, apparently organic-rich, rocks. The geologic framework, which includes both metasedimentary rocks apparently rich in base metals and igneous rocks both in and well north of the plutonic core, provides the potential for valuable mineral concentrations in a variety of settings.

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Late Paleozoic sedimentary sequence, southwestern Brooks Range

By I. L. Tailleur, C. F. Mayfield, and I. F. Ellersieck

Synthesis of 1976 fieldwork with earlier observations confirms the occurrence of upper Paleozoic sedimentary rocks within the structurally complex metamorphic belt of the Baird and Schwatka Mountains. They represent the only readily mappable stratigraphic sequence of several different lithologies that are less deformed and recrystallized than similar rocks elsewhere in the Brooks Range. As a result, these rocks are a valuable tool in reaching a better understanding of the structural complexities within the metamorphic belt, and also in relating the palinspastic positioning of the metamorphic rocks with lithologically different and partly coeval rocks in the north half of the western Brooks Range.

In the south half of the Ambler River quadrangle the only recognizable upper Paleozoic sedimentary rocks are several small, discontinuous outcrops of carbonate rocks containing black chert nodules. This distinctive lithology has been observed in the Jade Mountains, Cosmos Hills, and along the south edge of the schist belt and is characteristic of the Lisburne Group. Metamorphic recrystallization has erased the fossil record; however, further east, in the Wiseman quadrangle, the identification of Carboniferous foraminifers (Bird, 1977) in similar carbonates supports the identification of the Lisburne Group at the south edge of the Brooks Range.

In the north half of the Ambler River quadrangle and northeastern Baird Mountains quadrangle the late Paleozoic sequence is exposed in three areas: on the west branch of Nanielik Creek (lat 67°47–45′ N., long 159°14′ W.), along the north edge of the Shishakshinovik pluton (lat 67°25.5′ N., long 156°16′W.), and at the head of Komakak Creek (lat 67°35′ N., long 156°07′ W.).

The Nanielik Creek exposures form a north-trending narrow band of discontinuous, low ridges below and between apparently allochthonous mid-Paleozoic carbonates. The ridges are capped by less than 100 m of deformed, dark-colored, fine-grained carbonate and various amounts of nodular to irregularly interlayered black chert, typical of the Lisburne Group. Lithostrotion-like corals and other silicified Lisburne fossils substantiate the stratigraphic identification. The carbonate-chert unit lies on less than 20 m of schistose quartz conglomerate probably correlative with the Lower Mississippian Kekiktuk Conglomerate. The same conglomerate conformably underlies porphyritic rhyolitic volcanic rocks 7 km to the north. Carbonates of the Lisburne Group are missing from this section. Stratigraphic position and potassium-argon date of 319 ± 10 m.y. on rhyolite associated with allochthonous late Paleozoic beds on the north slope of the eastern De Long Mountains give strong evidence for felsic igneous activity during Carboniferous time.

A thicker, somewhat expanded section of late Paleozoic rocks is exposed north of the Shishakshinovik pluton. Tectonic disorder probably accounts for the limited exposure of the topmost unit in the sequence. On the side slope of one ridge where this unit was observed, dismembered layers of grayish orange-weathering calcareous siltstone occur within dark-colored phyllite folded about Lisburne carbonates. On the ridge crest light-colored phyllitic and quartzitic beds appear to lie conformably upon the Lisburne. Pale yellowish-orange phyllite is infolded with Lisburne on a nearby ridge. None of these varicolored metaclastic rocks occur in the underlying sequence, and they resemble none of the rocks in other nearby units. They are, however, lithologically similar to the top unit, the Permian and Triassic Sadlerochit Group, in the subthrust late Paleozoic sequence at Mount Doonerak about 350 km to the east (Dutro and others, 1976). Below the metaclastic rocks is cherty carbonate, about 100 m thick, of the Lisburne Group. It consists of intervals of black limy carbonate, white thin-bedded dolomite, and, at the base, fossiliferous limestone with black chert. Gross structure approximates a tectonically slivered, recumbent syncline, as implied by duplication of a black phyllitic unit above and below the section. The phyllitic shale has uniform lithology except for a few thin reddish-weathering crinoidal limestone beds. An assemblage of conodonts of Osage age (J. W. Huddle, written commun., 1973) indicates a stratigraphic level correlative with the Kayak Shale of the north and northeastern Brooks Range. The unit appears to have a sharp lithologic break with the Lisburne Group above and grades into coarser clastic rocks below. Between 100 and 200 m of thick-bedded quartzite, phyllite, and conglomeratic quartzite, as coarse as cobble size, forms the base of the sequence. Locally, basal beds have been altered by the underlying granite. This late Paleozoic sequence clearly correlates with the similar sequence at Mount Doonerak and was probably once coextensive with it. Therefore, the coarse clastic unit can be assigned to the Kekiktuk Conglomerate as the basal clastic unit at Mount Doonerak has been.

Lithologic variation in the late Paleozoic sequence at the Komakak Creek locality, 25 km north, seems relatively minor. As far as can be determined from the internally disturbed and dismembered strata there, the widespread basal clastic unit consists of light-colored to black quartzite and phyllite. The Kayak Shale grades up from the black quartzite and crops out more widely as a result of thickening around the thin Lisburne Group in the core of a recumbent syncline. No exposures of the Sadlerochit are recognized here.

Mull and Tailleur (1977) emphasized the identification of the Doonerak sequence with the late Paleozoic sequence that transgressed northward across the northeast Brooks Range and speculated on the tectonic and subsurface implications. The transgressive late Paleozoic sequence is nearly 400 km from the Topagoruk test well, south of Point Barrow, which penetrates what must be the northern shoreward limit of the sequence. If this sequence is continuous to the Topagoruk stratigraphic section, coeval but lithologically different rocks in the Endicott Mountains to the north must be allochthonous. Another aspect is the possible correlation of this section with a probably dislocated and unconformable sequence on the Lisburne Peninsula. There, the Upper Mississippian part of the Lisburne Group intertongues with the top of Mississippian coaly beds exposed in the vicinity of Kapaloak Creek Tailleur, 1965).

Late Paleozoic sedimentation, therefore, appears to have transgressed most of what has become the Brooks Range. It covered an erosional surface on rocks now forming the core of the fold belt and may require postulation of a pre-Mississippian upland, perhaps with local basins, extending northward beyond Point Barrow.

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Sadlerochit(?) Group in the Schwatka Mountains, south-central Brooks Range

By C. G. Mull and I. L. Tailleur

C. G. Mull joined I. L. Tailleur in a mapping project in the Ambler River quadrangle during the 1976 field season, in a continuation of a regional structural study begun in 1975. Unpublished reconnaissance mapping by Tailleur in 1955 and by G. H. Pessel in 1973 in the area of Shishakshinovik Pass (T. 34 N., R. 11 and 12 E., Kateel River Meridian) revealed the presence of Lisburne Group carbonates in a terrain composed dominantly of pre-Mississippian carbonates and schists (Pessel and others, 1973; Pessel and Brosgé, 1977). The 1976 field program discovered that sandstone and siltstone outcrops of probable Sadlerochit Group overlie the Lisburne Group in this area.

The exposures are located on the east side of the middle headwater tributary of the Kogolktuk River in sec. 4, T. 23 N., R. 12 E. (Kateel River Meridian) (see fig. 14). Outcrops of reddish-brown-weathering quartzose siltstone grading to black phyllitic shale overlie the Lisburne on the crest of a ridge at about 1,270 m elevation. Slivers of fine-grained quartzose sandstone are found down the slope to the west of the ridge crest. Although no fossils were found, the section is very similar to the fossiliferous Sadlerochit Group described by Dutro and others (1976) from the north side of Mount Doonerak in the Wiseman quadrangle. The rocks are unlike any of the pre-Lisburne rocks mapped in the area.

The Lisburne Group in the area of Shishak-

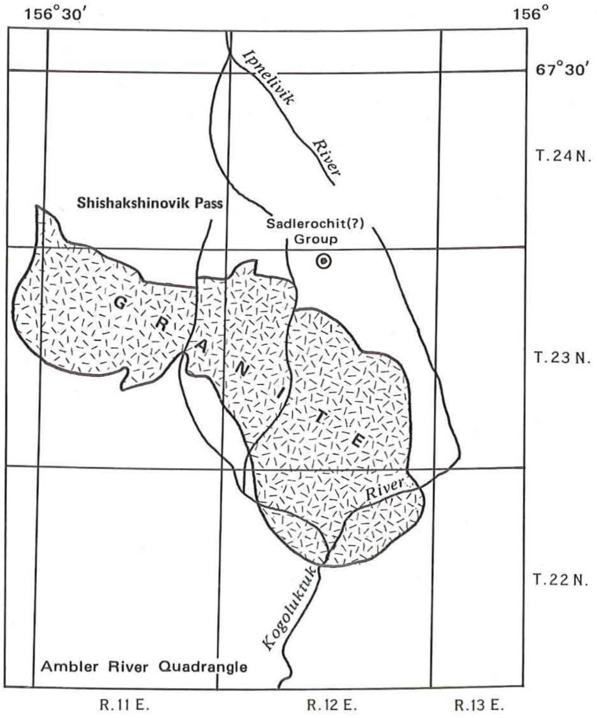

FIGURE 14.—Sketch map showing outcrop of probable Sadlerochit Group. Granite generalized from Pessel and Brosgé (1977).

shinovik Pass is similar to other exposures of Lisburne discovered in the Schwatka-Baird Mountains area (Tailleur and others, 1977). In the Shishakshinovik Pass area it overlies fossiliferous Kayak Shale and a thin resistant unit of schistose quartzite considered to be the Kekiktuk Conglomerate (Pessel and Brosgé, 1977). In sec. 6, T. 23 N., R. 12 E., the Kekiktuk is about 15 m thick; it dips approximately 45° N. and overlies a thick unit of white-weathering contorted schistose conglomeratic quartzite that dips approximately 10° N. In sec. 9, south of the exposure of probable Sadlerochit Group, the Kekiktuk seems directly to overlie a Cretaceous granite, which appears to have intruded the white schistose quartzite unit seen elsewhere beneath the Kekiktuk Conglomerate.

Regionally the entire complex of Kekiktuk, Kayak, Lisburne, and Sadlerochit(?) dips north off the north flank of the granite. The sequence is overlain by regionally north-dipping allochthonous sheets composed dominantly of Devonian and older rocks overlain by scattered exposures of Mississippian clastic and minor carbonate rocks. North of the Noatak River, a sequence of regionally north-dipping lower Paleozoic carbonates and thick Upper Devonian Hunt Fork Shale and Kanayut Conglomerate forms the Endicott Mountains and is thrust over the northern Schwatka Mountains allochthonous rocks (Mull and others, 1976).

The sequence on the north flank of the granite is very similar to the sequence exposed on the north side of Mount Doonerak (Dutro and others, 1976) and is in a similar structural relationship beneath the overlying allochthonous rocks. The sequences at Shishakshinovik Pass and Mount Doonerak are very similar to correlative sequences in the northeastern Brooks Range, as outlined by Dutro and others (1976). The discovery of probable Sadlerochit Group in the Schwatka Mountains further strengthens the interpretation of the Endicott Mountains as an allochthonous thrust from the south (Mull and others, 1976) and favors the hypothesis that the Mount Doonerak area originated as a structural window, as discussed by Dutro, Brosgé, Lanphere, and Reiser (1976). The terrane formed by the Kekiktuk to Sadlerochit sequence and the unconformably underlying rocks is probably the parautochthonous core of the Brooks Range, exposed intermittently along the axis of a regional anticlinorium (Mull and others, 1976).

Regional stratigraphic relationships in the Brooks Range date the major thrusting as Early Cretaceous (Mull and others 1976; Tailleur and Brosgé, 1970). However, potassium-argon dates from the granitic intrusions of the Schwatka Mountains are Senonian to Cenomanian (Pessel and others, 1973; Brosgé and Reiser, 1971). These dates suggest that the anticlinorial core of the southern Brooks Range was uplifted after the large-scale thrust transport of the Brooks Range allochthons.

Palinspastic restoration of the allochthonous sheets of the Endicott Mountains to a relative pre-thrusting location that was south of the Cretaceous granite and probably south of the entire present Brooks Range leads to major implications concerning the evolution of northern Alaska. The Late Devonian clastic wedge composed of the Kanayut Conglomerate and Hunt Fork Shale is considered to have been derived from erosion of an extensive tectonic land. This source area has been called the Barrow platform (Payne and others, 1952), the Arctic platform (Payne, 1955; Miller and others, 1959), the Innuitian foldbelt (Tailleur and Brosgé, 1970), Barrovia (Tailleur, 1973), and the Beaufort uplift (Morgridge and Smith, 1972). The boundary of this tectonic land during the Late Devonian has been indicated or inferred to have been somewhere north of the present Brooks Range; some workers have inferred that it lay north of the present coastline.

In much of the Arctic Slope subsurface and in the northeastern Brooks Range geologists have long recognized that the uplift from which the Devonian clastic wedge was derived is unconformably overlain by a basal transgressive clastic unit, the Mississippian Kekiktuk Conglomerate (Brosgé and others, 1962). Throughout this area the Kekiktuk forms the base of the conformable sequence that includes the overlying Kayak Shale, Lisburne Group, and Sadlerochit Group. The presence of the Kekiktuk to Sadlerochit sequence in the Mount Doonerak area, the discovery of the same sequence in the Schwatka Mountains, and the absence of the Kanayut-Hunt Fork wedge in both areas suggests that the inferred southern limit of the Late Devonian uplift (Barrow platform, Arctic platform, Barrovia, or Beaufort uplift) must be shifted at least as far as the area of the present southern Brooks Range. The suggestion of a Late Devonian orogenic belt in the Schwatka Mountains area thus opens the possibility that the pre-Late Devonian rocks of the southern Brooks Range may have been subjected to two orogenic episodes: (1) the Mesozoic orogeny that developed the present Brooks Range, and (2) an earlier event (or events) from which the Late Devonian Kanayut and Hunt Fork clastic wedge was derived. The possibility that two major orogenic events may have affected the area may modify concepts of the genesis of ore deposits along the south margin of the Brooks Range.

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Apparent south vergent folding and possible nappes in Schwatka Mountains

By C. G. Mull

Reconnaissance in the Schwatka Mountains has revealed the presence of a number of structures with apparent south vergence. This apparent structural style contrasts with the style of much of the Brooks Range, which exhibits prominent north-vergent folds and thrusts. Large-scale south-vergent folds have been noted in the area of the Alatna, Reed, Mauneluk, and Kugrak River drainages in the Survey Pass quadrangle. The folds are best exhibited in the massive, resistant, light-gray-weathering limestone and marble of the Silurian to Upper Devonian Skajit Limestone. These rocks stand out in sharp contrast to the adjacent less resistant, dark-weathering rock units, which are dominantly black shale, phyllite, calcareous schist, and other greenschist-grade metamorphic rocks. In some of the folds both the upper and inverted limbs are clearly exposed in classic alpine nappe forms. No detailed mapping for complete documentation of the geometry has been carried out on any of the folds. However, reconnaissance maps showing the distribution of the major rock units in the Survey Pass and adjacent Wiseman quadrangle have been compiled by Brosgé and Reiser (1971) and Brosgé and Pessel (1977). Mapping in the Ambler River quadrangle to the west has been compiled by Pessel and Brosgé (1971).

Although granitic bodies underlying the Arrigetch Peaks and Mount Igikpak occupy a large area in the south-central Survey Pass quadrangle, the apparent south-vergent folds do not appear to be the direct result of proximity to the granitic masses. However, in a broad sense, these granites also exhibit a southward asymmetry. On the north side of the granites, the regional dip of the overlying stratigraphic units is approximately 30° to 45° to the north or northeast. On the south side of the granites, the flanking sedimentary units appear to dip northward under the margin of the igneous rocks at dips of from 30° to 70°; tracing of these units both eastward and westward reveals regional dips to the south. These relations suggest that much of the north-dipping sedimentary section adjacent to the south side of the granitic bodies may be overturned. The apparent asymmetry of the Arrigetch Peaks pluton was diagrammatically illustrated but not discussed by Mull, Tailleur, Mayfield, and Pessel (1976). The regional relations suggest that at least the upper levels of the granitic bodies were intruded under a stress field that favored a south-vergent structural style.

Potassium-argon dates from the Arrigetch Peaks range from 86 to 92 m.y. (approximately Turonian to Senonian, Brosgé and Pessel, 1977; Brosgé and Reiser, 1971). These dates suggest that in the southern Brooks Range a stage of dominantly vertical basement-involved tectonics followed the Early Cretaceous (dominantly Neocomian) period of extreme crustal shortening indicated by the allochthonous units of the Endicott and De Long Mountains (Mull and others, 1976; Tailleur and Brosgé, 1970). This stage of dominantly vertical uplift probably formed the regional anticlinorium of the Schwatka Mountains and adjacent areas of the southern Brooks Range. The sedimentary and metasedimentary rocks of the area thus probably represent the uplifted parautochthonous core of the Brooks Range from which the formerly overlying allochthonous sheets have been eroded. Evidence for the allochthonous nature of parts of the Endicott Mountains has been discussed by Mull, Tailleur, Mayfield, and Pessel (1976) and Dutro, Brosgé, Lanphere, and Reiser (1976).

Consideration of the sequence of events and structural style of the Schwatka Mountains and adjacent Endicott Mountains suggests that the area represents an alpine root zone as defined by Roeder (1973). Roeder suggests that such a zone forms when the direction of subduction at a compressional plate boundary reverses or begins to flip to the opposite polarity. In such an event the thrust belt formed during the initial stage of subduction and thrusting is thought to be uplifted and kinked by the development of incipient subduction and thrusting in the opposite direction. Erosion then exposes the vertically dipping or overturned stumps of thrust sheets that were formerly deeply buried under the stack of overlying imbricate allochthonous units. The apparent regional relations (fig. 15) in the Brooks Range are compatible with Roeder's concept of formation of an alpine root zone. However, extensive fabric data are needed to document further this inferred regional style and sequence of events in the origin of the Brooks Range.

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Arctic hydrology studies

By C. E. Sloan

A hydrologic reconnaissance of the western Arctic area between Kotzebue and the Colville River was made in April 1976. The locations of nine springs and their associated icings in the vicinity of Kotzebue were determined by an examination of Landsat imagery. The springs ranged in discharge from less than 0.04 to 0.37 m^3/s and averaged about 0.20 m^3/s. Except for Kavrorak Spring near Kivalina, which was slightly brackish, the water quality of the

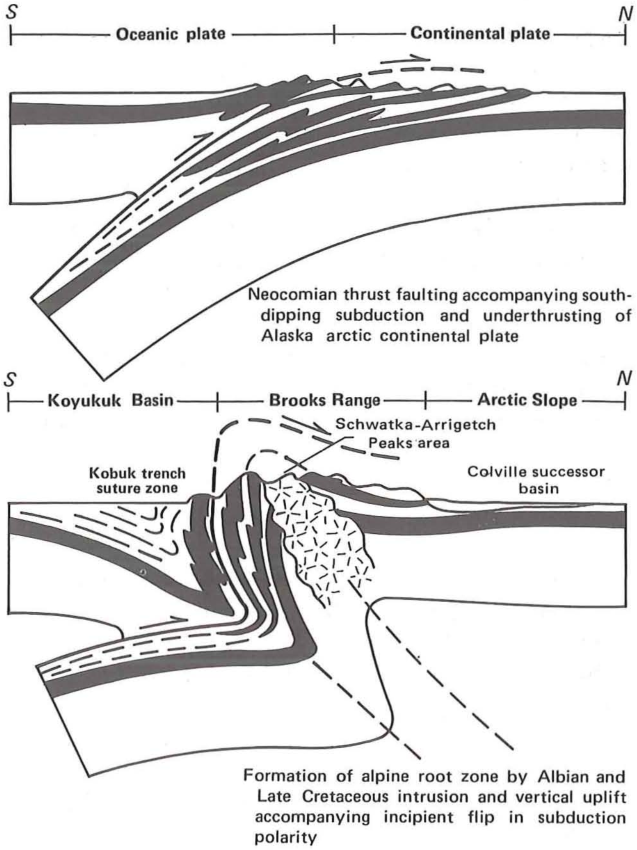

FIGURE 15.—Diagrammatic inferred sequence of events in tectonic evolution of the Brooks Range. Modified from Roeder (1973).

springs was excellent for drinking water supplies or other intended uses.

No springs or icings were evident on the imagery for the area north of Point Hope, and none were found in the field.

No stream flow could be found or measured in any of the streams between Point Hope and Point Barrow, although pools of water under ice were found in several of the larger streams.

Teshekpuk Lake, third largest in Alaska, is about 6 m deep near the center where sampled. Eight other lakes sampled in this area were about 2 m deep.

North Slope water resources studies

By Gordon L. Nelson

The principal objective of this study was to define the availability of water during winter, when freezing of surface water sources creates severe shortages for consumers. From electric resistivity studies (P. Hoekstra, written commun., 1976), seasonal formation of aufeis, and lack of recharge to river reaches dewatered by consumers, it appears that flow both in river channels and through the underlying gravels ceases entirely during late winter throughout much of the North Slope.

The formation of aufeis seems to be a reliable indicator of flowing water. Aufeis ceases to form on a reach of river when flows drop to very low levels. Where flow continues throughout the year, large thicknesses of aufeis continue to build throughout the winter. Since aufeis formation is visible from satellite imagery, remote sensing is useful in determining times of very low to no flow.

Because of the inadequacy of natural water sources during the late winter, artificial storage of summer streamflow appears to be a logical alternative to costly and potentially environmentally damaging withdrawals from lakes and rivers. Summer streamflow is more than adequate both to recharge storage facilities and to supply summer demands.

EAST-CENTRAL ALASKA

A newly identified sequence of rocks in the Yukon-Tanana Upland, Alaska

By Florence R. Weber, Helen L. Foster, and Terry E. C. Keith

Metamorphic rocks that crop out between the Chena and the upper Salcha River valleys of the Yukon-Tanana Upland (see fig. 2(8)), Alaska have been divided into five locally mappable units. These rocks were originally mapped as part of the "pre-Middle Ordovician," by J. B. Mertie (Mertie, 1937), but Mertie's descriptions of the rocks were derived primarily from exposures at the northwestern edge of the upland in the Livengood area where the rocks are considerably different from those of the Chena-Salcha area.

The metamorphic rocks are divided into the following units, listed in apparent ascending order: (1) quartzite and quartz-mica schist with interlayered amphibole gneiss and schist, (2) phyllite and recrystallized limestone, (3) black quartzite, (4) maroon quartzite, and (5) metamorphosed arenite and greenschist.

The first unit consists primarily of fine- to medium-grained quartzite and quartz-mica schist, commonly garnetiferous, with interlayered amphibole gneiss and schist. Foliation is isoclinally folded. The rocks exposed at the surface are greenschist facies, except locally where they may be upgraded by thermal metamorphism. In the Eielson deep test hole (Forbes and Weber, 1975) rocks believed to be in this unit may exceed 2,300 m in thickness and range in grade from greenschist to amphibolite facies (from garnet to kyanite isograd).

The second unit consists primarily of gray phyllite, calcareous phyllite, and thinly layered white recrystallized limestone. Near the base of the unit are amphibole gneiss and schist similar to those in the first unit. Veinlets of white quartz and white quartz mixed with calcite are ubiquitous. In the upper Chena River area, the rock of this unit is mostly a fine-grained medium-dark-gray very thin bedded slightly recrystallized limestone. Groups of beds composed primarily of limestone are commonly 15 to 24 m thick, but some are as thick as 150 m. In the lower Chena River area, the rock is mostly calc-phyllite, grading into calc-schist or thinly layered medium-grained marble. This unit is present at the top of the Eielson deep test hole where it is more than 760 m thick, but the thickness may be increased somewhat by tight folding. Near the top of the unit, dark-gray quartzite is locally interlayered with calcareous rocks and the contact with the overlying unit may be gradational.

The third unit consists of fine-grained dark-gray to black quartzite interlayered with argillite, black slaty appearing rock, and light-gray quartzite. Some of the fine-grained black quartzite could be metamorphosed chert. The thickness of this unit is unknown but could be as much as 3,000 m.

In places, finely banded maroon quartzite, interlayered with dark-gray quartzite, spotted phyllite, and, in a few places, white and gray coarse-grained marble, all intricately folded and sheared, occurs as a fourth unit between the black quartzite and the metamorphosed arenite units. These rocks mostly occur near small plutons and have been affected by thermal metamorphism.

A fifth unit, composed of metamorphosed and sheared arenite, greenschist, quartzite, marble, and phyllite, is mapped in contact with either the black quartzite or the maroon quartzite. Some of the metamorphosed arenites might be termed semischists and were probably derived mostly from arenaceous sediments but also from arkosic sediments and graywackes, including tuffaceous graywackes. They are generally light gray to light green and are characterized by grains ("eyes") of strained quartz which range from 3 to 8 mm in diameter. Rocks containing abundant quartz "eyes" have been commonly referred to in the field as "grit." The greenschists are light to dark green and generally well foliated. Minor amounts of green or gray phyllite are interlayered locally. Recrystallized gray limestone and, less commonly, orange-weathering dolomite are also interlayered. These rocks are probably low to middle greenschist facies. Their thickness is unknown, but map relations suggest that it might be in the range from 1,500 to 3,000 m.

The age of the protoliths of metamorphic rocks of the Chena-Salcha area is unknown, but they definitely predate the Mesozoic granitic plutons in the area. No fossils have yet been found.

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Ultramafic rocks near Volkmar Lake, Big Delta quadrangle, Yukon-Tanana Upland, Alaska

By Terry E. C. Keith and Helen L. Foster

Ultramafic rocks occur as one or more small masses in the metamorphic terrane northeast of Volkmar Lake in the Big Delta A-2 and A-3 quadrangles. An aeromagnetic high roughly delineates the area of outcrop. Most of the ultramafic rocks weather medium to dark brown. The rocks are mostly well foliated with foliation parallel to that of the nearby country rock. Locally the rock is massive.

The well-foliated rocks are composed of layers consisting dominantly of amphibole or chlorite. Serpentine is commonly present in the amphibole layers. Clots of fairly large magnetite crystals occur, and locally abundant small magnetite grains are concentrated along the foliation and may outline microfolds. Actinolite and talc are present in places in differing minor amounts.

The more massive type of ultramafic rock consists dominantly of serpentine, mostly antigorite, with monor amounts of magnetite, actinolite, and chlorite. Compressed biotite in some zones indicates that the rock was originally peridotite. However, no other textures or any primary minerals remain. Large (about 30 mm long) elongate amphibole crystals randomly oriented in a matrix of fine-grained serpentine with or without chlorite and talc are locally common.

Other isolated foliated masses of ultramafic rocks occur elsewhere in the metamorphic terrane of the Big Delta quadrangle and were probably tectonically emplaced. Textures and mineralogy indicate that the ultramafic rocks were regionally metamorphosed with the surrounding country rocks and thus were emplaced prior to the major regional metamorphism of the area.

Gneiss dome in the Big Delta C-4 quadrangle, Yukon-Tanana Upland, Alaska

By Helen L. Foster, Florence R. Weber, and Cynthia Dusel-Bacon

A large area, at least 400 km², of sillimanite gneiss has been mapped in the central part of the Big Delta C-4 quadrangle south of the Salcha River. The gneiss is fairly uniform appearing over the area and is dominantly medium-grained quartz-biotite-muscovite-sillimanite gneiss. The margins of quartz grains are mostly slightly crushed and granulated, and the grains are fractured. Most of the gneiss is well weathered. Outcrops commonly show a crude layering, possibly caused by weathering along flat-lying limbs of folds. Locally, small lenses and layers of marble are preserved in the gneiss body.

The boundaries of the sillimanite gneiss have only been roughly defined, but on the north it is bordered by quartz-mica garnet schists interlayered with marble and quartzite. Some of the schists contain staurolite, sillimanite, kyanite, and andalusite.

This is the first occurrence of kyanite found in the Big Delta quadrangle, except in the Eielson deep test hole at a depth of 2,504 m. Kyanite is also rare elsewhere in the Yukon-Tanana Upland, probably partly because of the quartzitic composition of the metamorphosed sediments but perhaps also because sediments metamorphosed deep enough in the crust to form kyanite are rarely exposed.

The gneiss crops out in a topographically high area in which drainage heads near the center of the gneissic terrane and streams extend out in many directions. The preliminary mineralogy and map relations of the gneiss terrane suggest a gneiss dome.

The Shaw Creek fault, east-central Alaska

By Travis Hudson, Helen L. Foster, and Florence R. Weber

A helicopter reconnaissance of parts of the Shaw Creek fault in east-central Alaska (fig. 16) was completed on July 19, 1976 as part of the Alaska Geologic Earthquake Hazards Project. This fault, one of several northeast-trending structures in east-central Alaska (Foster, 1970, 1972), was examined primarily to determine if surficial features indicative of recent tectonic displacement are present. The fault was included in a summary of active faults of Alaska by Brogan and others (1975). It is in the Yukon-

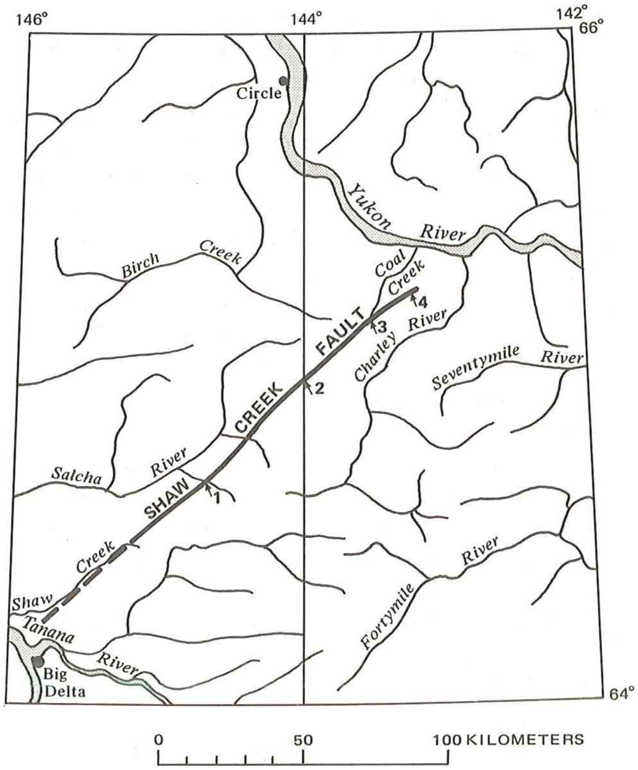

FIGURE 16.—Location of the Shaw Creek fault in east-central Alaska and index to localities mentioned in text; (1) Porcupine Creek, (2) Lost Creek, (3) upper Hanna Creek, and (4) upper Sam Creek.

Tanana Upland, a part of Alaska that is only locally glaciated.

The Shaw Creek fault trends N. 40°-50° E. for about 190 km from near the mouth of Shaw Creek on the Tanana River (Big Delta quadrangle) to near the Tintina fault zone in the vicinity of Sam Creek (Charley River quadrangle). Many parts of the northern two-thirds of the fault are surficially or topographically expressed, but the southern part, in the vicinity of lower Shaw Creek, is covered by alluvium; the fault is approximately linear and everywhere appears to be vertical or very steeply dipping. The distribution of bedrock units adjacent to the fault suggests that the southeast side is upthrown (Foster and others, 1973).

The fault was examined northeast of Porcupine Creek in the Big Delta quadrangle over about the north half of its known extent. From south to north this part can be divided into four segments that differ in their general characteristics of surficial or topographic expression.

(1) A 35-km segment from Porcupine Creek to near Lost Creek in the Big Delta quadrangle is topographically expressed by alined, broad and generally symmetric saddles on the ridges. As a whole, this segment lacks surficial expression along lower ridge slopes and in the valley floors.

(2) A 32-km segment from the headwaters of Lost Creek in the Big Delta quadrangle, across the northwest corner of the Eagle quadrangle to the vicinity of upper Hanna Creek in the Charley River quadrangle, has several types of surficial features associated with it. In addition to the alinement of major saddles on ridges, this segment of the fault is marked by the presence of small ponds in the low parts of some saddles, alined springs, and commonly a distinct break in vegetation. Lithologic contrasts across the fault cause local subdued slope breaks, such as along the trace just east and north of VABM Bend in the southeastern corner of the Charley River quadrangle. Two pingos, apparently located on the fault trace, were observed along this segment.

(3) A 16-km segment from upper Hanna Creek to about 5 km east of Mount Kathryn in the Charley River quadrangle has a distinctive topographic expression, which is especially clear along the approximately 6.5 km of the fault just east of upper Coal Creek where the trace is defined by the alinement of sharp notches on adjacent ridges. Where the fault crosses to the east side of Coal Creek, a well-defined vegetation break rather than topographic break is present for a few kilometers. This segment was not checked on the ground, but the distinct topographic break west of upper Coal Creek may be due to the juxtaposition of very different lithologic units. Brabb and Churkin (1969) have mapped a contact between adamellite and gneiss to the east against mica schist to the west in the vicinity of upper Coal Creek. This contact may coincide with the Shaw Creek fault.

(4) The approximately 16 km of fault from east of Mount Kathryn northeast to the Tintina fault zone in the Charley River quadrangle is not clearly expressed either topographically or surficially, but it may trend down the main drainage of upper Sam Creek. If it does, then the northeastern end of the fault bends in a more easterly direction compared to its general strike farther to the southwest (Foster and others, 1973, p. 390). This deflection may reflect right-lateral displacements on the Tintina fault.

Surficial features indicative of recent tectonic displacements, such as scarps or deflected drainages, were not observed throughout the length of the Shaw Creek fault that was studied. The lack of such features suggests that the Shaw Creek fault is inactive. All of the fault-related surficial or topographic features that we studied appear to be produced by differential erosion of juxtaposed lithologic units, preferential erosion along the fault zone, or locally by the presence of a groundwater barrier.

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Geochemical anomalies in bedrock, west half of Kantishna River quadrangle

By Robert M. Chapman

R. M. Chapman and W. W. Patton, Jr. collected 75 bedrock samples for geochemical analysis in the west half of the Kantishna River quadrangle (see fig. 2(9)). Sampling was done, as time permitted, in conjunction with reconnaissance geologic mapping (Chapman and others, 1975). Five rock types, irrespective of age, are represented by the samples: (1) felsic and intermediate plutonic, hypabyssal and extrusive rocks, including some dikes and quartz veins; (2) mafic plutonic and hypabyssal and (or) extrusive rocks; (3) hornfels and hornfelsic rocks; (4) sedimentary and low-grade metasedimentary rocks; and (5) iron-stained, low-grade metasedimentary rocks, with some disseminated pyrite, intruded by many small dikes and quartz veins. No metalliferous deposits were found, but some prospecting was reportedly done in the Bitzshtini Mountains many years ago.

Background and anomalous amounts of 16 selected elements in the 75 samples are given in table 1. These amounts are conservatively interpreted from inspection of the analytical data and from comparisons with values used in other Alaskan geochemical surveys and in various published tables of crustal abundance of elements. On the basis of these figures, anomalous amounts of one or more of the 16 elements occur in 49 of the 75 samples. At least a few anomalous amounts of two or more of these elements are found in each of the five rock groups, but the

TABLE 1.—*Summary of amounts of 16 elements in bedrock samples from west half of Kantishna River quadrangle*

[Semiquantitative spectrographic analyses by C. Heropoulos; Au and Hg analyses by J. D. Hoffman. N.d., not detected at limit of detection (parentheses) or at value shown.]

Element	Background		Anomalous	
	No. of samples	Range (ppm)	No. of samples	Range (ppm)
Ag	68	N.d. (.07)	7	0.7-20
Au[1]	75	N.d. (.05)	--	--
As	70	N.d. (100)	5	300-1,000
B	68	N.d. (2)-200	7	300-10,000
Be	65	N.d. (0.7)-5	10	7-20
Bi	70	N.d. (7)	5	7-30
Cu	69	0.7-100	6	150-700
Hg[2]	68	N.d. (.02)-.10	7	0.12->10
Li	53	N.d. (100)	12	100-1,000
Mo	73	N.d. (2)-5	2	10
Pb	61	N.d. (7)-50	14	70-1,000
Sb	74	N.d. (20)	1	200
Sn	65	N.d. (2)-7	10	10-200
V	73	N.d. (1)-200	2	500-1,000
W	75	N.d. (10)	--	--
Zn	72	N.d. (15)-200	3	300-2,000

[1] Atomic absorption method

[2] Mercury detector method

largest number of elements (13) that are present in anomalous amounts, and also the highest average of anomalous values per sample (2.8), are in the group-5 rocks.

Anomalies are particularly common within a 50-km^2 area that includes the Bitzshtini Mountains and several adjacent hills at the head of the Cosna River. Quartzitic sandstone, quartz wacke, slaty siltstone, phyllite, and some chert, all probably of early Paleozoic age, intruded by numerous quartz veins and small rhyolitic, and rarely mafic, dikes are exposed in this area. The rocks are conspicuously iron stained, and some show minor hornfelsic alteration and contain andalusite and tourmaline. Sixteen samples, including 8 of the 10 from group-5 rocks, are from this area, and 14 of these contain anomalous amounts of one or more of the elements listed in table 1. Ag, Sn, As, B, Bi, and Li anomalies are most abundant, and a few Be, Zn, Cu, Mo, Pb, and V anomalies also occur (table 2). This concentration of anomalies and the geologic setting are suggestive of a granitic body at shallow depth.

On the basis of this very limited geochemical reconnaissance, the area in and around the Bitzshtini Mountains merits additional geologic and geochemical investigations to evaluate its mineral-deposit potential. Felsic and intermediate igneous rocks and adjacent hornfelsic rocks in the marginal zones of several plutons and the rhyolitic rocks in the southwest corner of the quadrangle (Chapman and others, 1975) also show enough anomalous amounts of several elements to encourage additional sampling.

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Geohydrology of the Fairbanks-North Star Borough

By Gordon L. Nelson

A study of water levels in wells in the Birch Creek Schist of former usage shows that levels continue in a four-year decline; some water levels in the uplands have dropped as much as 9 m in the past four years. During this period precipitation has been about 25 percent below normal.

Determining natural losses of ground water as base flow to streams is desirable in establish-

TABLE 2.—*Anomalies, in parts per million, in 16 bedrock samples from area at head of Cosna River*

[Semiquantitative spectrographic analyses by C. Heropoulos]

Sample No.	Description	Ag	As	B	Be	Bi	Cu	Li	Mo	Pb	Sn	V	Zn
74ACh-40	Schistose quartz wacke, slaty siltstone, quartz veins	20	--	--	7	30	700	--	--	1,000	200	--	2,000
73ACh-79	Quartzitic sandstone, quartz veins	--	1,000	>2,000	--	--	--	--	--	--	--	--	--
73ACh-80	Vuggy quartz vein	--	300	>2,000	--	--	--	--	--	--	--	--	--
74APa-28.1	Porphyritic rhyolite	1.5	--	500	10	--	--	--	--	--	--	--	--
74ACh-84	Quartzitic sandstone, siltstone, felsic dikes, quartz veins	0.7	500	10,000	7	7	--	--	--	--	15	--	--
74ACh-85	Metasiltstone, felsic dikes, quartz veinlets	--	--	--	7	20	--	200	--	--	15	--	--
74ACh-87	Hornfels, altered sandy siltstone, with andalusite and tourmaline; dikes, quartz veins	--	300	7,000	--	10	--	--	--	--	15	--	--
73ACh-83	Quartzitic sandstone, quartz veins	--	--	--	--	--	--	--	--	--	--	--	--
74ACh-93	Graphitic phyllite	0.7	--	--	--	--	--	--	10	--	--	1,000	--
74ACh-95	Porphyritic rhyolite	1.0	--	--	--	7	--	300	--	--	15	--	--
74ACh-96	Meta-gabbro or ultramafic dike	5.0	700	--	--	--	--	--	--	--	--	--	700
74ACh-97	Chert, Fe-coating	--	--	--	--	--	--	200	--	--	--	--	--
73ACh-85	Rhyolite	1.0	--	--	--	--	--	--	--	--	15	--	--
74ACh-67	Hornfelsic metawacke, siltstone	--	--	--	--	--	--	--	--	--	--	--	--
74ACh-66	Slightly hornfelsic metawacke	--	--	--	--	--	100	--	--	--	--	--	--
74ACh-65	Quartzitic sandstone, slaty siltstone, quartz veins	--	--	--	--	--	300	--	--	--	--	--	--

ing the quantity of water that can safely be withdrawn for domestic consumption. In several small basins adjacent to the Chena River flood plain, loss as base flow from the schist amounts to only 0.05–0.1 cm/yr. In the Caribou Creek area, 24 km north of Fairbanks, this loss is about 5 cm/yr.

Arsenic concentrations in excess of Environmental Protection Agency standards for drinking water have been detected in numerous wells northwest of Fairbanks. The areal distribution and causes of this contamination are not well understood; however, the occurrence seems to be natural since some of the contaminated wells are in drainages that have not been disturbed by mining activities. High levels of arsenic also seem to correlate with high levels of iron, suggesting concentration in a reducing environment.

WEST-CENTRAL ALASKA

Lower Paleozoic graptolitic section in the Terra Cotta Mountains, southern Alaska Range

By Michael Churkin, Jr., Bruce L. Reed, Claire Carter, and Gary R. Winkler

Field investigations in the Terra Cotta Mountains, approximately 35 km southeast of Farewell, indicate that an apparently unbroken lower Paleozoic section of shale, sandstone, and limestone is about 1,000 m thick. The lower part contains an Early Ordovician through Late Silurian marine fauna. Nonfossiliferous limestone and sandstone higher in the section may be Devonian (fig. 17). These rocks form north-trending folds that are overturned to the west. Laboratory studies by Carter document a very complete succession of graptolite faunas, including more than eight zones in the argillaceous lower part of the section. Paleocurrent analyses by Winkler indicate an abrupt incursion in post late Early Silurian time of quartzofeldspathic sandstone and mudstone (turbidites). These sediments were transported from the south into an older deep marine basin that previously had been the site of slow deposition of pelagic ooze and mud derived from the northeast. The sandstone in turn grades upward into thick, nonfossiliferous calcareous siltstone, sandstone, and limestone, and also turbidites that were derived from the east to northeast. Systematic analyses of limestone samples from throughout the stratigraphic section were made for conodonts, chitinozoa, and other noncalcareous fossils, but none were found.

The lower approximately 380 m of the section is a hemipelagic graptolitic shale and ribbon chert that accumulated slowly in a deep oceanic environment, probably on the lower part of a continental slope or a continental rise. These rocks overlie, with apparent conformity, an unknown thickness of phyllitic siltstone and sandstone that may be as old as Cambrian. The encroachment of quartz and feldspar sand detritus from the south indicates an abrupt reversal of major sediment provenance after late Early Silurian time; the source for this detritus may have been an offshore borderland. In the middle 465 m of the section, interbedded quartzofeldspathic turbidites and finely laminated dark limestone grade upward into more than 575 m of detrital limestone, calcareous siltstone, and sandstone. The deposition of abundant calcareous detritus and a return to southwestward-directed currents indicate that by Devonian(?) time the adjacent continental margin to the northeast was again the dominant provenance. Many of these carbonate rocks are impure and nonfossiliferous and have primary sedimentary structures, including graded bedding, that indicate deposition by turbidity currents. We believe, therefore, that they also were deposited in moderately deep water, perhaps as a thick apron on the continental slope. Although the Ordovician graptolitic shale that forms the lower part of the section has not been recognized in sedimentary rocks in the Dillinger River area to the northeast, the middle and upper parts of the section are lithologically similar to and, at least in part, time equivalents of strata in the Dillinger River area.

The stratigraphy established for the Terra Cotta Mountains (fig. 17) provides a reference section for stratigraphic and structural studies elsewhere in west-central and southwestern Alaska and puts constraints on reconstructions of early Paleozoic paleogeography. We believe that these Early Ordovician through Late Silurian rocks represent an ancient continental margin sequence deposited in deep water immediately seaward of bioclastic limestone, including reef deposits north of the Alaska Range that represent a continental shelf. Possible large-scale displacement on the Farewell fault (a segment of the Denali fault) complicates

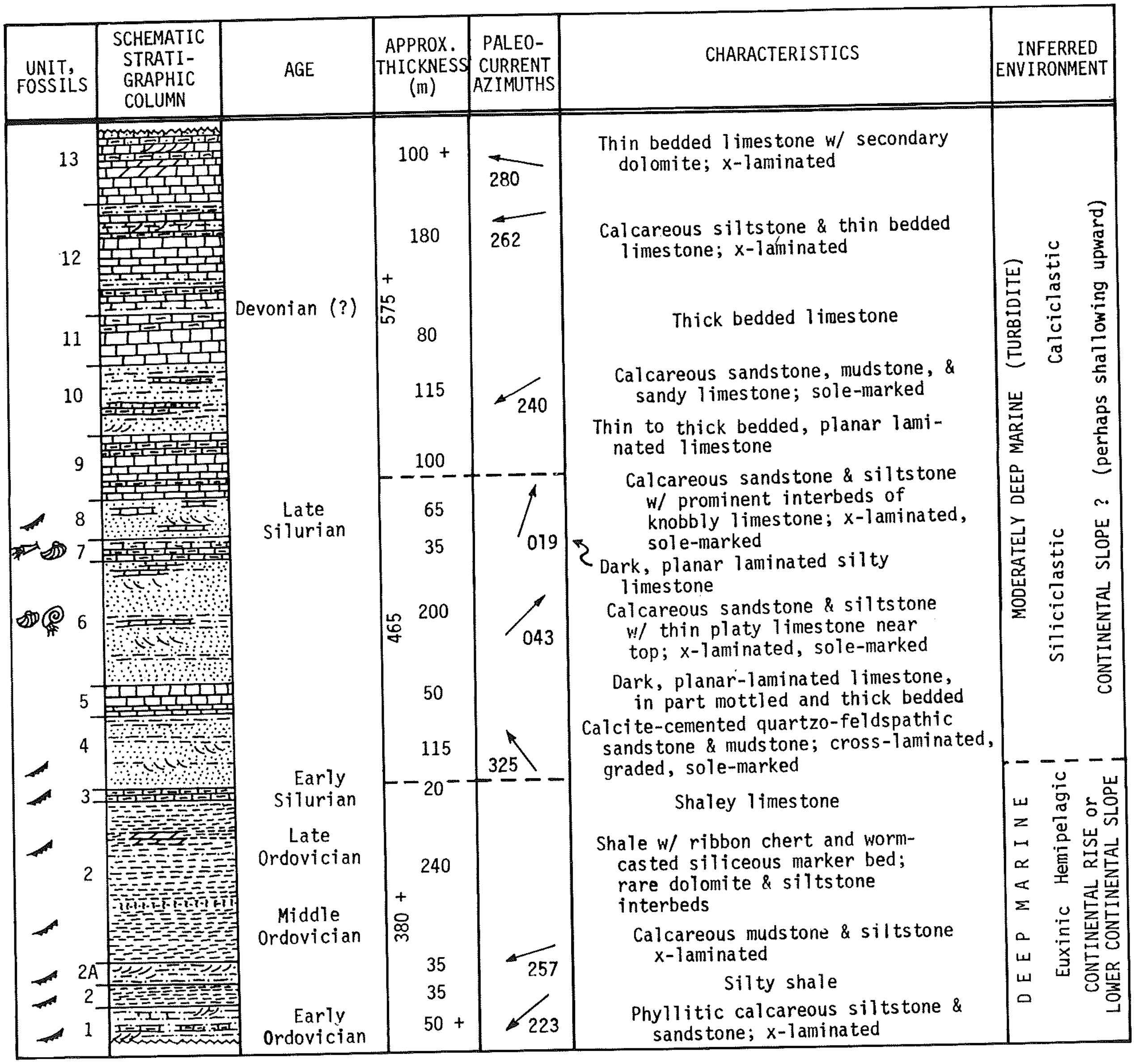

FIGURE 17.—Lower Paleozoic stratigraphic section, Terra Cotta Mountains.

paleogeographic reconstructions. Present evidence, however, indicates that strike-slip movement along the Denali fault in the Mount McKinley area has not exceeded about 40 km in the last 38 m.y. and that the right-lateral movement along the fault may diminish to the west. This assumption is also supported by the presence of a lower Paleozoic carbonate and shale sequence north of the Farewell fault at Lone Mountain, 50 km west of Farewell. If large-scale displacement of contemporaneous lower Paleozoic facies has not occurred along this segment of the Denali fault system, then shoreline and shelf facies may be present in lower Paleozoic rocks that are now concealed in the Minchumina basin and other basins north of the Alaska Range—a useful concept in exploring for petroleum and other commodities that are known to occur along ancient continental margins.

Late Paleozoic and Mesozoic stratigraphy of the Nixon Fork area, Medfra quadrangle, Alaska

By William W. Patton, Jr., J. T. Dutro, Jr., and R. M. Chapman

Results of the stratigraphic investigations of the late Paleozoic and Mesozoic sequence in the

Nixon Fork area are summarized in fig. 18. The lower part of the sequence, shown in section A, includes Permian, Triassic, and earliest Cretaceous (Neocomian) strata. It is exposed along a narrow band between the early Paleozoic carbonate rocks of the northern Kuskokwim Mountains and the Cretaceous terrigenous deposits of the Kuskokwim basin. These strata are composed predominantly of clastic rocks that were derived in large part from the early Paleozoic carbonate terrane.

The upper part of the sequence, shown in section B, is thought to be chiefly Late Cretaceous (Albian) and earliest Tertiary (Paleocene) beds. This section, which has an aggregate thickness of more than 3,000 m, is preserved in the Fossil Mountain syncline, a broad east-west trough within the Kuskokwim basin. The section grades from *Inoceramus*-bearing fine-grained marine sandstone, siltstone, and shale in the lower part into nonmarine plant-bearing "salt and pepper" sandstone and quartz-chert conglomerate in the upper part.

Pre-Ordovician unconformity in central Alaska

By William W. Patton, Jr.

The widespread belief that a major unconformity exists at the base of the Paleozoic section in central Alaska is founded at least in part on observations of H. M. Eakin (1918) in the Telsitna River area of the northern Kuskokwim Mountains. At this classic locality, fossiliferous Ordovician carbonates structurally overlie a metamorphic complex composed of mica schist and quartzite. Eakin described the contact as an angular unconformity and assigned the metamorphic complex a pre-Ordovician age. Reexamination of the Telsitna locality by W. W. Patton, Jr., J. T. Dutro, Jr., and R. M. Chapman strongly suggests that the contact is thrust faulted. Along the contact, slivers and blocks of the carbonate rocks are tectonically mixed with the metamorphic rocks, and at the base of the Paleozoic sequence, the carbonate rocks are greatly sheared and brecciated. The presence of a thrust along the contact does not disprove an unconformity, but, at present, the age of the metamorphic rocks is uncertain and the possibility that the carbonate and metamorphic terranes have been juxtaposed by large-scale lateral transport cannot be ruled out.

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SOUTHWESTERN ALASKA

Blue amphibole occurrences in southwestern Alaska

By J. M. Hoare and W. L. Coonrad

Blue amphiboles have recently been found at five localities in southwestern Alaska. Two localities are in the Goodnews B-7 and B-8 quadrangles; the others are 90 km to the south in the Hagemeister Island C-5 and C-6 quadrangles. In the Hagemeister quadrangle the blue amphiboles are closely associated with a metamorphosed and dismembered ophiolite complex. The amphiboles are in altered, moderately foliated volcanogenic rocks that also contain chlorite, pumpellyite, and actinolite. The two northern localities are in completely recrystallized quartz-chlorite schist and crenulated calcareous schist that contains detrital quartz and clinopyroxene grains.

No lawsonite or other recognized high-pressure minerals have been found. Consequently, the possible tectonic significance is questionable. On the other hand, all of the blue amphibole localities are in, or on the projected trend of, previously recognized fault zones. The fault zones trend northeast, dip southward, and show northwest tectonic transport. These zones probably extend to subcrustal depth because they also contain two or more sheared serpentine bodies, which are interpreted as rootless tectonic blocks because: (1) they are rather small; (2) they are moderately or highly sheared; (3) one of them is in fault contact with limestone; and (4) they are in or near large fault zones. The ultimate origin of the serpentine is presumably in the mantle. The isolated bodies could be pieces of mantle rock, but they probably are tectonically emplaced blocks of serpentinized peridotite that was intruded into the fault zones.

The fundamental tectonic identity of the highly tectonized rocks in the Goodnews and Hagemeister Island quadrangles is not yet understood, but the association of blue amphiboles, serpentinized peridotite and large amounts of pillow basalts suggests that plate tectonics is involved.

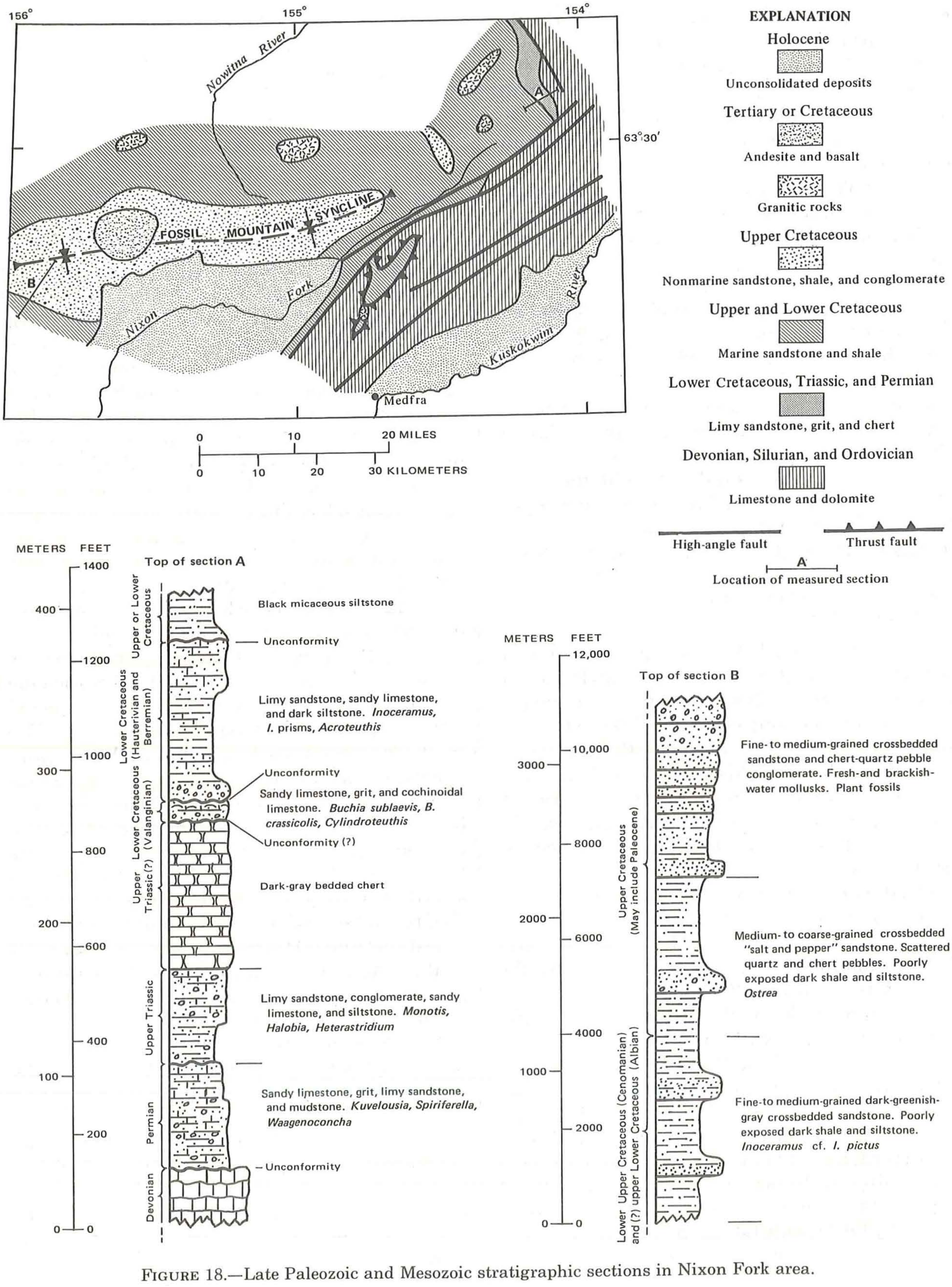

FIGURE 18.—Late Paleozoic and Mesozoic stratigraphic sections in Nixon Fork area.

SOUTHERN ALASKA

A Cretaceous accretionary flysch and melange terrane along the Gulf of Alaska margin

By George Plafker, David L. Jones, and E. A. Pessagno, Jr.

Highly deformed Cretaceous flysch and melange form a belt 1,700 km long and up to 100 km wide along the Gulf of Alaska margin from Chatham Strait to the Kodiak Islands (fig. 2(10), fig. 19). The flysch facies, which predominates, is mainly pelite and volcaniclastic graywacke with minor conglomerate and mafic volcanic rocks that comprise the Sitka Graywacke, part of the Yakutat Group, the Valdez Group, and the Kodiak and Shumagin Formations (Loney and others, 1975; Plafker and others, 1976; Jones and Clark, 1973; Moore, 1969; Moore, 1973). Discontinuously exposed in fault contact along the northern margin of the flysch sequence, and locally interspersed with it, is a melange of flysch, greenstone, limestone, chert, granodiorite, glaucophane-bearing greenschist, and rare bodies of layered gabbro and serpentinite. The melange is characteristically composed of blocks of competent rocks, as much as several kilometers in greatest dimension, enclosed in a pervasively sheared matrix of pelite or tuffaceous pelite. Names previously applied to this assemblage include Waterfall Green-

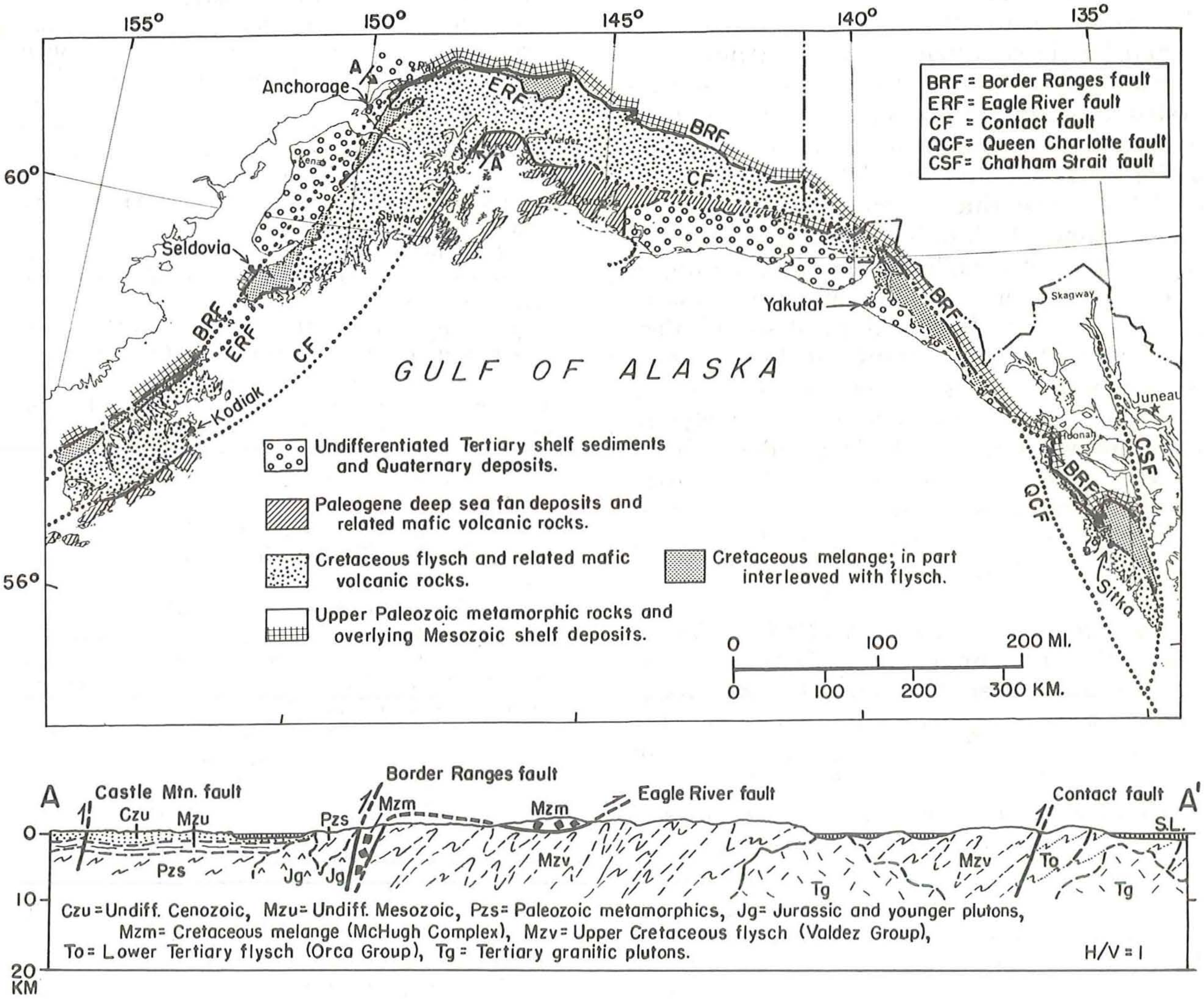

FIGURE 19.—Map and section showing distribution and generalized structural relations of part of the Cretaceous accretionary terrane along the Gulf of Alaska margin. Geology modified from Beikman, 1974a, b; 1975a, b; and unpublished data.

stone and Khaz Formation, both in the Kelp Bay Group, melange facies of Yakutat Group, McHugh Complex, and Uyak Formation (Loney and others, 1975; Plafker, unpub. data; Clark, 1972; Moore, 1969).

Blocks in the melange include rocks ranging in age from Permian to Early Cretaceous (Valanginian?). The matrix includes rocks ranging from Valanginian to Maestrichtian on the basis of the occurrence of upper Valanginian radiolarians in the chert and sparse Hauterivian to Valanginian, Campanian, and Maestrichtian megafossils in the clastic sequence.

The Cretaceous terrane, which corresponds to the Chugach terrane of Berg and others (1972), is one of at least four major Mesozoic and Cenozoic sequences that have been successively accreted to the continental margin in the Gulf of Alaska region (Plafker, 1969; 1972). It is interpreted to be made up of dismembered fragments of oceanic crust, pelagic sediments, and a turbidite sequence that were deformed and accreted to the continental margin by latest Cretaceous time. Much of the landward contact of the subduction complex is the Border Ranges fault (MacKevett and Plafker, 1974), above which is a penetratively deformed upper Paleozoic crystalline basement (including rare glaucophane-bearing greenschist) overlain by Mesozoic shelf deposits and extensively intruded by Mesozoic and Tertiary plutons. Upper plate blueschist assemblages at Seldovia with metamorphic ages of about 190 m.y. (Forbes and Lanphere, 1973) were most probably reset by Mesozoic thermal events. Similar schists occur in the Paleozoic terrane near Chitina (Metz, 1976) and probably in the St. Elias Mountains (Plafker, unpub. data). Slivers of pre-Cretaceous (Upper Triassic?) deep-sea rocks locally occur as selvages lying between the Cretaceous terrane and Border Ranges fault (Magoon and others, 1976). From the central Chugach Mountains to Kodiak Island, the seaward margin of the Cretaceous terrane is juxtaposed against a Paleogene subduction complex (Orca Group and equivalents) along a system of northward-dipping reverse faults, herein referred to as the Contact fault system (fig. 19). During latest Cretaceous and Paleogene time both subduction complexes were regionally deformed by at least 90° of counterclockwise oroclinal bending in the western Gulf of Alaska, and they were welded to the continent by emplacement of anatectically derived Tertiary granitic plutons and regional zeolite to amphibolite facies metamorphism.

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Conglomerate in flysch of the Orca Group, Prince William Sound, southern Alaska

By Gary R. Winkler and Russell G. Tysdal

Flyschoid sedimentary rocks of the Paleocene and Eocene(?) Orca Group contain abundant primary features that facilitate paleoenvironmental interpretations. Winkler (1976) suggested that the bulk of Orca detritus was deposited as the middle part of a deep-sea fan, an interpretation based principally on paleocurrents and facies associations of sandy and shaly flysch in eastern Prince William Sound. This hypothesis was tested further during August 1976 by critical examination of conglomerate localities in the Orca in western Prince William Sound.

The conglomerate initially accumulated in shallow water and subsequently was redeposited into deeper water. Although the conglomerate is intercalated with turbidite, its clasts generally are well rounded and consist of exotic lithologies. In detail, the conglomerate is very diverse and ranges from matrix-supported pebbly mudstone and sandstone to massive, clast-supported pebble, cobble, and boulder conglomerate. Walker and Mutti (1973) suggested that clast-supported conglomerates may be divided, on the basis of their grading, stratification, and fabric, into two basic types—disorganized and organized. A disorganized conglomerate lacks grading and stratification and seldom has a preferred fabric; an organized conglomerate may or may not be stratified but has inverse or normal grading and generally a preferred fabric. Walker (1975) distinguished two types of organized conglomerate—inverse to normally graded (unstratified), and graded-stratified; the latter generally has smaller clast sizes. Walker (1975) also suggested that disorganized conglomerates are deposited in feeder canyons or major channels on a steep paleoslope, whereas organized conglomerates are deposited downcurrent where slopes flatten, becoming progressively better organized downslope.

The thickest, most widespread conglomerates in the Orca Group are organized. Those at the entrance of Galena Bay in northeastern Prince William Sound, at Simpson Bay near Cordova, and at the north ends of Latouche and Evans Islands in southwestern Prince William Sound (fig. 20) are from 100 to 250 m thick, and generally are inverse to normally graded, although graded-stratified conglomerates also occur at all these places. The zone of inverse grading generally is present only in the basal, coarsest grained part of a bed and is succeeded above by massive or, in fewer places, normally graded conglomerate. Imbrication of elongate clasts is common; wherever we observed it, the longest axes of the clasts dipped upcurrent—an orientation that is seldom present except in turbidite conglomerates (Davies and Walker, 1974). The inferred current directions from clast imbrications were roughly parallel to flute or groove casts on the soles of adjacent nonconglomeratic strata. Although the lateral stratigraphic relations of these conglomerates have not been determined in detail, the rocks appear to be intercalated within thin-bedded shaly or sandy flysch. According to the model of Mutti and Ricchi Lucchi (1972), these conglomerates may be regarded as the filling of major channels that were incised into levee and overbank turbidites; as such, they probably are inner fan deposits that mark the entry points of major feeder channels onto the Orca deep-sea fan complex.

Orca conglomerates at other localities (fig. 20) are volumetrically minor but are very widespread; generally they are of the graded-stratified type and are much thinner and finer grained. In many places they are associated with or grade laterally into pebbly sandstone. We regard these deposits as a network of distributary channels that migrated widely over the middle fan and were responsible for the great thickness of the Orca.

Pebbly mudstones and olistostromes also occur within the Orca Group at widely scattered localities in Prince William Sound. They are associated with the inferred channel conglomerates or are interbedded with typical sandy or shaly flysch. In general, the pebbly mudstones contain only well rounded clasts of extrabasinal lithologies, whereas the olistostromes are characterized by a disorderly distribution of clasts, mostly of intrabasinal material and, in a few places, very large and angular. Inasmuch as gradations between the two end members are

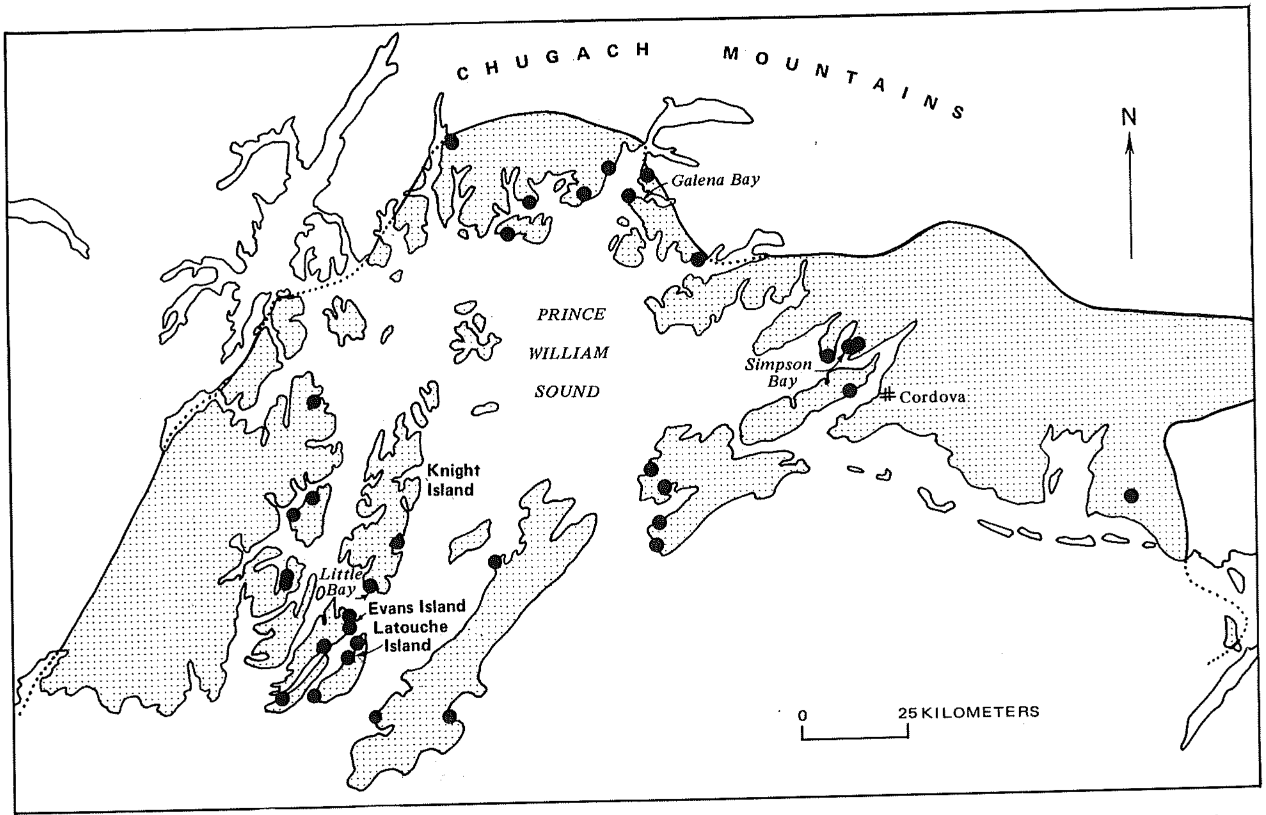

FIGURE 20.—Conglomerate localities (black dots) within the Orca Group (stipple pattern), Prince William Sound region.

present in a few places, as at Little Bay on southern Knight Island, it seems likely that both pebbly mudstones and olistostromes are formed by submarine slides with, respectively, lesser or greater erosive capabilities.

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Strata-bound iron-copper-zinc sulfide deposits, Prince William Sound region, southern Alaska

By Gary R. Winkler, E. M. MacKevett, Jr., and S. W. Nelson

Numerous, mainly strata-bound, iron-copper-zinc sulfide deposits occur in the Prince William Sound region of insular and coastal southern Alaska. The deposits are localized in weakly metamorphosed flysch and submarine tholeiitic basalt of the Paleocene and Eocene(?) Orca Group and—to a lesser extent—the Cretaceous Valdez Group, which may be the youngest host rocks for this type of deposit in the North American Cordillera. Mines in the Latouche and Ellamar districts produced about 97 million kg of copper and minor amounts of gold and silver between 1900 and 1930. In early reports, the deposits were ascribed to postmetamorphic epigenetic processes (Grant and Higgins, 1910; Capps and Johnson, 1915). Recent regional work, however, has indicated that the deposits mostly are syngenetic and are related to recurrent tholeiitic volcanism (Wiltse, 1973a).

Host rocks for most of the deposits are steeply dipping pillow breccia, aquagene tuff, and nonvolcanogenic sandstone and shale intercalated with tholeiites; on the Resurrection Peninsula near Seward, ultramafic and sheeted dike complexes beneath tholeiites are subordinate host rocks. The two largest known ore bodies at Latouche and Ellamar occur in thick pyritic sandstone and shale on the margins of tholeiites. The deposits typically are conformable and, although they range in size from a few centimeters to bodies over 300 m long and 13 m thick, they usually are very tabular. Most deposits are zoned with copper:zinc ratios decreasing stratigraphically upward. They consist of massive sulfides, chiefly pyrite or pyrrhotite, along with chalcopyrite, sphalerite, cubanite, and traces of galena, and locally overlie zones of host rock containing stringers and disseminations of sulfide minerals. Some ore minerals have been remobilized along crosscutting fault zones, probably during regional metamorphism; however, the deposits lack alteration haloes, and the sulfide minerals are brecciated and crystalloblastic.

The genesis of the iron-copper-zinc sulfide deposits of the Prince William Sound region is somewhat problematic. Apparently several tectonic settings may be adequate sites for formation of mineralogically similar massive sulfide deposits (Gilmour, 1971; Hutchinson, 1973; Sillitoe, 1973). Strata-bound sulfide deposits in mafic volcanic rocks elsewhere generally are believed to have formed at midocean rises or marginal ocean basin spreading centers (Cyprus type) or at island arcs (Kuroko type). Wiltse (1973b) has proposed that the Prince William Sound deposits originated in an outer arc-trench slope environment. However, generation of the Prince William Sound deposits at a spreading center or an island arc does not adequately account for the available petrochemical, stratigraphic, and distributional data. It seems more plausible to us that local centers of submarine mafic volcanism were the environments in which these deposits formed. Although the tholeiite host rocks have chemical features of an oceanic genesis, they formed recurrently near an active continental margin (Winkler, 1976). The tholeiites are not tectonic emplacements but were intruded into and interstratified with thick wedges of terrigenous flysch that have been accreted progressively to the continent. The flysch has little volcaniclastic detritus that can be ascribed to nearby coeval island arc magmatism, and there are no known calc-alkaline volcano-plutonic rocks of approximately the same age in coastal southern Alaska; hence no associated inner magmatic arc has been recognized. Sea-floor volcanoes, either discrete or alined in chains, that are generated near the ancient continental margin during subduction and accretion thus seem likeliest to produce appropriate host rocks for the strata-bound sulfide deposits of Prince William Sound.

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Cooperative stratigraphic project in lower Cook Inlet and Kodiak areas, U.S. Geological Survey and State of Alaska Division of Geological and Geophysical Surveys

By Irven F. Palmer and W. M. Lyle[3]

Two separate cooperative field projects were completed during the 1976 field season in southern Alaska. One project area extended from Harriet Point south along the west side of Cook Inlet to Cape Douglas on the Alaska Peninsula (fig. 2(11)). The other project included

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[3] Alaska Division of Geological and Geophysical Surveys.

work on Kodiak Island, Sitkalidak and Sitkinak Islands, and Chirikof Island (fig. 2(12)).

New data on petroleum reservoir and source-rock characteristics were obtained and stratigraphic sections that supplement existing data were measured and sampled. Data have been obtained on sedimentary structures, enhancing understanding of depositional environments. New petrographic information answers questions on reservoir quality, diagenesis, and provenance. Micropaleontological age dates were obtained, and a new assessment of basin maturity is possible from organic geochemical data.

All new information will be used to enhance geologic extrapolations from onshore to offshore areas where economic evaluations must be made for those areas being considered for OCS leasing.

Results of these projects will be published in the State of Alaska open-file series.

Stream relocation and benthic invertebrates in Canyon Slough near Valdez, Alaska, 1976

By J. W. Nauman, C. E. Sloan and D. R. Kernodle

A study of the effects of stream relocation at Canyon Slough along a part of the trans-Alaska pipeline was conducted to determine if the relocated stream bed was colonized by benthic organisms similar to those in the natural stream bed. Inasmuch as Canyon Slough is a salmon spawning stream, indirect evaluation of conditions for salmon spawning beds could be made by comparing the benthic faunas.

Drifting benthic invertebrates were collected during 1-hour drift-net samplings. The nets were installed in midchannel at two locations, one in the natural stream channel and one about 1 mile downstream in the relocated channel.

The total number of genera and midge genera as well as the species diversity was higher in the new channel than in the natural channel upstream of the relocation. However, fewer individuals were collected per unit volume of flow in the new channel than in the natural channel.

Two midge genera (in larval stages), *Cricotopus* sp. and *Diamesa* sp., were not found at the natural stream site but were very abundant in the relocated channel. This difference may be caused by the additional sunlight penetration permitted by the straight, wide stream channel at the relocation site.

These initial results suggest that the relocated stream was colonized by a benthic community somewhat more diverse than that in the natural channel. Therefore, the new stream bed area should provide a more than adequate spawning substrate.

Study of modern lacustrine and glaciolacustrine sediments for earthquake-induced deformational structures, Kenai Peninsula

By J. D. Sims and M. J. Rymer

Bottom sediments of five lakes on the Kenai Peninsula were sampled for evidence of earthquake-induced deformation. The lakes sampled are: Tustumina, Skilak, Hidden, Kenai, and Summit. Interest in these lakes was stimulated by hypotheses developed from a study of sediments in Van Norman Reservoir, Calif., after the 1971 San Fernando earthquake (Sims, 1973). During that study three zones of deformational structures were found and correlated with moderate earthquakes that shook the San Fernando area in 1930, 1952, and 1971. Results of that study, coupled with the experimental formation of deformational structures similar to those from Van Norman Reservoir (Keunen, 1958), led to a search for similar structures in Pleistocene and Holocene lakes and lake sediments in other seismically active areas. The lakes for this study were chosen specifically because of their location within the area affected by the 1964 Prince William Sound earthquake, and the presence of varved sediments that allow counting of years between sedimentologic events.

Major emphasis was placed on Tustumina and Skilak Lakes, the two largest of the lakes studied. The sampling plan was based on the previous year's preliminary work, in which the presence of varves, ash beds, and deformational structures was confirmed (Sims and Rymer, 1976; Rymer and Sims, 1976). In all lakes except Kenai preliminary bathymetric maps were required to site the sample localities. In all, 34 cores were collected, ranging in length from about 0.5 to 6.0 m. The goals in the present investigation are to determine (1) the ease of correlation of discrete zones of deformational structures within a given lake, (2) the variability of type and magnitude of structures with mean grain size of sediments within a given zone, (3) the correlation of the date of formation (by varve count) of a deformational structure with the time of occurrence of moderate to large historical earthquakes affecting the Kenai Peninsula, and (4) the ease of correlation of zones of deformational structures between lakes on the peninsula.

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Placer River fault, Seward and Blying Sound quadrangles

By Russell G. Tysdal and James E. Case

The Placer River fault is a major high-angle reverse fault that trends northward across the Seward and Blying Sound quadrangles, extending from Day Harbor at the south to beyond Turnagain Arm at the north (fig. 21). It constitutes a zone that ranges from about 50 to 150 m wide and locally is marked by notches, stream valleys, and benches on the downthrown side. The fault dips about 65° W. or more along most of its length, although a dip of 50° W. was measured along one segment. The style of deformation in the fault zone ranges from rocks that are fault breccias cemented by quartz veinlets along fractures, to cohesive microbreccias, and to protomylonites (classification of Higgins, 1971).

The fault juxtaposes slate, graywacke, and greenstone of the Cretaceous Valdez Group, metamorphosed to the chlorite and biotite zones of the greenschist facies, over other rocks of the Valdez Group that largely are metamorphosed to the chlorite zone of the greenschist facies. Rocks west of the fault form a prominent belt of schist that is about 5 km wide and more than 70 km long; and, west of Day Harbor, in a greenstone sequence composed of tuff, pillow basalt, sheeted dikes, gabbro, and minor serpentinized dunite bodies. The schist belt forms a doubly plunging anticline with its northern nose plunging toward Turnagain Arm and the less well-defined southern nose plunging toward Day Harbor. The greenstone sequence forms part of an anticline that plunges gently northward toward the schist belt.

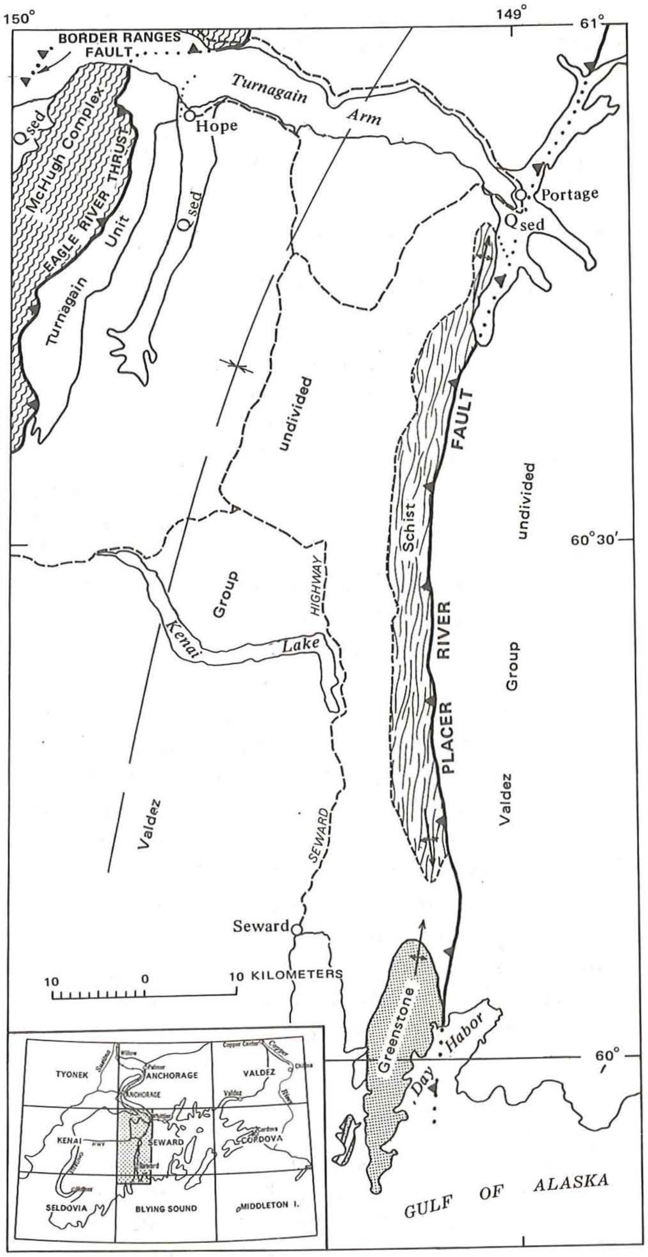

FIGURE 21.—Map showing rock units in the western part of the Seward and Blying Sound quadrangles.

In the northern part of the Seward quadrangle, the Placer River fault passes beneath Quaternary valley fill for more than 30 km before emerging near the northern margin of the quadrangle. No trace of the fault was seen in the unconsolidated sediments, and no evidence of recent movement was found along any part of the fault.

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The McHugh Complex in the Seward quadrangle, south-central Alaska

By Russell G. Tysdal and James E. Case

The McHugh Complex was named by Clark (1972, 1973) for an assemblage of rocks that crop out in the Anchorage quadrangle, north of Turnagain Arm (fig. 21). Clark recognized a clastic and a volcanic unit in the McHugh, stating that the two are lithologically distinct but chaotically juxtaposed, and that a melange-like deformation is characteristic of parts of the complex. The McHugh was believed to be juxtaposed above the Valdez (?) Group along the Eagle River thrust fault.

Mapping in the Seward quadrangle, south of Turnagain Arm, revealed that a clastic unit shown on Clark's maps as a part of the McHugh is conformable with the Valdez. The clastic unit, informally called the Turnagain unit (fig. 21), is as much as 6 km thick, consisting of massive, ridge-forming mud-chip sandstone. The sandstone is quartzo-feldspathic and ranges from fine to coarse grained. It is conglomeratic west of Hope, consisting of granule- to boulder-size clasts set in a matrix of mud-chip sandstone; clast types recognized include granite, chert, greenstone, limestone, argillite, and sandstone.

The massive mud-chip sandstone is overlain eastward by a sequence of interbedded argillite and chert (about 15 m thick), argillite (about 15 m thick), mud-chip sandstone, and argillite with local interbeds of mud-chip sandstone. The Turnagain unit intertongues southward with the Valdez Group, and the massive ridge-forming characteristic decreases in prominence. These observations lead us to consider the Turnagain unit as a mappable part of the Valdez Group.

West of the Eagle River thrust fault, as mapped in the Seward quadrangle, only melange is present. Within the melange are large blocks of chiefly unsheared mud-chip sandstone like that of the Turnagain unit. Bedded chert, argillite, and pillow basalt with associated bedded chert locally are interlayered within the mud-chip sandstone of these blocks. Thin sections of the mud-chip sandstone reveal a small percentage of rock fragments of basalt and of clinopyroxene. Furthermore, thin sections show that part of the strongly sheared rocks of the melange are compositionally the same as the mud-chip sandstone of the isolated blocks and of the Turnagain unit. These data lead us to believe that the Turnagain unit and the blocks of mud-chip sandstone within the melange are all part of the same unit.

The melange also contains isolated pods of sheared mafic and ultramafic rocks, but they are not nearly so abundant as north of Turnagain Arm (Clark, 1972, 1973). Float of brecciated limestone was found at one location, but its source is uncertain. These rock types and probably some or many of the strongly sheared rocks of the melange, and perhaps some bedded sandstone strata and chert-bearing rocks, are interpreted to be tectonically admixed parts of the melange.

Clark (1973) believed that the age of the McHugh Complex was Late Jurassic and (or) Cretaceous, chiefly on the basis of a potassium-argon date of 146 ± 7 m.y. obtained from a granitic clast from conglomeratic sandstone. She assumed that granitic clasts in conglomerates yield only slightly younger ages than their source terrane. We believe, however, that the conglomerate in the Seward quadrangle is conformable with, and part of, the Valdez Group. Our evidence indicates that the Turnagain unit, which includes conglomerate and abundant volcanic debris, is unlike any of the remainder of the Valdez within the quadrangle. We believe it to be an upturned part of the Valdez with its top to the east, forming the western limb of a broad synclinorium (fig. 21). The western part of this synclinorium contains a belt of rocks that has yielded the only fossils from within the area of figure 21 and immediately to the north. The fauna, *Inoceramus kusiroensis* Nagao and Matsumoto (Jones and Clark, 1973), are all Maestrichtian (latest Cretaceous). The Turnagain unit thus is considered to be slightly older, also of Late Cretaceous age.

The melange is a fault breccia that formed subsequent to deposition of the Turnagain unit, probably in the early Tertiary. We consider the melange to be the fault breccia associated with the Border Ranges fault of MacKevett and Plafker (1974), a plate boundary fault that juxtaposes upper Paleozoic and lower Mesozoic rocks on the north against mainly upper Mesozoic marine rocks for more than 1,700 km in the northern Kodiak, Kenai, Chugach, and Saint Elias Mountains and the Alexander Archipelago (MacKevett and Plafker, 1974; Plafker and others, 1975). The Border Ranges fault is not exposed in the area of figure 21 but is believed to trend northeastward beneath the Quaternary sediments and water in the northwesternmost part of the figure (see, for example, maps in MacKevett and Plafker, 1974; Tysdal, 1976).

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Late Wisconsin history of the south shore of Turnagain Arm, Alaska

By Reuben Kachadoorian, A. Thomas Ovenshine, and Susan Bartsch-Winkler

Results of fieldwork during the last week of July, 1976, along the valleys of Sixmile, Resurrection, and Palmer Creeks and along the south shore of Turnagain Arm between Sixmile Creek and Resurrection Creek have given us a better understanding of the late Wisconsin history of the south shore of Turnagain Arm. Observations during the fieldwork were also made on pre- and post-late Wisconsin sedimentation, but we are herein reporting only on the late Wisconsin.

Critical late Wisconsin exposures occur along the shoreline about 3 km east and 2 km west of Resurrection Creek and in the valleys of Sixmile and Resurrection Creeks. Data obtained from the exposures east and west of Resurrection Creek are used to put together the following sedimentation sequence.

The oldest late Wisconsin sediments exposed along the south shore of Turnagain Arm are the 14,000-year-old (Schmoll and others, 1972) Bootlegger Cove Clay. These sediments are exposed from sea level to an altitude of 15 m. Overlying the Bootlegger Cove Clay are 4 m of deltaic deposits. The deltaic deposits, in turn, are overlain by as much as 11 m of outwash debris, which reaches a maximum altitude of 29 m. Morainal debris, about 55 m thick, overlies the outwash sediments and reaches an altitude of about 83 m in the exposures west of Resurrection Creek.

Late Wisconsin sediments in Resurrection Creek valley are not well exposed because they have been eroded, covered, or modified by Holocene stream action. However, about 3.6 km upstream of the mouth of the creek, at an altitude of 23 m, 3 m of Holocene stream gravels is underlain by 3 m of lake sediments, which, in turn, is underlain by about 4 m of deltaic deposits (Edward Eichlotz, oral commun., 1975). The top of the deltaic sediments in this sequence is at an altitude of 20 m, which compares favorably with the altitude (18 m) of the deltaic sediments along the coast. It is unknown whether the Bootlegger Cove Clay underlies the deltaic deposits 3.6 km upstream of the mouth of Resurrection Creek.

Late Wisconsin sediments in Sixmile Creek valley are more extensive and better exposed than those in Resurrection Creek valley. No deltaic deposits, however, were noted in the valley. Lake sediments were noted from about 0.5 km from the mouth of the creek to 6.5 km upstream. At this upstream point, 11 m of lake sediments overlies bedrock; the top of the sediments is 83 m above sea level. The maximum thickness of lake sediments, about 33 m, occurs between altitude 45 and 76 m, 5 km from the mouth of Sixmile Creek.

The late Wisconsin deposits along the south coast of Turnagain Arm between Sixmile and Resurrection Creeks consist chiefly of morainal debris, ice-contact sediments, and outwash. These sediments were deposited on an undulating planed bedrock surface ranging generally in altitude between 27 to 30 m. The maximum altitude reached by the morainal debris in the vicinity of Sixmile Creek is not known for certain but appears to be as high as 106 to 121 m.

The sediments described that occur in the valleys of Sixmile and Resurrection Creeks and along the south shore of Turnagain Arm between Sixmile and Resurrection Creeks are post-Bootlegger Cove Clay (14,000 B.P.) and were deposited during a westward advance of a glacier in Turnagain Arm probably coeval with advance of ice to the Elmendorf Moraine at Anchorage. Schmoll (oral commun., 1976) stated that a carbon-14 date on top of the Elmendorf Moraine is 12,000 years old. Thus, the sediments are considered to be late Wisconsin in age.

The glacier in Turnagain Arm advanced in a pulsating mode, and when it reached a point about 4 km east of Resurrection Creek, it became stagnant. Outwash from the glacier was deposited as deltaic deposits in a sea at least 4 m deep overlying Bootlegger Cove Clay. Once the sea was filled here, the outwash was deposited on a flat-lying subaerial surface. The glacier then continued westward for about 6 km and overrode the deltaic and outwash sediments. The glacier eventually reached a present altitude of about 83 m at the terminus, about 1 to 2 km west of Resurrection Creek.

As the glacier advanced, it first dammed Sixmile Creek and then Resurrection Creek. It extended about half a kilometer upstream in both creeks. A lake formed in Sixmile Creek, the surface of which reached at least the present altitude of 83 m. The depth of the lake in Resurrection Creek is unknown because Holocene activity of the creek has destroyed much of the late Wisconsin evidence. The lake may have reached a present altitude of about 77 m.

When the glacier in Turnagain Arm started to retreat about 12,000 years ago, it started to waste away, and streams developed locally along the contact of ice and bedrock. During the retreat of the ice, the glacial lakes in Sixmile and Resurrection Creeks were also draining and stream sediments were deposited locally.

On the basis of the present altitude of the Bootlegger Cove Clay and the overlying deltaic deposits, the area must have been uplifted about 20 m owing to the regression of the sea and isostatic rebound after the ice retreated.

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Preliminary studies of a 93-meter core at Portage, Alaska

By A. Thomas Ovenshine, Susan Bartsch-Winkler, Jeff Rupert, and Reuben Kachadoorian

During the 1964 Alaskan Earthquake, land near Portage, Alaska, subsided approximately 2 m, lowering into the intertidal zone of Turnagain Arm. Ten years later, an earthquake-generated layer of new intertidal silt had covered the 1964 forest, shrub, and grassland and had reached a thickness of approximately 1.5 m in the Portage area. At this level very little sediment was still being added, and new surface vegetation was beginning to take hold. The sequence of events (subsidence, inundation, vegetation kill, deposition, revegetation), along with available field evidence (two possible vegetation layers below the 1964 soil horizon suggesting two previous cycles of deposition such as occurred between 1964 and 1974 at Portage), prompted us to drill in search of further cycles of earthquake-caused sedimentation in Portage's past that could be dated by carbon-14 methods.

Preliminary studies show that seven distinct facies can be recognized from the 93-m core obtained at Portage (fig. 22). About 1 m of artificial gravel pad (unit 1) caps the core, overlying about 4 m of post-1964 intertidal silt (unit 2). Unit 3 (5 to 17 m depth) consists of stream-rounded gravel and sand. Sand and silt make up unit 4 (17 to 20 m depth). Spherical(?) inclusions of sand up to 4 cm in diameter are found in several of the silty layers. At 20 m a gas pocket was intersected during drilling, and plant debris was carried to the surface in the drilling mud (Kachadoorian, oral commun., 1975), but none was recovered in the core. A silt layer making up unit 5 (20 to 32 m depth) contained several spherical sand inclusions like

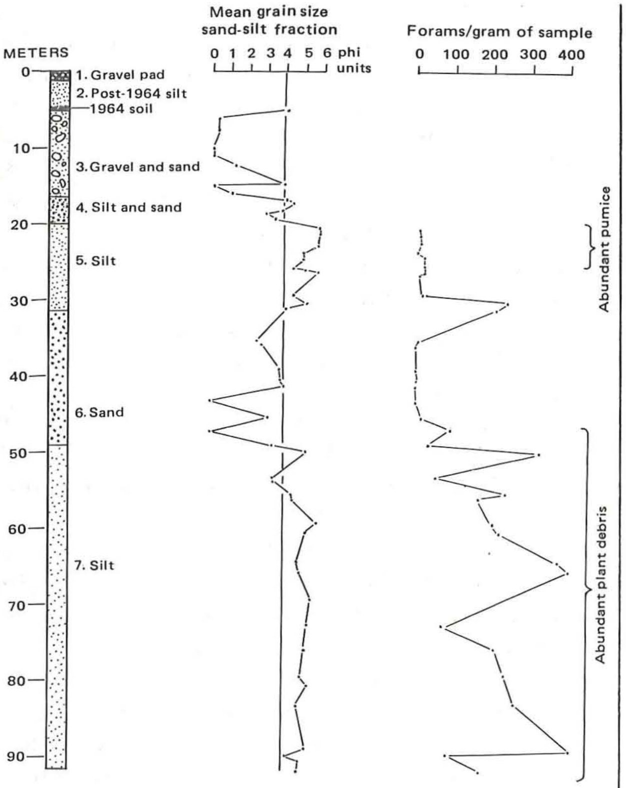

FIGURE 22.—Diagram showing the seven lithologic facies, mean grain size, and foraminifers per gram of sample from the 93-m core obtained at Portage, Alaska.

those described in unit 4. At the top of unit 5, abundant pumice was found, and at the base of the unit, laminated or planar bedding was seen in the radiographs. A sudden rise in the population of foraminifers apparently occurred in this laminated section. Unit 6 (32 to 49 m depth) is predominantly sand. Unit 6 also contained spherical sand inclusions within several silty layers, as were found in units 4 and 5. Unit 7, from 49 to 93 m depth, is made up of fine-grained silt and clay. Plant debris and foraminifers are abundant. A gas packet was intersected in the drilling at the top of this unit at 50 m depth, and two carbonaceous layers were observed at 60 and 65 m depth. Spherical sand inclusions, laminated bedding, convolute bedding, crossbeds, and mud clasts were observed in the radiographs. Herringbone crossbeds, possibly indicating an intertidal environment, were seen in the radiographs from the upper part of unit 7.

These preliminary observations on the Portage core suggest gradual filling of a fiord embayment in late Holocene time. Below about 50 m depth, the sediments consist of silt and clay and are finer grained than present-day surface sediments analyzed in Upper Turnagain Arm during 1973 and 1974 (Ovenshine and others, 1976; Bartsch-Winkler and others, 1975). Foraminiferal and diatom populations increase in the core sediments below 50 m depth, probably indicating deeper water environment with normal salinity—conditions more favorable for growth of these species. As the basin filled with sediment, the textures coarsened, alternating between sand and silt layers, with a marked decrease in microfaunal abundance. Near the surface, between 5 and 10 m depth, well-washed stream gravels occur and are overlain by a marsh deposit. The marsh was inundated after the 1964 earthquake and consequently is overlain by intertidal silt of the present-day regime.

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Engineering geology of Anchorage Borough

By Henry R. Schmoll

The radiocarbon date on shells from a site along Turnagain Arm indicates that these shells are contemporaneous with those previously dated from the type Bootlegger Cove Clay, having an age of about 14,000 yars B.P. (Schmoll and others, 1972). This date, together with the similarity of marine foraminifers from several sites along Turnagain Arm to those from the Bootlegger Cove Clay, indicates that marine water extended well up Turnagain Arm during this marine transgression, and that glacier ice had at least temporarily withdrawn at this time.

The Planning Department of the Anchorage Borough has continued to use several reports on geology and water resources (Schmoll and Dobrovolny, 1972a, b, 1973, 1974a, b; Dobrovolny and Schmoll, 1974; Zenone and others, 1974) in various ways ranging from subdivision review and analysis to the preparation of a comprehensive plan for development of the entire borough. These reports are also being used as models for environmental geology studies undertaken by the Alaska Division of Geological and Geophysical Surveys in other areas (R. D. Reger, oral commun., 1976).

Mapping of features on the site of the Fourth Avenue landslide and observations of similar features at other sites in Anchorage have led to an informal program of continued observation of these features with respect to the continued stability of these areas.

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Urban hydrology studies in the Anchorage area

By Chester Zenone

Preliminary analysis of hydrologic and ground-water quality data from the Merrill Field landfill site indicates that the potential for downward movement of pollutants into underlying public supply aquifers is minimal. A test drilling program was conducted in the summer of 1976 to obtain additional water-quality information and core samples for laboratory hydrologic tests. Results of those tests will permit quantification of potential vertical water and pollutant rates of movement through the beds confining the aquifer under the present pumping and hydraulic head conditions.

To date, the overall water quality of Sand Lake, an important "real estate" lake in the Anchorage area, seems to have been little affected by extensive urban development of its shoreline (Donaldson, 1976). However, a serious pollution potential is posed by snowmelt runoff to the lake from adjacent residential subdivisions. Analysis of the runoff from one area showed concentrations of dissolved solids 10 times as great as those in the main body of the lake; concentrations of lead and iron greater than known to occur naturally or below landfills were also present in the runoff.

The need to evaluate ground water/surface water relations prior to urban development and drainage projects in order to assure maintenance of lake levels and preservation of natural wetlands was emphasized in a recent report by Zenone (1976). Urban development practices appear to have caused at least part of a 1.5 to 1.8 m decline in the level of Sand Lake between 1963 and 1970. The lake seemed to have stabilized at the lowered level by 1975-1976 and apparently had adjusted the reduced drainage basin area and other basin water-budget factors. Other nearby small closed-depression lakes and ponds are potentially threatened by alterations in the drainage basin similar to those around Sand Lake.

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Reinterpretation of the origin of inferred Tertiary tillite in the northern Wrangell Mountains, Alaska

By George Plafker, Donald H. Richter, and Travis Hudson

Diamictite interbedded with fluvial deposits and volcanic flow rocks constitutes a stratified sequence more than 1,000 m thick within the McCarthy D-3 quadrangle along the northern foothills of the Wrangell Mountains in the White River drainage (fig. 2(13)). The sequence, which lies along an active strand of the Totschunda fault (Richter and Matson, 1971), is tilted as much as 60° and is complexly faulted into discrete blocks. The diamictite was found and originally described by Capps (1916) who interpreted it as tillite. Subsequent, more detailed studies by Denton and Armstrong (1969) provided additional data on the distribution and characteristics of this diamictite and dated it as Miocene and Pliocene on the basis of potassium-argon analyses of the interbedded flow rocks. Like Capps, Denton and Armstrong also believed the diamictite to be tillite. Largely on the basis of their studies of this sequence, they inferred a regional climatic deterioration beginning in the Miocene that resulted in a minimum of 12 major glaciations in the Wrangell Mountains and adjacent White River valley during the interval from 10 to 2.7 m.y.

During the course of helicopter-supported studies of earthquake hazards along the Totschunda fault, we spent parts of 2 days in July 1976 examining the sequence containing diamictite in the upper White River area. On the basis of our brief study of these deposits, we conclude that the diamictite does not represent tillite laid down by continental glaciers. Although we could not spend enough time studying these unusual deposits to be certain of their origin, the available data suggest to us that they probably formed largely, if not entirely, as lahars derived from the summit region of Tertiary volcanic cones of the Wrangell Mountains. Evidence to support our reinterpretation of the origin of the diamictite is primarily its local provenance, the scarcity of glacially worked clasts, and its limited areal distribution.

The coarse clasts in the diamictite are not derived from a Carboniferous bedrock terrane as was inferred by Denton and Armstrong (1969, p. 1127); instead they are composed almost entirely of the late Cenozoic Wrangell Lava that forms numerous volcanoes and extensive flows throughout the region (MacKevett, 1976). Rock types other than Wrangell Lava are virtually absent in all of the diamictites we examined. A systematic count made of 400 clasts larger than 1 cm in maximum dimension that were exposed on a 6-m^2 joint surface normal to the bedding of one of the thickest diamictites showed that all were Wrangell Lava types except possibly for one light-gray felsite clast of uncertain origin. The clast lithology indicates a local source area to the south in the volcanic pile that caps the Wrangell Mountains; clearly, a much more variable clast lithology would be expected in a till deposited by extensive ice sheets of the type postulated by Denton and Armstrong. It is noteworthy that clasts in the fluvial deposits interbedded with the diamictite locally contain significant amounts of the Triassic Nikolai Greenstone and other older rocks. This mixture suggests that the fluvial deposits were laid down by streams that eroded both the volcanic piles and the older basement rocks that were exposed along the flanks of the volcanoes, whereas the diamictites originated almost entirely from higher elevations on the volcanoes.

Undoubted glacially polished, striated, and smoothed clasts such as those figured by Capps (1916, pl. 12) and Denton and Armstrong (1969, pl. 1B) are relatively rare in the diamictite. We could not find anything approaching the 3–10 percent glacially worked clasts reported by Denton and Armstrong (1969, p. 1127). Only one cobble with the characteristic features of ice transport was found in a traverse through eight of the diamictite beds, and none was found in our sample count of 400 clasts. Flat faces with subangular corners are relatively common clasts, but these are largely original joint surfaces of the typically blocky Wrangell Lava. None of the surfaces that we examined is definitely striated; on some clasts, flow banding in the volcanic rocks imparts a lineation to the surfaces that could conceivably be mistaken for glacial scratches. In marked contrast to these diamictites, 39 of 104 clasts (38 percent) from a 1-m^2 area in a Pleistocene till near the Nabesna River were definitely striated and polished. The scarcity of glacially worked clasts in the diamictites argues against deposition as tills. However, it is probable that alpine glaciers existed locally in the diamictite source area.

Although Denton and Armstrong (1969, p. 1136–1137) postulate that the diamictites record extensive and repeated late Tertiary glaciation of the mountains of southern Alaska, it is significant that they are extremely limited in areal extent. The locality on the north flank of the Wrangell Mountains, where diamictites are exposed in an area about 3 km long by 2½ km wide, is the only known occurrence. If glacier development during the late Tertiary were at all comparable to that of the Pleistocene, the deposits should be much more widely distributed. They also would be easily recognizable because they occur well above the upper limit of the highest Pleistocene moraines in the same area. The intermittent deposition of ice-rafted marine glacial deposits along the Gulf of Alaska mainland coast during the Miocene, Pliocene, and Pleistocene was cited as evidence of widespread glaciation possibly correlative with deposition of the Wrangell Mountains diamictites (Denton and Armstrong, 1969, p. 1136–1137). However, the available evidence suggests that the anomalous Tertiary glaciation along the Gulf of Alaska coast during this time was a local phenomenon that resulted from a combination of extremely high coastal mountains and heavy precipitation (Plafker and Addicott, 1976). Glaciers still reach tidewater at many places along the Gulf of Alaska coast and marine glacial deposits continue to be deposited, but there is no equivalent large-scale glaciation in the interior. Similarly, there is no reason to assume that late Tertiary glaciations in the coastal belt were necessarily accompanied by glacial advances in the interior.

In conclusion, we suggest that the Miocene and Pliocene diamictites of the northern Wrangell Mountains area were locally derived from the Wrangell Lava terrane of the Wrangell Mountains and that they are not tillites deposited during major glacier advances. Their restricted areal distribution, distinctive provenance, and stratigraphic occurrence favor deposition as lahars that were laid down in a deep basin along the north flank of the Wrangell volcanoes. This basin may have developed as a local structural rift due to strike-slip displacement on the Totschunda fault. The minor content of glacially worked clasts in the diamictites indicates that ice caps and radiating valley glaciers were present at least intermittently on the higher parts of the volcanoes. Thus, the late Tertiary volcanoes of the Wrangell Mountains need not have differed much in height and degree of ice and snow cover from the present ones.

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Potassium-argon ages of disseminated copper and molybdenum mineralization in the Klein Creek and Nabesna plutons, eastern Alaska Range

By Miles L. Silberman, Janet L. Morton, D. C. Cox, and Donald H. Richter

Granitic plutons south of the Denali fault in the east Alaska Range are host rocks for seven disseminated copper and molybdenum deposits (Richter, Singer, and Cox, 1975) (see fig. 2(14) for general location). Richter, Lanphere, and Matson (1975) showed that the plutons were emplaced between 108 and 117 m.y. ago, during one of five intrusive-metamorphic episodes affecting the area. Concordant potassium-argon ages of biotite and hornblende reported by these workers indicate that the isotopic data represent ages of crystallization for these plutons. Potassium-argon ages of disseminated copper and molybdenum deposits that occur in these rocks were determined from potassium-argon analyses of hydrothermal biotite, muscovite, potassium feldspar, chlorite, and amphibole from the copper prospects at Baultoff, Horsfeld, Carl Creek, and Ptarmigan Creek in the Klein Creek pluton and Orange Hill and the center fork of Bond Creek in the Nabesna pluton. Molybdenum mineralization ages were determined by potassium-argon analyses of hydrothermal muscovite from the molybdenum prospects at Orange Hill and the east fork of Bond Creek, and from biotite, feldspar, and chlorite from intrusive rocks associated with molybdenum mineralization in the same areas.

The copper mineralization ages of 107 to 118 m.y. in the Klein Creek pluton and 110 m.y. at Orange Hill in the Nabesna pluton (table 3) along with the emplacement ages reported by Richter, Lanphere, and Matson (1975) for these rocks suggest that major copper mineralization occurred during the emplacement and crystallization of the granites. Molybdenum mineralization age of 106 to 108 m.y. at Orange Hill, in the Nabesna pluton, is related in time to quartz porphyry intrusions that probably formed as late-stage differentiates of the middle Cretaceous part of the Nabesna pluton.

The tabulated age data also indicate that two younger stages of intrusion and mineralization occurred within the Nabesna pluton. A major intrusion, containing disseminated chalcopyrite, was emplaced at the center fork of Bond Creek 81 to 89 m.y. ago. At the east fork of Bond Creek, trondhjemitic intrusions and a silica breccia pipe containing disseminated molybdenite and pyrite were emplaced 20 to 22 m.y. ago. This igneous activity is probably related to volcanism of the Miocene to Holocene Wrangell Lava in the region.

One of the most interesting aspects of the new data is the potassium-argon ages from chlorite, which replaces hydrothermal biotite in altered copper-bearing granitic rock at Baultoff and Carl Creek. The chlorite ages are concordant with the potassium-argon ages of hydrothermal

TABLE 3.—*Potassium-argon ages from the Nabesna and Klein Creek plutons*

Prospect	Sample No.	Mineral	Age, m.y.
		Klein Creek pluton	
Baultoff (copper)	BF-4	Potassium feldspar	110 ± 4
		Chlorite	114 ± 4
	BF-6	Muscovite	114 ± 4
Horsfeld (copper)	HF-1	Biotite	113 ± 4
	HF-4	Hornblende	107 ± 4
	HF-22A	Hornblende	114 ± 4
Carl Creek (copper)	CC-5	Potassium feldspar	109 ± 4
		Chlorite	109 ± 4
	CC-8	Hornblende	108 ± 4
Ptarmigan Creek (copper)	Pt-1	Hornblende	118 ± 5
		Nabesna pluton	
Orange Hill (copper)	AMS-29	Biotite	112 ± 4
		Hornblende	115 ± 5
	AMS-27A	Biotite	111 ± 3
	AMS-24A	Biotite	110 ± 3
(molybdenum)	AMS-24	Biotite	104 ± 3
		Potassium feldspar	108 ± 4
	AMS-32A	Muscovite	105 ± 3
Bond Creek, center fork (copper)	BC-8	Biotite	81.0 ± 2.4
	BC-14	Biotite	88.9 ± 2.7
Bond Creek, east fork (molybdenum)	EF-2	Biotite	22.2 ± 0.9
	EF-7	Muscovite	22.1 ± 0.6
	EF-17	Chlorite	21.2 ± 0.6

potassium feldspar from the same samples. Chlorite, which replaces magmatic biotite from altered trondhjemite at east fork, Bond Creek, gave potassium-argon ages in agreement with those determined from biotite and hydrothermal muscovite from the same group of intrusive rocks. The results suggest that chlorite may be useful for dating alteration and mineralization by the potassium-argon method, at least in some areas.

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Carbonate sedimentation, sabkha facies, diagenesis, and stratigraphy, lower part of the Chitistone Limestone—the Triassic host rock for Kennecott-type copper deposits

By Augustus K. Armstrong and E. M. MacKevett, Jr.

This paper briefly summarizes recently completed detailed investigations of the Chitistone Limestone that are described by Armstrong and MacKevett (1977 and unpub. data). The investigations show that sabkha deposits were important in the genesis of Kennecott-type copper ore. The Upper Triassic Chitistone Limestone and superposed Upper Triassic and Jurassic sedimentary rocks were deposited in a marine basin on and surrounded by the Nikolai Greenstone, a thick, extensive, largely subaerial succession of tholeiitic basalt with intrinsically high copper content. The lowermost 110 m of the Chitistone contains three incomplete upward-shoaling lime mud cyclic sequences that each consist of shallow subtidal limestone grading upward to intertidal stromatolitic microdolomite. The youngest cycle contains well-developed sabhka features and dolomitic pisolitic and laminate crust caliches and underlies shallow-marine limestone. The massive chalcocite-rich lodes at the Kennecott and nearby deposits are related to the youngest supratidal sequence, which represents a regional sabkha facies that developed 90-110 m above the Nikolai Greenstone. This facies, which contained abundant gypsum-anhydrite, was exposed to vadose weathering that leached much gypsum-anhydrite and developed a vuggy zone interbedded with porous dolomitic caliche zones. Subsequent marine deposition capped the porous zone with an impermeable seal. The youngest sabkha horizon served as a permeable conduit for the ore-forming solution and was instrumental in localizing the major Kennecott-type ores.

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Stable isotope geochemistry, sulfide mineralogy, and potassium-argon ages of the Kennecott massive sulfide deposits, Alaska

By Miles L. Silberman, Alan Mathews,[4] R. W. Potter, and Arie Nissenbaum[5]

The Chitistone Limestone, host rock for the Kennecott massive sulfide deposits near McCarthy (see fig. 2(15)), is underlain by the Nikolai Greenstone. The Nikolai contains many quartz-epidote veinlets and veins, which appear to be best developed in the upper part of the formation. Although most of them lack copper minerals, some have chalcopyrite, bornite, and native copper (Bateman and McLaughlin, 1920; E. M. MacKevett, Jr., written commun., 1976).

Most workers (Bateman and McLaughlin, 1920; Armstrong and MacKevett, 1976) favor hypotheses which suggest that the copper is ultimately derived from the greenstone. Bateman and McLaughlin (1920) suggest that copper was dissolved from the greenstone and transported by heated fluids of meteoric origin, probably generated by the Tertiary porphyry intrusions that occur near the Kennecott mines, and was then deposited both in the quartz-epidote veins and in the more favorable host rock of the Chitistone Limestone as large, massive sulfide bodies. Armstrong and MacKevett (1976), on the contrary, state that the massive sulfides originated as a low-temperature sabhka deposit formed by the action of cool, highly oxygenated ground waters that leached copper from an extensive terrane of Nikolai Greenstone and deposited it in the reducing environment of the sabhka.

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Silberman, Potter, and Nissenbaum (1976) suggested that the originally stratiform sabhka deposits were remobilized and recrystallized by the action of relatively cool, dilute, ^{18}O-depleted fluids, similar to modern meteoric water, generated perhaps by the porphyry intrusions of late Tertiary age. Such a fluid must have been hot enough, or of such a composition, to be capable of remobilizing the original ore.

Stable-isotope analyses of the quartz and epidote from the copper-bearing veins in the greenstone and from minerals in the porphyry intrusions were made in order to discover some relation between the fluids responsible for alteration of the igneous rocks, deposition of the veins, and remobilization of the massive sulfide ore deposits.

δ^{18}O values of quartz and epidote from three veinlets in the upper part of the greenstone, near the Kennecott deposits, are approximately +15 to 16 and +4 to 5 °/oo, respectively. δ^{18}O of feldspars, hornblende, and chlorite from late Tertiary igneous rocks near Kennecott are in the range +6 to 12 °/oo. δ^{18}O of hydrothermal feldspar from a sample of altered Nikolai Greenstone from the Mother Lode mine is +16 °/oo.

The oxygen isotope values of the igneous minerals overlap the upper range of normal magmatic values, but some are characteristic of minerals from igneous rocks that have undergone exchange with fluids enriched in oxygen-18, such as would be expected in formation waters from sedimentary rocks like those exposed near Kennecott. The high value of δ^{18}O from the hydrothermal feldspar from the Mother Lode altered greenstone sample, and the potassium-argon age of 180 m.y. (Silberman and others, 1976), suggest early deuteric alteration, perhaps by sea water, resulting from processes taking place near the time of emplacement of the greenstone. Perhaps some argon was lost because the alteration mineral assemblage is fine grained.

The age of the greenstone, based on fossil evidence, is late Middle and (or) early Late Triassic (MacKevett, 1972), which would be about 205 m.y. (Geological Society of London, 1964). Additional isotopic age determinations on unaltered parts of the greeenstone are being attempted.

The very large fractionation of oxygen-18 between quartz and epidote in the veins in the greenstone implies a low temperature of formation. At 500°C, the fractionation between these minerals is about 5 °/oo and the fractionation increases with decreasing temperatures (J. R. O'Neil, written commun., 1976). Fluid inclusions in the quartz of these veins are too small to allow homogenization temperature or salinity measurements to be made.

Silberman, Potter, and Nissenbaum (1976) reported δ^{18}O of carbonate minerals from the Chitistone Limestone, near the ore deposits, of +17 to +22 °/oo, which represents depletion of oxygen-18 relative to unaltered parts of the Chitistone, and δ^{13}C of +3.7 to ±1.5°/oo, which is about the same as unaltered Chitistone. Several new δ^{18}O and δ^{13}C analyses of late calcite veinlets, which contain disseminated copper sulfides, are +9 to +14 °/oo and +0.4 to +2.4 °/oo, respectively. These values show systematic depletion in oxygen-18 and show some irregular depletion in carbon-13 relative to the unaltered Chitistone. Fluid inclusions in these veins have salinity values of approximately 15 °/oo. Temperature is by far the most important factor in determining the δ^{18}O of minerals in equilibrium with waters (J. R. O'Neil, written commun., 1976). The fluid inclusion homogenization temperatures of the calcite veins of approximately 50°C (93°C, with pressure correction, using method of Potter, 1977) and the mineral assemblage of the sulfides reported by Silberman, Potter, and Nissenbaum (1976) and Potter, Silberman, Nissenbaum, and Mathews (1977), implying temperatures less than 93°C, point to low-temperature processes taking place during the remobilization of the ore and precipitation of the calcite veinlets in the ore deposits. The fluids involved were evidently cool, saline, and oxidizing and probably had a significant nonmeteoric component, as evidenced by the salinity. The δ^{13}C values, although somewhat variable, are uniformly positive and imply that the source of carbon for the calcite was the limestone, with little contribution from deeper sources. Variation in the δ^{13}C of the calcite veinlets does imply some variation in the fluid carbon composition.

Without yet being able to determine the age of emplacement of the quartz-epidote veins or the final remobilization and recrystallization of the sulfides, it is impossible to relate these processes to the alteration of the igneous rocks, whose age can be determined. It is possible that three unrelated processes occurred at Kennecott, perhaps separated in time but all occurring after initial formation of a strata-bound sabhka-type ore deposit. The three processes are:

(1) Alteration of the Chitistone Limestone near the ore deposit, reprecipitation of the massive sulfides, and formation of the calcite veinlets containing sulfides by the action of saline, cool, oxidizing fluids, which consisted largely of a nonmeteoric component.

(2) Formation of quartz-epidote veinlets in the greenstone, from the action of a cool fluid, probably enriched in oxygen-18. Geologic evidence strongly supports a deuteric origin for the quartz-epidote veins. Amygdules and vesicles in the greenstone contain quartz-epidote, chlorite, and copper minerals, as do the veinlets. The main copper-bearing veins in the Nikolai are quartz-calcite and are localized in shear zones. They lack epidote (E. M. MacKevett, Jr., written commun., 1976).

(3) Alteration of the igneous rocks intruded in the region near the Kennecott mines by the action of formation waters enriched in oxygen-18.

Only the last of these three events has been dated at about 6 to 15 m.y. by the potassium-argon ages of altered and unaltered quartz porphyry and dacite intrusions. Additional isotopic age determinations and stable-isotope measurements are in process on samples of altered igneous rocks, including Nikolai Greenstone, from the general region and near the mines, to determine if any significant isotopic exchanges affected these rocks. We hope to be able to determine the age of formation of the quartz-epidote veins by these analyses.

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LANDSAT data interpretation, McCarthy, Tanacross, and Talkeetna quadrangles

By Nairn R. D. Albert and William Clinton Steele

Recent work using LANDSAT imagery of the McCarthy, Tanacross, and Talkeetna quadrangles, as part of the Alaskan Mineral Resource Assessment Program (AMRAP), has provided unique geologic, structural, and surficial reflectivity information relevant to mineral resource assessment. Interpretative techniques included visual analysis of a black and white, single-band LANDSAT mosaic of Alaska and of various computer-generated color and black and white products (most of which are now available from the EROS Data Center in Sioux Falls, S. Dak.).

In the McCarthy quadrangle, two types of lineaments were identified (Albert and Steele, 1976a). One type seems to be related to a worldwide regmatic shear pattern or planetary fracture system, whereas the other type is related to faults, folds, and fractures that are probably the result of local and regional tectonics. The correlation between known mineral deposits and these two types of lineaments is very good, particularly where the lineaments cross mineralogically significant rock types. At these locations the relative incidence of mineral deposits is more than 17 times that of the overall quadrangle. Because of the difficulty of analyzing the numerous lineaments and mineral deposits in the McCarthy quadrangle, a computer program was developed (Steele, 1976) that:

1. computes bearing and length of lineaments;

2. generates a histogram of bearing versus cumulative length;
3. relates mineral deposits to lineament bearing;
4. calculates the area within a desired distance of the lineaments.

Recent additions to the program allow it to:

1. calculate mean lineament length;
2. determine a significance value for mineral deposit proximities to lineament;
3. plot a map of lineaments with any desired trends.

Several iron oxide-colored areas identified on simulated natural color imagery correspond to areas identified from independent data by Singer and MacKevett (1976) as having exploration potential.

Numerous lineaments recognized in the Tanacross quadrangle (Albert and Steele, 1976b) can be extended for many hundreds of kilometers, and commonly correspond to geologic, structural, tectonic, and geophysical breaks and trends (fig. 23). The structural and tectonic character of the quadrangle seems to be more closely related to the longer lineaments and to the regmatic shear pattern than were the Nabesna (Albert, 1975) and McCarthy quadrangles. A major northeast-trending fracture or fault zone between lineaments K and L (fig. 23) is suggested by the following evidence:

1. The zone corresponds well to major breaks in aeromagnetic contours in the Tanacross quadrangle (Griscom, 1976) and to a strong aeromagnetic trend in the Gulkana quadrangle (Alaska Division of Geological and Geophysical Surveys, 1973).
2. The zone corresponds to major gravimetric contours for most of its length and to a minor gravimetric low in the Tanacross quadrangle inferred by Barnes (1976).
3. The zone is associated with the epicenter of the 1964 Alaska earthquake and with the boundary between areas of uplift and subsidence inferred by Plafker (1969).
4. The zone seems to terminate the Wrangell Mountains, which are located on the southeastern side of the zone, as is the area of uplift described by Plafker (1969).
5. The zone parallels and coincides with several faults inferred from aeromagnetic data in the Tanacross quadrangle (Griscom, 1976).
6. In the Tanacross quadrangle, the zone contains several faultlike features that are parallel to it and that are visible on conventional aerial photographs.
7. The zone contains numerous shorter lineaments, observed on LANDSAT imagery of the Tanacross quadrangle, that parallel it.
8. The zone seems to cause the elongation of a nearby major circular feature.
9. The zone seems to pass just to the southeast of Prindle Volcano, which shows evidence of a deep connection because of peridotite and granulite inclusions (Foster and others, 1966).

A conjectured east-trending tectonic or structural break occurring approximately between lat 63° 10' N. and 63° 15'N. is suggested by the following evidence.

1. Lineaments with N. 29° W. trends, although strongly visible in most of the quadrangle, do not occur south of this zone.
2. Lineaments with N. 39° W. trends crossing the zone are deflected to approximately N. 45° W. trends.
3. Aeromagnetic data (Griscom, 1976) show an approximately east-trending aeromagnetic low near this proposed break in the eastern part of the quadrangle. According to Griscom, this low largely corresponds to an east-trending row of plutons, most of which are probably connected at depth.
4. In the southwestern part of the quadrangle, Griscom (1976) shows a series of inferred northeast-trending faults, several of which correspond to faults indicated on the geologic map (Foster, 1970) that seem to be terminated by the conjectured break.
5. Aeromagnetically inferred northwest-trending faults near the break also seem to be terminated by it.
6. Gravimetric data (Barnes, 1976) show a corresponding east-trending boundary between a high and a low gravity anomaly just to the west that alines with a significant "saddle" across a north-trending gravity high in the Tanacross quadrangle.

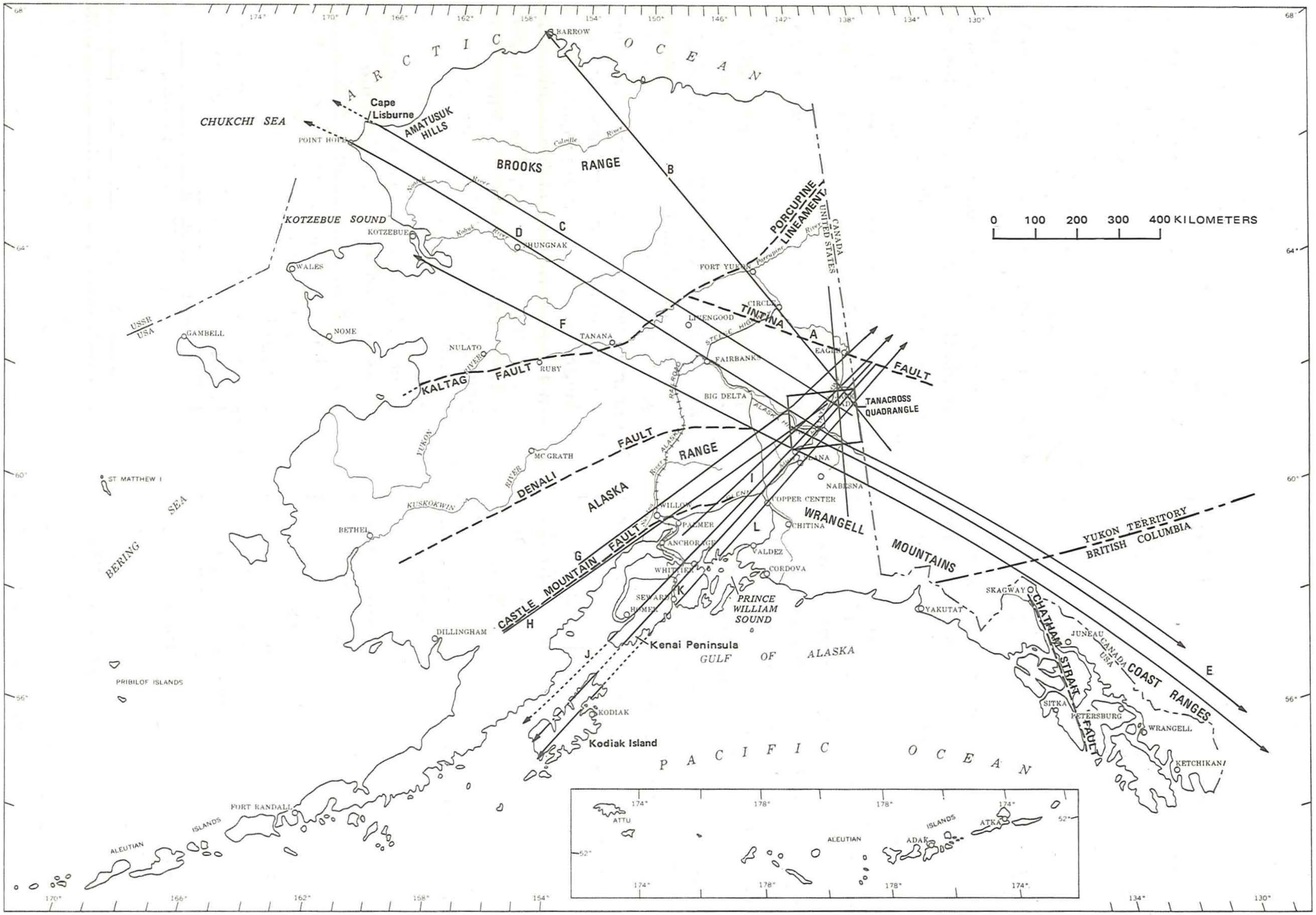

FIGURE 23.—Index map of Alaska showing the approximate location of the Tanacross quadrangle, and geologic features, geographic features, and lineaments outside the quadrangle that are described in the text.

7. Geologic data (Foster, 1970) show east-trending contacts that correspond to the conjectured break.

Because of the scarcity of known mineral deposits in the Tanacross quadrangle and the lack of data on those that are known, correlations with lineaments observed on LANDSAT imagery were not made.

Most circular features identified on LANDSAT imagery are associated with igneous rock types, and those that are not clearly associated with these rock types are probably related to covered intrusive bodies. The significance of the several sets of arcuate features identified on LANDSAT imagery is unclear, but one set seems to reflect the structure of the metamorphic basement through overlying volcanic rocks. Because of the heavy vegetation cover and because spectral response for certain vegetative phenomena are similar to those for iron-oxide areas, we could not specifically delineate any mineralogically significant iron-oxide areas.

Preliminary work on the Talkeetna quadrangle seems to corroborate numerous geologic features and relations that have heretofore only been conjectured by the field geologists. These features include;

1. northeast-trending lineaments that may have controlled the development of the Yenlo Hills and Little Peters Hills;
2. northeast- to east-northeast-trending lineaments that correspond to the Yentna mineral belt and correlate with and connect several faults mapped by B. L. Reed (written commun. 1976);
3. concentric circular features in the Dustin Peak area that may reflect a concealed pluton connecting a group of smaller intrusive bodies visible on the surface.

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Paleozoic sedimentary rocks in the northwest part of Talkeetna quadrangle, Alaska Range, Alaska

By Augustus K. Armstrong, Anita G. Harris, Bruce Reed, and Claire Carter

A sequence of Paleozoic sedimentary rocks, informally called sedimentary rocks of the Dillinger River, is exposed on the north flank of the Alaska Range north of the Tatina River and between the South Fork of the Kuskokwim River and the Dillinger River. North of the Tatina River the sequence is unconformably overlain by Jurassic and Lower Cretaceous graywacke and siltstone. To the east, near Shellabarger Pass, the sequence and the Mesozoic sedimentary rocks are overlain by an allochthonous terrane of upper Paleozoic flysch. The lower contact of the sequence has not been seen.

Sedimentary rocks of the Dillinger River as now recognized consist of three units: interbedded lime mudstone and shale of undetermined thickness; apparently unfossiliferous deepwater lime mudstone (micrite) more than 900 m thick; and interbedded lithic arenite, shale, and limestone at least 700 m thick. Owing to complex structural features and sparse megafossils, the relative ages of these units are not yet known.

A well-exposed section on the Jones River (sec. 2, T. 27 N., R. 22 W.) consists of an upper massive turbidite subgraywacke at least 360 m thick, underlain by 250 m of well-bedded argillaceous lime mudstone (micrite) and a lower 300-m-thick unit of massive-bedded lithic arenite that contains interbeds of dark-gray silty shale. The lower clastic unit, which shows rhythmic and graded bedding and contains numerous shale fragments, is interpreted as a turbidite. The middle lime mudstone unit is dolomitic and does not contain megascopic chert nodules. Study of these carbonates by scanning electron microscope shows that they are composed of calcite crystals in the 10- to 30-µm size range, with varying amounts of small dolomite rhombs, clay materials, fine chert, and 19- to 50-µm pyrite crystals (fig. 24). Petrographic studies indicate that fossil fragments are extremely rare in the carbonate rocks. Sedimentary structures in these limestones include fine crossbedding, parallel lamination, and worm burrows and trails.

Claire Carter has identified graptolites from two horizons in the Jones River section. Beds at the base of the limestone unit yielded *Pristiograptus jaegeri* Holland, Rickards, and Warren, which is a British form from the upper Wenlock (Silurian) zones of *Cyrtograptus lundgreni* and *Monograptus ludensis*. The younger bed contains *Monograptus* cf. *M. ludensis* (Murchison), and *Monograptus* sp. *M. ludensis* is found in the British zones of *M. ludensis* and *Neodiversograptus nilssoni* (upper Wenlock and lower Ludlow).

Anita G. Harris has studied a suite of samples collected from a 353-m-thick section of limestone on the north side of the Dillinger River (SW ¼, sec. 6, T. 28 N., R. 20 W.). She found identifiable but stretched and slightly to badly deformed conodonts throughout the section. They are Silurian (Wenlockian and Ludlowian) in age.

New data concerning age of the Arkose Ridge Formation, south-central Alaska

By Béla Csejtey, Jr., Willis H. Nelson, G. Donald Eberlein, Marvin A. Lanphere, and James G. Smith

Reconnaissance geologic mapping and iso-

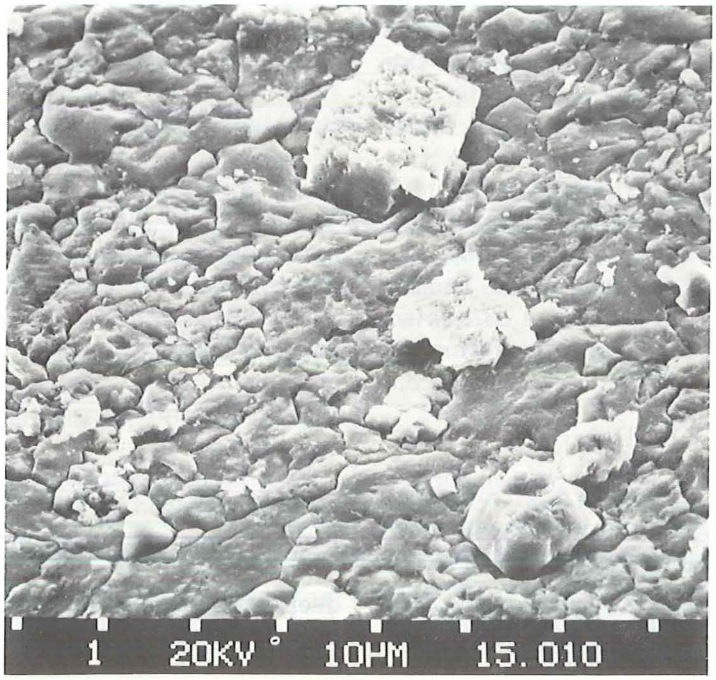

FIGURE 24.—Scanning electron microscope photomicrograph of a typical limestone from sedimentary rocks of the Dillinger River. It is composed of 10- to 30-µm subhedral to anhedral calcite crystals with well-defined boundaries. Dolomite rhombs (5- to 20-µm size) and small clay minerals occur between the calcite crystals.

topic age calculations from the southern Talkeetna Mountains of south-central Alaska, in conjunction with thin-section studies of the Arkose Ridge Formation, suggest that the Arkose Ridge Formation is Cretaceous in age; this age estimate is similar to that of Grantz and Wolfe (1961). More recently, Detterman and others (1976) considered the Arkose Ridge Formation to be of Paleocene age.

Potassium-argon age determinations and recent mapping in the southern Talkeetna Mountains revealed that, in addition to granites of Late Cretaceous to early Tertiary age (Csejtey, 1974), large areas are underlain by Middle and Upper Jurassic granitoids and associated metamorphic rocks. The Arkose Ridge Formation rests unconformably on these Jurassic rocks, but its relation to the younger granites is less obvious.

Along the middle course of the Little Susitna River, the northern wall of its glaciated valley is formed by the edge of a large tonalite pluton, approximately 1,100 km^2 in area. The Arkose Ridge Formation crops out along the southern side of the valley (fig. 25). Eight potassium-argon age determinations from the tonalite pluton, seven of which are on coexisting biotite-hornblende mineral pairs, yielded Late Cretaceous to early Tertiary concordant ages: about 60 to 72.5 m.y. Petrographic and structural characteristics of the tonalite pluton, especially its uniformly coarse to medium grain size, conspicuous good to fair flow foliation, and lack of fine-grained border facies, indicate that the pluton was emplaced at some depth in the earth's crust, either in the lower part of the epizone or in the transitional zone between the epizone and mesozone of Buddington (1959). Such a pluton requires a minimum roof thickness of 5 to 7 km. The contact between the tonalite pluton and the Arkose Ridge Formation is covered by glacial deposits, but the two rocks crop out about 1 km from each other. There is no evidence in the area that the tonalite and the Arkose Ridge were faulted together. Close to the tonalite the Arkose Ridge is extremely indurated but becomes rather friable a few kilometers away. Were the Arkose Ridge Formation of Paleocene age, its proximity to the tonalite pluton requires that the pluton have been rapidly unroofed, which is unlikely. Thus,

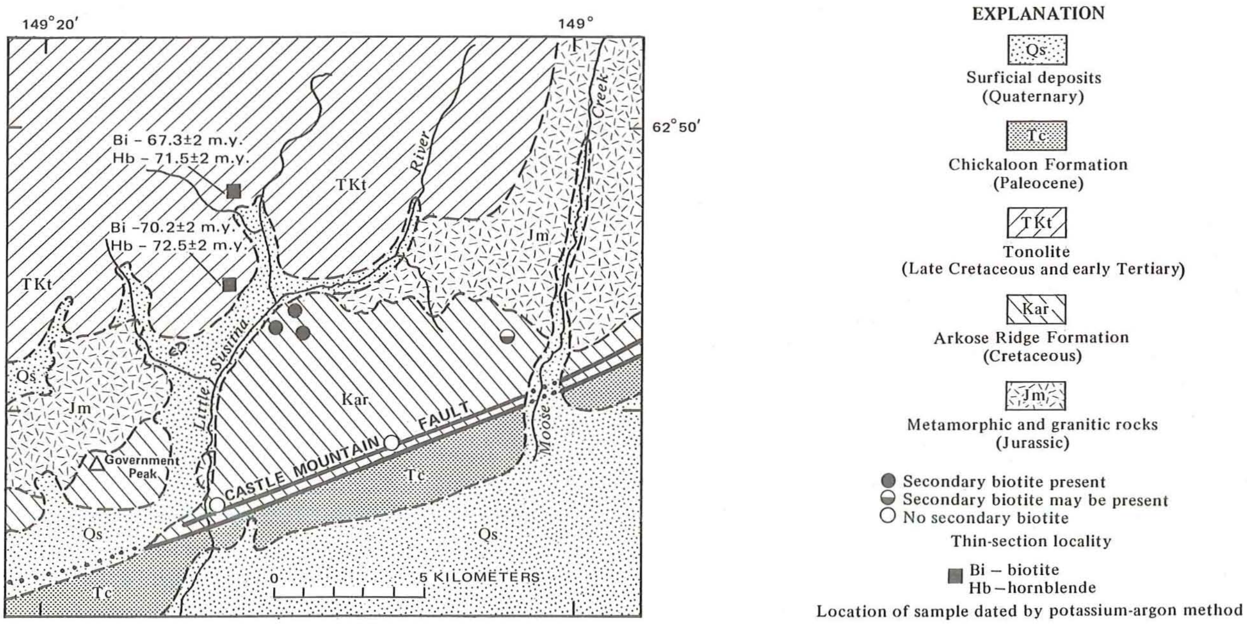

FIGURE 25.—Generalized geologic map of the Little Susitna River area, southern Talkeetna Mountains, Alaska.

the field evidence suggests that the Arkose Ridge Formation is older than, and was intruded by, the approximately 60- to 72-m.y.-old tonalite pluton.

To verify the apparent intrusive relation, thin sections of the Arkose Ridge Formation, about 1 to 20 km from exposed tonalite, were examined for contact-metamorphic effects. Four thin sections about 1 km from the tonalite showed clearly secondary in situ growth of fine-grained biotite and subordinate chlorite and muscovite. One thin section about 5 km away showed clearly secondary muscovite and chlorite and some fresh biotite that may be secondary overgrowth on detrital biotite. Six additional thin sections of Arkose Ridge samples, 8 to 20 km from the tonalite pluton, displayed no obviously secondary biotite, and only four of the sections showed minor amounts of secondary muscovite and chlorite. (These sections courtesy of R. L. Detterman, 1976.)

In the absence of a directed fabric, the development of secondary biotite in the Arkose Ridge Formation indicates a thermal event subsequent to deposition. An obvious source for this thermal event appears to be the nearby tonalite pluton. However, evidence for an even younger thermal episode in the southern Talkeetna Mountains casts some doubt on the relation of the development of secondary biotite to the intrusion of the tonalite. Three potassium-argon age determinations on muscovite from mica schist of probable Jurassic age, about 15 km west of the Arkose Ridge Formation containing the secondary biotite, gave reset ages of roughly 57, 58, and 64 m.y. On the other hand, the tonalite adjacent to the Arkose Ridge strata with the secondary biotite has not been appreciably affected, as the concordant ages on two biotite-hornblende mineral pairs from that part of the pluton indicate (see fig. 25). This fact, plus the range of the reset muscovite ages, suggests that the younger thermal episode affected the southern Talkeetnas unevenly and with relatively low intensity, and that the likely thermal source for the secondary biotite in the Arkose Ridge Formation was indeed the intrusion of the tonalite. To help solve this problem, M. L. Silberman is currently carrying out potassium-argon age determinations on biotite from the Arkose Ridge Formation.

All available evidence seems to suggest that the Arkose Ridge Formation is older than Tertiary and that it may be a part of the Early and Late Cretaceous Matanuska Formation or of Early Cretaceous age. Such age assignment for the Arkose Ridge would greatly simplify the tectonic history of both the southern Talkeetna Mountains and the Matanuska Valley.

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The Donnelly Dome and Granite Mountain faults, south-central Alaska

By Travis Hudson and Florence R. Weber.

As part of the Alaska Geologic Earthquake Hazards Project, the Donnelly Dome and Granite Mountain faults, in the southern parts of the Mount Hayes D-3 and D-4 quadrangles (fig. 26), were briefly examined in July of 1976 to determine whether surficial features related to recent tectonic displacements were present. These faults are probably continuous with one another and together form a 20- to 30-km-long fault system that marks part of the northern boundary of the central Alaska Range. Topographic and geologic relations across the faults consistently indicate normal displacement with relative upthrow of the southside (Péwé and Holmes, 1964, Holmes and Péwé, 1965). The faults were included in a summary of active faults of Alaska by Brogan, Cluff, Korringa, and Slemmons (1975).

The Donnelly Dome fault is best expressed from Donnelly Dome eastward for 6 km where its arcuate trace changes strike from N. 50° W. in the vicinity of the Richardson Highway to N. 80° W. east of Ober Creek. It may also extend west of Donnelly Dome about 3 km along a N. 35°E. trend where a conspicuous alinement of springs is present. Throughout most of the

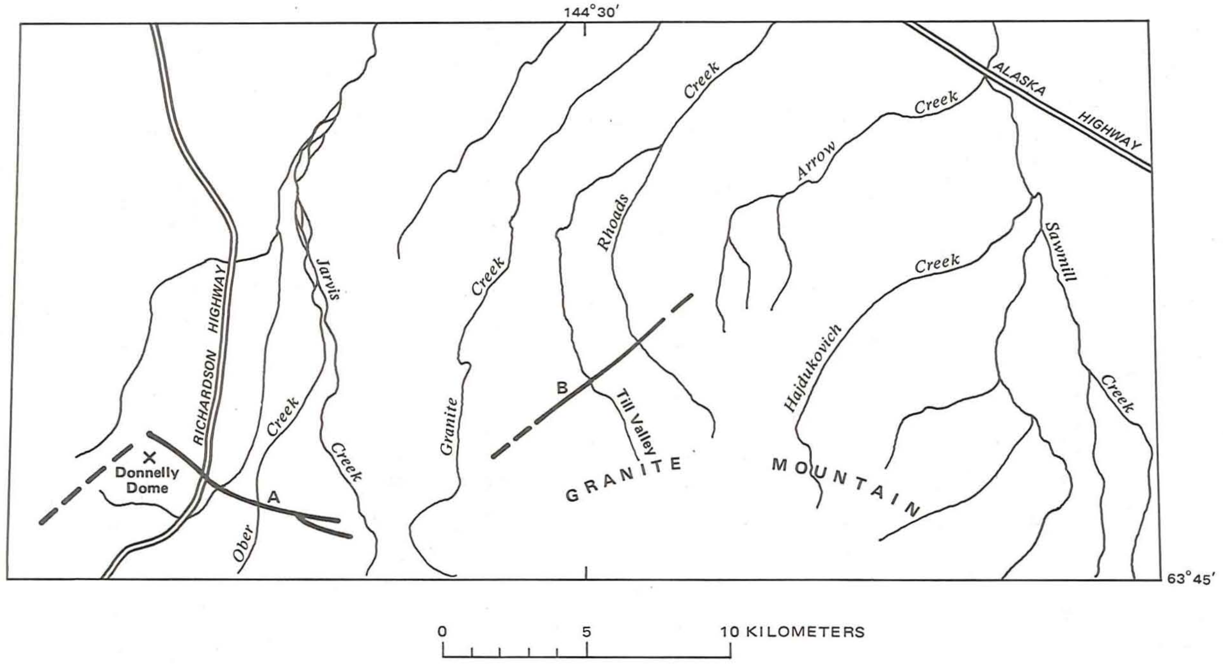

FIGURE 26.—Index map and location of the Donnelly Dome (A) and Granite Mountain (B) faults in the Mount Hayes D-3 and D-4 quadrangles, south-central Alaska.

length east of Donnelly Dome the fault is defined by a major north-facing escarpment within morainal and glaciofluvial deposits regarded by T. D. Hamilton (written commun., 1976) as late Wisconsin (Donnelly) in age. This north-facing escarpment is 20 to 60 m high and commonly rises steeply from the base and slopes more gently, either gradually or in a series of subdued steps, toward the top. Near the Richardson Highway the base of the scarp is locally a shallow linear depression. Just east of Ober Creek the escarpment cuts an alluvial terrace that may postdate slightly the maximum Donnelly advance. The terrace surface contains clearly defined stream channels that appear to have eroded and subdued the 30-m-high main escarpment. Slightly to the north is a parallel but short and sharp 3-m break that is not continuous to either the east or west. As mapped by Péwé and Holmes (1964), the main escarpment may split into two segments just east of the stream terrace. One branch continues on a N. 80° W. strike for about 1 km, and one shifts to a more southerly trend for about 2 km. No trace of the Donnelly Dome fault was observed east to Jarvis Creek.

The Granite Mountain fault trends about N. 60° E. along the northwest side of Granite Mountain in the Mount Hayes D-4 and D-3 quadrangles (Péwé and Holmes, 1964, Holmes and Péwé, 1965). Granite Mountain rises abruptly from alluvial plains along the southside of the Tanana River valley. All along the mountain front, colluvial and alluvial deposits form large aprons grading outward to the lower alluvial plains. Morainal lobes of Donnelly and older age extend northward from the mountain front from all the main drainages.

The trace of the Granite Mountain fault is commonly obscured by the colluvial and alluvial deposits of the mountain front. The fault is best defined in the vicinity of Rhoads Creek in the Mount Hayes D-3 quadrangle where a 75-m escarpment separates parts of a moraine of Donnelly age that were probably once continuous. Even here, however, the actual trace of the fault defining the contact between granite to the southeast and moraine to the northwest is obscured by colluvial deposits. Only one area of colluvial-alluvial deposits along the mountain front contains surficial features that are possibly fault related. A 1-km stretch west from Till Valley, straddling the Mount Hayes D-3 and D-4 quadrangle boundary, contains some discontinuous, relatively sharp, northwest-facing scarps as much as 3 m high. These features occur upslope from the projected trace of the fault and could reflect slumping within the colluvial-alluvial apron rather than fault displacement. Irregular tension fractures occur in a moraine at the mouth of the first valley west of Till Valley.

In summary, the Donnelly Dome and Granite Mountain faults define a 20- to 30-km-long range-front system characterized by predominantly normal displacement and by changes in strike as at the north side of Donnelly Dome, in the vicinity of Jarvis Creek, and perhaps at the northermost part of Granite Mountain. Indications of Quaternary displacement are best preserved in glacial deposits of the maximum Donnelly advance (at least 17,000 years B.P. and possibly as much as 30,000 to 35,000 years B.P. (T. D. Hamilton, written commun., 1976)). Moraines of Donnelly age have been offset vertically a maximum of 75 m on the Granite Mountain fault, but deposits that are apparently of the same age have been displaced as little as 20 m on the Donnelly Dome fault. If perched morainal remnants along the east side of Donnelly Dome correlate with older glacial deposits immediately to the north of the dome, as much as 100 m of vertical Quaternary displacement is indicated for the Donnelly Dome fault. The available data suggest that displacements have been recurrent but of different magnitudes in different parts of the fault system.

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A late Tertiary thrust fault in the central Alaska Range

By Florence R. Weber and Donald L. Turner

Investigators mapping in separate areas have recognized faults bounding the south edge of Paleozoic and Mesozoic rocks in the central and eastern Alaska Range. The faults have been variously interpreted as normal and reverse and include those mapped by Petocz (1970, faults E and parts of A), Hanson (1963, thrust fault at the south end of Rainbow Ridge) and Rose (1967, fault B and possibly others). As a result of geologic mapping in the vicinity of the Richardson Highway in the south-central Mount Hayes quadrangle, we believe that the faults listed above, and a newly recognized extension east of the Richardson Highway, are all parts of a single thrust fault. This fault primarily thrusts rocks of late Paleozoic age southward over upper Tertiary sediments.

The fault trace has been mapped over a straight-line distance of at least 50 km from Eureka Creek west of the Delta River to Magnetite Creek east of Gakona Clacier. From near the mouth of Eureka Creek, the fault trends northeasterly to the Richardson Highway then shifts to a southwesterly trend along the mountain front to McCallum Creek and beyond. The trace is exposed in the Gulkana River valley and continues eastward to cross low divides into the headwaters of Gunn Creek and the broad valley occupied by Gakona Glacier. The fault is particularly well exposed in gullies east of McCallum Creek and in a gulch draining south from "The Hoodoos" in the northwestern corner of the Mount Hayes A-3 quadrangle. In these areas volcanic and sedimentary rocks of Pennsylvanian and Permian age are thrust, at a low angle, southward over Tertiary sedimentary rocks. Broad folds, overturned slightly to moderately to the south, are developed in the Tertiary strata near the thrust between McCallum Creek and the Gulkana River valley.

The Tertiary rocks can be divided into two units. The lower unit, possibly 150 to 300 m thick, is predominantly lignitic sandstone and shale but also contains some conglomerate and ash. The upper unit contains several thousand meters of conglomerate.

The potassium-argon age of the hornblende separated from an ash sample collected by Edward Burran from the lower unit is 5.26 m.y. This age is in good agreement with fossil age determinations made by Estella Leopold (boundary between Miocene and Pliocene) (written commun., 1973) and Jack Wolfe (oral commun., 1973) on plant collections from beds immediately above and below the dated ash.

Dating of the deposits deformed by thrust faults establishes that major tectonic compression occurred in this part of the Alaska Range at a geologically young time, possibly in the Pliocene. Also during this time major strike-slip motion possibly occurred on the Denali fault, 15 km to the north (Reed and Lanphere, 1974; Turner and others, 1974).

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Preliminary observations on late Cenozoic displacements along the Totschunda and Denali fault systems

By George Plafker, Travis Hudson, and Donald H. Richter

A helicopter-supported reconnaissance study of the Alaskan segments of the Totschunda and Denali fault systems (see fig. 2(16)) was completed during the 1976 field season as part of the Geologic Earthquake Hazards project. The results show that the recency, sense, and amount of displacement differ significantly along these major faults and that these differences may be useful for predicting their future behavior and the earthquake hazard associated with them.

The Totschunda fault (Richter and Matson, 1971) extends in a northwest direction for 200 km from the border with Canada to its junction with the Denali fault near Mentasta Pass (fig. 27). For most of its length (segment B, fig. 27) the trace is well defined and marked by scarplets, ponds, fissures, and offset drainages in bedrock, glacial deposits, and some alluvial and colluvial deposits. The extreme southeastern part (segment A, fig. 27) can be traced in bedrock through a topographically rugged area, but this area does not contain Quaternary

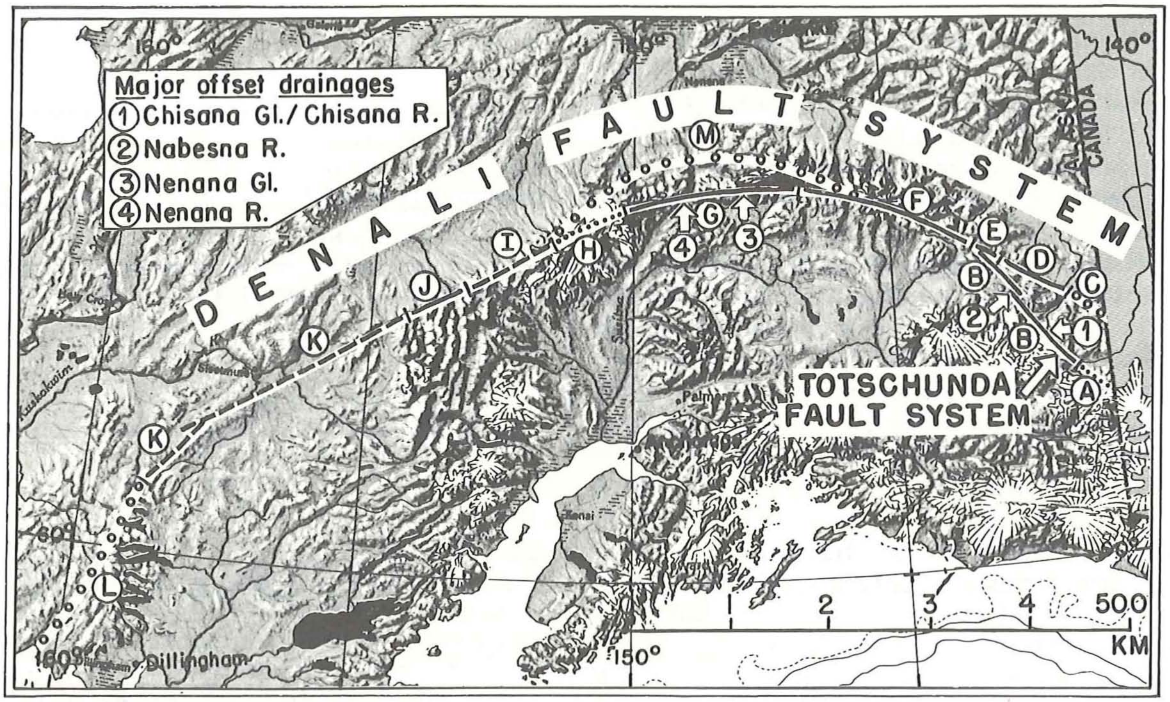

FIGURE 27.—Index map of the Denali and Totschunda fault systems showing segments referred to in text (lettered) and major offset drainages (numbered). Solid line indicates continuous active fault trace; dashed line indicates discontinuous, poorly defined fault trace; dotted line indicates fault trace in bedrock with unknown Quaternary activity; open dots indicate inactive fault segment.

deposits useful in determining the recency of faulting. Displacement is dominantly horizontal and dextral with offsets of supposed late Wisconsin moraines along the trace of as much as 146 m. The most recent displacement on the fault may predate deposition of the White River Ash Bed approximately 1,520–1,720 years B. P. (Péwé, 1975) because soils containing the ash do not appear to be offset along the fault trace.

The Denali fault extends in a broad arc for 1,600 km across Alaska from the Canadian border on the east to Bristol Bay on the west (St. Amand, 1957; Grantz, 1966). Between the Tetlin River and McKinley Park (segments E, F, G, fig. 27) scarplets, ponded drainage, fissures, and offset streams clearly suggest horizontal displacement. Dextral offsets of probable late Wisconsin glacial deposits and topographic features are as much as 87 m along segment E, and 116 m along both segments F and G. Judging from the relative age and preservation of offset features along the fault trace, segment G clearly has had the most recent movement, possibly within the last few hundred years. In contrast, the fault trace in segments E and F have about the same appearance as the active part of the Totschunda fault trace, which apparently did not move since the White River Ash Bed was deposited between 1,520 and 1,720 years B. P.

The remainder of the Denali system shows little or no evidence for an active fault trace comparable to the trace already described. Segment D is characterized by a discontinuous degraded north-facing scarp in Holocene and probable late Pleistocene deposits. Undated Pleistocene glacial moraines along part of this segment have been offset as much as 251 m in a dextral sense. Segment H is in a topographically rugged area where the fault can be easily traced in bedrock, but where no information could be obtained on its Quaternary offset history. Offset of a granodiorite pluton indicates that this fault segment has undergone a total of 38 km of dextral displacement since the early Oligocene (Reed and Lanphere, 1974). Segment I is marked by discontinuous, poorly defined alined drainages and scarps with local dextral offests of bedrock ridges to about 0.6 km but no significant lateral displacement of glacial deposits. Segment J, which is defined by a degraded and discontinuous north-facing scarp in late Quaternary alluvial and colluvial deposits, shows no unequivocal evidence for Quaternary strike-slip offsets. Segment K is marked by discontinuous, poorly defined slope breaks and by alinement of major drainages or topographic features. No Holocene scarps or Quaternary offsets were found along the extreme easternmost or westernmost parts (segments C and L, fig. 27) or along the Hines Creek strand (segment M, fig. 27) of the Denali fault system in Alaska.

Absolute ages of the offset late Wisconsin glacial features along the Denali and Totschunda faults are not available, but samples have been collected for carbon-14 analysis that may permit dating of these features. If the Holocene Epoch began approximately 8,000 years ago (Péwé, 1975), then rough estimates of the average dextral displacement rate along the Denali and Totschunda fault systems are between 1 and 2 cm/yr. If this average strain rate is approximately correct, strain buildup could be at least 20 to 30 m on the part of the fault systems east of segment G, assuming that last movement along this part predates White River Ash Bed and that there is no significant strain relief by creep. This rate implies that a major earthquake could be overdue in eastern Alaska. Such an earthquake could affect at least 350 km of the Denali/Totschunda systems (segments B, E, F) and might involve dextral displacements on the order of tens of meters.

An estimate of the total amount of late Cenozoic dextral displacement along the active segment of the Denali and Totschunda fault systems can be derived from the offset of major antecedent drainages. Four such valleys (fig. 27) are systematically offset an average of 4.0 km (Chisana Glacier/Chisana River–3.6 km, Nabesna River–3.6 km, Nenana Glacier–4.0 km, Nenana River–4.4 km). Displacement rates of 1–2 cm/yr suggest that major dextral displacement on these segments could have begun as recently as 200,000 to 400,000 years ago.

A major unresolved problem concerns how the Quaternary dextral displacement of about 4 km along the eastern part of the fault systems is taken up in that part of the Denali system west of segment G where there is no evidence of large Quaternary horizontal slip. One possibility is that the strike-slip movement is taken up along a zone of thrust faults or oblique thrust faults that trend southwestward into the Alaska Range from the vicinity of Ripsnorter Creek near the western end of segment H. Available data suggest that the most likely location for such a fault zone is along the major structural contact that juxtaposes a Paleozoic carbonate terrane on the northwest against a Mesozoic flysch terrane to the southeast (Beikman, 1974).

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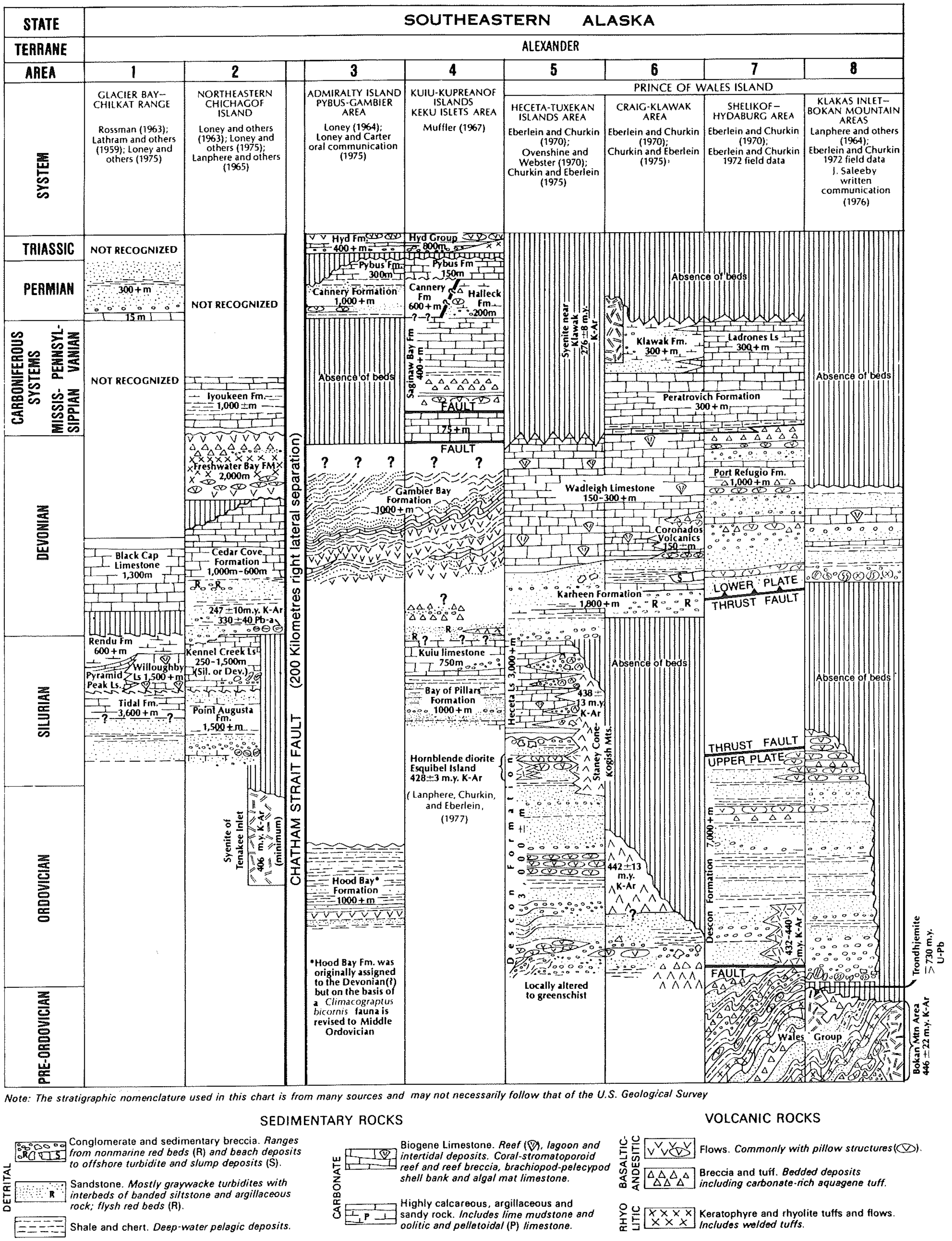
SOUTHEASTERN ALASKA

Correlation of the rocks of southeastern Alaska with other parts of the Cordillera

By Michael Churkin, Jr. and G. Donald Eberlein

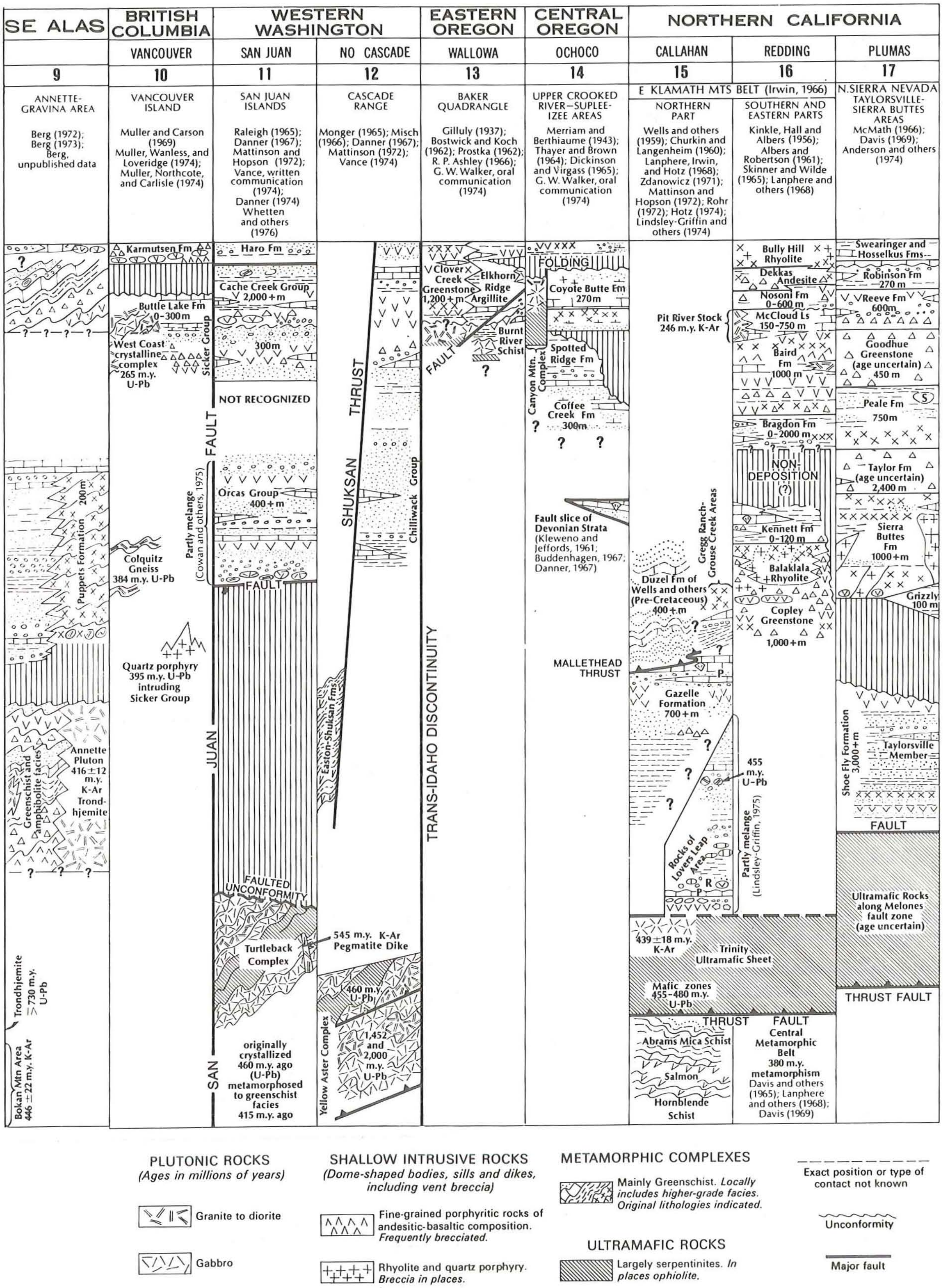
Correlation of the rocks of southeastern Alaska with other parts of the Cordillera made possible a new plate-tectonic interpretation of the development of these borderland terranes. The Precambrian and Paleozoic sequences rich in volcanic and plutonic rocks in southeastern Alaska form an enigmatic terrane along the outer border of the North American Cordillera. Comparable borderland terranes occur farther south on Vancouver Island, B. C., San Juan Islands of Washington, northern Cascade Mountains, eastern Oregon-westermost Idaho, central Oregon, and northern California (fig. 28).

All of these terranes appear allochthonous with respect to the North American continent because their geology cannot be correlated with that of the adjacent continent and because they contain ophiolites, suture zones, and large



Note: The stratigraphic nomenclature used in this chart is from many sources and may not necessarily follow that of the U.S. Geological Survey

FIGURE 28.—Correlation of borderland terranes from southeastern



Alaska to northern California. From Churkin and Eberlein (1977).

transcurrent faults. Furthermore, major differences in stratigraphy, magmatic and tectonic activity, metamorphism, and especially differences in age and type of basement among the terranes suggest that at least six lithospheric plates are represented.

The terrane in the southern part of southeastern Alaska has a Precambrian crystalline metavolcanic and metasedimentary basement, but an andesitic to basaltic basement of Ordovician age occurs farther north. In contrast ultramafic rocks form the basements of some borderland terranes south of Alaska. Transcurrent faults segment and truncate parts of the Cordillera, but since the borderlands are in themselves composed of several plates, models of a single allochthonous plate are difficult to apply. More likely, during Precambrian and Paleozoic time, multiple microcontinental plates and volcanic arcs moved outboard and inboard to accommodate a succession of marginal ocean basins opening and closing behind migrating arcs. This movement was followed in the Mesozoic and Cenozoic by large-scale northwestward drift.

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Reconnaissance engineering geology and geologic hazards of the Metlakatla area, Annette Island

By L. A. Yehle

A reconnaissance engineering geology report for the city of Metlakatla, Annette Island (fig. 2(17)) has been completed (Yehle, 1977). Evaluation of earthquakes and other geologic hazards is emphasized. Bedrock in the area consists of hard, metamorphic rocks at shallow depth beneath firm nonorganic surficial deposits possibly averaging 3 m in thickness. These deposits in turn are overlain by very soft muskeg and peat possibly averaging 1.5 m in thickness. A few large earthquakes have affected Metlakatla since its founding in 1887; they probably caused only very minor damage to the few large building in the area. The largest earthquake was the magnitude 8.1 Queen Charlotte Islands earthquake of August 22, 1949, with the principal epicenter 200 km southwest of Metlakatla. Effects from future large earthquakes probably will be minimal except in and near structures founded on thick muskeg and other organic deposits where strong ground shaking and possibly some liquefaction of organic deposits should be expected. The most important earthquake-related waves are tsunami waves, which may reach heights of 6 m. Those developed by distant earthquakes can be forecast. Geologic hazards other than those related to earthquakes are mostly of little importance to Metlakatla. Locally, however, significant landslides may occur along the steep slopes bounding lakes that provide the city's water supply and hydroelectricity.

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Metamorphosed trondhjemite of the Alexander terrane in Coast Range plutonic complex

By Richard D. Koch, Raymond L. Elliott, James G. Smith, and Henry C. Berg

Recent fieldwork in the area between Foggy Bay and Cape Fox in the Prince Rupert D-3 quadrangle, southeastern Alaska, has shown that an elongate body of rock originally mapped as greenschist (Wright and Wright, 1908; Buddington and Chapin, 1929) is instead a sheared trondhjemite pluton, informally referred to as the Cape Fox pluton. This body is exposed over an elliptical area 9 km by 19 km along the western margin of the Coast Range plutonic and metamorphic complex. Despite its inclusion in the Coast Range complex, the Cape Fox pluton may be a part of the older Alexander terrane that lies in a roughly parallel belt to the west (Berg and others, 1972).

The Coast Range plutonic and metamorphic complex is a linear belt that extends 1,700 km along the Pacific coast from British Columbia through southeastern Alaska into Yukon Territory (Douglas and others, 1970; Hutchison, 1970; Roddick and Hutchison, 1974). Within the Ketchikan and Prince Rupert quadrangles the complex forms three irregular belts with northerly trends (Elliott and others, 1976; Berg and others, 1977). The easternmost belt lies just west of Portland Canal and consists predominantly of discrete granodiorite and quartz monzonite plutons. A central belt of high-grade paragneiss and foliated plutonic rocks is flanked on the west by a third, heterogeneous belt of phyllite, schist, greenschist, amphibolite, and minor marble with subordinate plutonic rocks. In the Ketchikan region, potassium-argon dating indicates that the Coast Range complex formed mainly during two major metamorphic and intrusive episodes 80 m.y. and 50 m.y. ago (Smith, 1975).

The Alexander terrane is an irregular belt of allochthonous sedimentary, volcanic, and metamorphic rocks that extends for 1,000 km along the Pacific coast from Dixon Entrance to the Wrangell Mountains (Berg and others, 1972). The oldest fossil-bearing rocks in the terrane are Lower Ordovician graptolitic shales, but intrusive relations and a thick underlying section of undated beds suggest that the section extends into the Cambrian and probably into the Precambrian (Eberlein and Churkin, unpub. data, 1976). the youngest fossil-bearing rocks assigned to the Alexander terrane are Late Triassic. The terrane is cut by granitic plutons ranging in age from Precambrian(?) to Cenozoic. The south half of the terrane includes several trondhjemite plutons that are Silurian or older. The largest of these trondhjemite plutons is the 400-m.y.-old or older Annette pluton on Annette Island (Berg, 1972).

The Cape Fox pluton was originally a medium-grained hypidiomorphic granular biotite trondhjemite. Potassium-feldspar was absent or present in small amounts, and biotite was the only original mafic mineral. Most of the pluton has been sheared and altered during regional metamorphism that produced cataclastic, commonly semischistose rocks. The granitic texture was, in places, completely destroyed. The degree of deformation and alteration is not uniform, and variation is apparent even at outcrop scale. Parts of some outcrops are now chlorite-epidote-muscovite-plagioclase-quartz schist and strongly resemble greenschist. Most outcrops are characterized by abundant angular quartz porphyroclasts. The southeastern margin of the pluton is a 1-km-wide band of quartz-mica schist produced by cataclasis and structural intercalation of the pluton with the adjacent metavolcanic and metapelitic rocks.

The Cape Fox pluton and surrounding country rocks are inferred to have been regionally metamorphosed during the Coast Range metamorphic event 80 m.y. ago. This age is based in part on a partially reset potassium-argon date of 67 m.y. made on biotite from a sample of schist collected 12 km north of the pluton. Comparison of this date with a pattern of reset ages to the north (Smith, 1975) suggests a metamorphic age of 80 m.y. for this schist. A granodiorite stock near Sykes Lake, 25 km north of the Cape Fox pluton, has a distinct thermal aureole that overprints the surrounding regionally metamorphosed schists. The pluton yielded discordant potassium-argon dates, but the hornblende date of 78 m.y. indicates that a significant regional metamorphic event occurred at least 80 m.y. ago.

The likelihood that the Cape Fox pluton and surrounding rocks were regionally metamorphosed before 80 m.y. ago suggests that this pluton may correlate with other pre-80 m.y. trondhjemite plutons in southern southeastern Alaska. The only such plutons known in the region are part of the Alexander terrane. Petrographic, modal, and chemical evidence suggests a possible correlation with Silurian or older Annette pluton, a trondhjemite stock on Annette Island 40 km to the northwest. If this correlation is correct, it will mark the first documented occurrence of Alexander terrane rocks in the Coast Range plutonic and metamorphic complex.

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Investigations of the Wilson Arm molybdenite deposit

By Travis Hudson, Raymond L. Elliott, and James G. Smith

The Wilson Arm molybdenite deposit, in the Ketchikan B-2 quadrangle of southeastern Alaska (fig. 2(18)), was briefly visited in September 1976 in order to study and sample the intrusive rocks associated with the mineralization. Field examination confirmed that the two felsic stocks in the area are composite hypabyssal bodies separated at the surface by a narrow septum of gneiss. The stocks are oval in plan and sharply discordant with the enclosing metamorphic and plutonic rocks. The contact zone is commonly a complex irregular network of pegmatite, aplite, and porphyry dikes and sills. Lamprophyre dikes crosscut all intrusive phases and mineralized zones along a consistent northeast trend, but locally they have been slightly displaced by small crossfaults. A preliminary report by Elliott, Smith, and Hudson (1976) summarizes many aspects of the general geology and setting of the stocks as known prior to 1976.

Both stocks contain many textural facies. The southern stock includes biotite-quartz porphyry, biotite-quartz-feldspar porphyry, and seriate fine- to medium-grained biotite granite. The porphyritic rocks commonly have an aplitic groundmass; irregular pods and veins of quartz-feldspar pegmatite are relatively abundant in some parts of the southern stock. The principal mineralization occurs in the northern stock, which includes fine-grained equigranular biotite granodiorite(?), fine-grained equigranular biotite granite, and a variety of porphyritic rocks with groundmass that is locally aphanitic but generally fine grained and aplitic.

Molybdenite-quartz veins and molybdenite fracture coatings occur over large areas of the northern stock, and pyrite is nearly ubiquitous in and around it. The pyrite occurs as disseminated euhedra in porphyries, in veinlets cutting both molybdenite-bearing and molybdenite-free rocks, and as disseminations in country rocks adjacent to the stock. Amphibolite observed near the southern contact of the northern stock is particularly rich in pyrite. The ubiquitous pyrite of the northern stock contrasts sharply with its absence in the southern stock, which appears nonmineralized over most of its area. Chlorite commonly occurs along fractures in many molybdenite- and(or) pyrite-bearing rocks of the northern stock.

Samples of the different phases and mineralized parts of the stocks have been collected, and the objectives of present laboratory work are to describe the petrology, determine the major- and trace-element chemistry, and obtain the potassium-argon age of the intrusive complexes. These data will define the general characteristics of the host rocks of the important Wilson Arm molybdenite deposit and assist in identifying similar rocks and mineralized zones elsewhere in southeastern Alaska.

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I and L vein system, Bokan Mountain, Prince of Wales Island

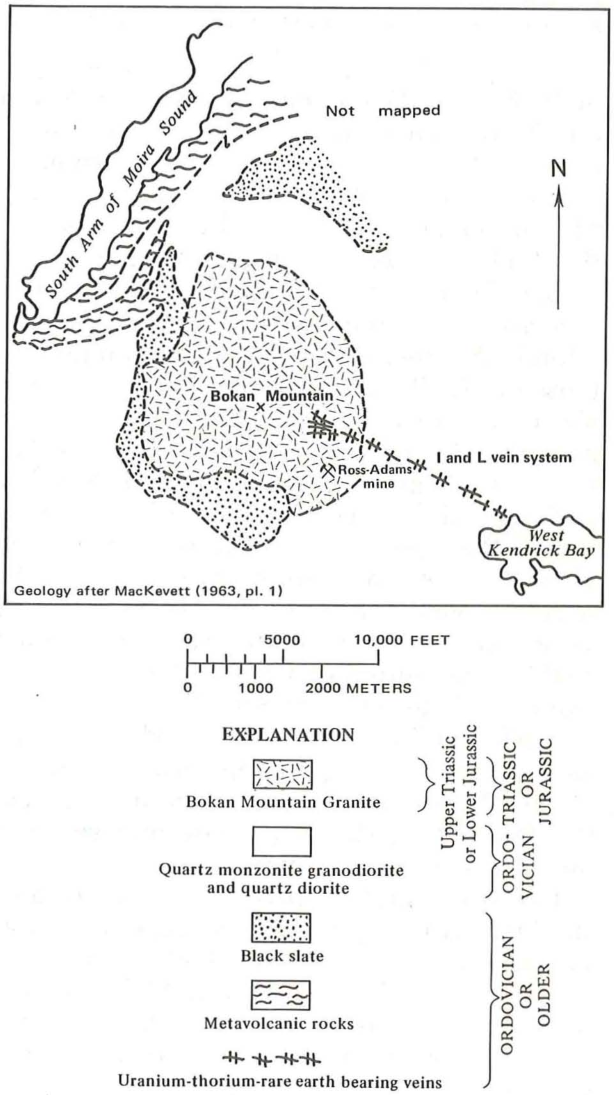
By Mortimer H. Staatz

The only uranium produced in Alaska has come from an irregular, steeply dipping pipe in the Bokan Mountain Granite on southern Prince of Wales Island. MacKevett (1963, pl. 1) noted 39 other uranium localities either in or within 2.5 km of this pluton's border. In addition to uranium, these localities also contain thorium and rare earths. These metals are localized chiefly in small pegmatites in the central parts of the Bokan Mountain Granite and in veins in the outer parts of the granite and in the adjacent country rock. The best known group of veins occurs near the southeast corner of the granitic pluton, and the northwest end of these veins lies 0.3 km north of the opencut of the uranium producing Ross-Adams mine (fig. 29). This vein system is named the I and L system after three claims that cover its northwestern end.

The I and L system comprises one to at least nine parallel to subparallel veins that dip steeply and have a N. 50°–75° W. strike. This vein system has been traced from an elevation of 370 m at its northwest end for 2.6 km to sea level on the west arm of Kendrick Bay. The veins range from 0.25 to 152 cm in thickness. The vein system is bounded on the north and south by several well-defined fractures that are clearly visible on the aerial photographs. Several small transverse veins, which strike almost at right angles to the main vein system, are found on the north side of the main system in one small area. These poorly exposed veins, which have been traced for at most about 12 m, strike from N. 10° to 55° E.

The mineralogy of the veins is complex, and 33 minerals have been recognized, although many occur only locally. The principal gangue minerals are quartz and albite. Uranium occurs chiefly as thorium-bearing uraninite. Brannerite was identified in several of the transverse veins. Thorite is the principal thorium mineral in the northwest and central part of the vein system, but in the southeast part of the system and in the transverse veins thorium occurs chiefly in allanite. Rare-earth minerals besides allanite are bastnaesite, xenotime, monazite, and carbonate minerals. The mineralogy of these veins is similar in many respects to thorium-bearing veins in other states (Staatz, 1974, p. 498).

The uranium content of 43 samples collected by the author and E. M. MacKevett (1963, p. 77 and 87) ranges from 0.005 to 2.8 percent. Samples also contain highly variable thorium and rare earth contents, which range from a few hundredths to more than 10 percent. The rare earths were apparently fractionated within individual veins, as parts of a vein may be high in the cerium group of rare earths and other parts may be high in the yttrium group. These veins also contain abnormally high amounts of barium, beryllium, nobium, strontium, tin, and zirconium. Abnormal amounts of beryllium are generally not associated with deposits containing rare earths and thorium, although this element is found in a thorium- and rare-earth-bearing breccia at Hicks Dome in Illinois.



Geology after MacKevett (1963, pl. 1)

FIGURE 29.—Generalized geologic map of the Bokan Mountain area showing the I and L vein system.

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Miocene or younger strike-slip(?) fault at Canoe Passage, southeastern Alaska

By Richard D. Koch, James G. Smith and Raymond L. Elliott

A high-angle strike-slip(?) fault was mapped in 1976 along Canoe Passage between Etolin and Brownson Islands, astride the boundary between the Craig and Petersburg quadrangles, southeastern Alaska (Berg and others, 1976). The pronounced physiographic expression of this fault extends more than 25 km north from Ernest Sound and includes Canoe Passage, Menefee Inlet, and lowland areas on Etolin Island. A prominent steep topographic rise (possible fault-line scarp) flanks the western side of the fault on parts of Etolin Island. Fault gouge produced from metapelitic rocks within Canoe Passage, brecciated zones in Miocene and probable Miocene granitic rocks bordering Canoe Passage, and soda springs below and above tide level mark the trace of the fault. The northern part of the fault trace is concealed by vegetation and alluvium on Etolin Island but could extend into Zimovia Strait; the southern end extends into Ernest Sound.

Dissimilar lithologies are exposed on opposite sides of Canoe Passage along most of its length. No lithologic correlations could be made across the fault; thus, the magnitude and sense of displacement are not known.

Two young granitic plutons were affected by the fault. An unweathered Miocene (19.7 m.y.; potassium-argon date on biotite) medium-grained miarolitic leucocratic biotite quartz monzonite is exposed on Etolin Island for 5 km along the western shore of Canoe Passage (Buddington and Chapin, 1929). The elliptical shape of the pluton's inland contact is truncated by Canoe Passage, and rocks along this straight edge are locally brecciated. Metasedimentary and metavolcanic rocks lie directly (0.3 to 1 km) across Canoe Passage from this pluton. Rocks correlative with the pluton have not been identified on the east side of the fault.

A Miocene(?) epizonal pluton (biotite alaskite) is exposed for 1.5 km along the east shore of Canoe Passage on northern Brownson Island. Petrographic and field evidence suggest that this body does not correlate with the quartz monzonite pluton on the west side of the fault, and no other rocks on the western side of the fault are correlated with this pluton. The alaskite pluton is highly sheared, fractured, and brecciated locally along the shore of Canoe Passage.

The straightness of the fault and the abundance of strike-slip faults elsewhere in southeast Alaska (Twenhofel and Sainsbury, 1958; Ovenshine and Brew, 1972) suggest that fault movement along Canoe Passage has been predominantly strike-slip. If the 19.7-m.y.-old quartz monzonite was severed by such a fault, its eastern part is not exposed along Canoe Passage. The minimum strike-slip movement necessary to conceal the eastern part of the pluton would displace it to Ernest Sound where glacial action may have eroded it below sea level. This displacement requires a minimum of 8 km of right-lateral movement since the middle Miocene, at an average rate of at least 4 mm per year.

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Structural elements of Insular Belt and Coast Range plutonic complex near Ketchikan, Alaska; a progress report

By Henry C. Berg, James G. Smith, Raymond L. Elliott, and Richard D. Koch

The Insular Belt near Ketchikan is subdivided into three tectonostratigraphic units which are, from west to east, the Alexander terrane, Gravina-Nutzotin belt, and Taku-Skolai terrane (fig. 30) (Berg and others, 1972). The Coast Range plutonic complex lies mainly within Taku-Skolai terrane.

The Alexander terrane is an allochthonous block of heterogeneous sedimentary, volcanic, metamorphic, and intrusive rocks ranging in age from Precambrian to Late Traissic (the youngest bedded rocks assigned to Alexander terrane). The composition and maximum age of the basement of the terrane are uncertain, but

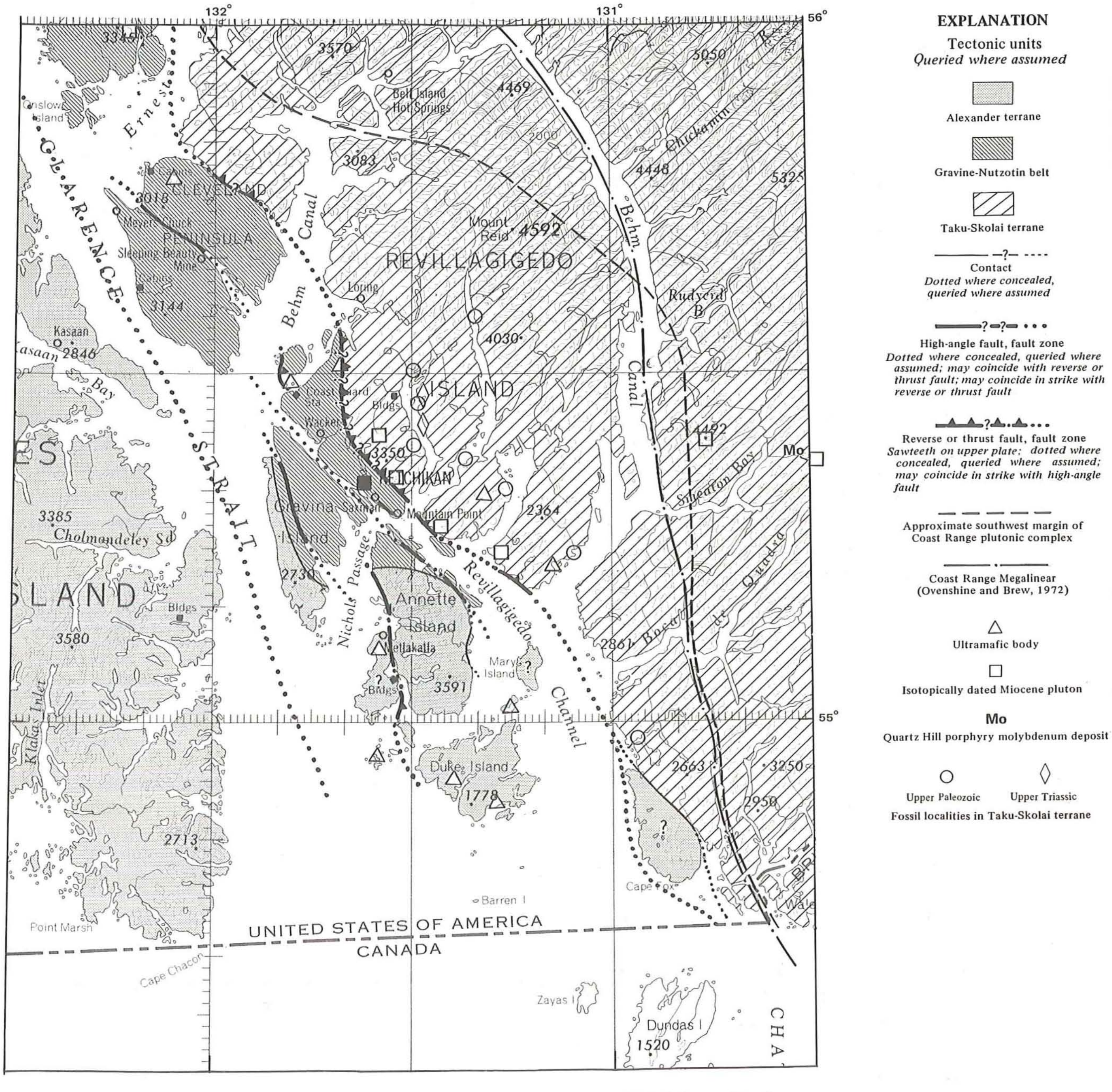

FIGURE 30.—Structural elements near Ketchikan, Alaska.

much of it probably is continental crust of Precambrian age. Strata in the Alexander terrane record several episodes of magmatic arc-related volcanism, sedimentation, and intrusion. The terrane is characterized by locally intense, multiple deformation and metamorphism that began in Precambrian time. The Alexander allochthon probably originated at low latitudes relative to the present North American continent and subsequently was transported northward by large-scale transcurrent faulting (Jones and others, 1972).

Depositional relations with Gravina-Nutzotin belt establish that the Alexander terrane was approximately in its present position by late Mesozoic time.

The Gravina-Nutzotin belt comprises a distinctive suite of Upper Jurassic to mid-Cretaceous sedimentary, volcanic, and intrusive rocks distributed in a narrow inland belt that nearly parallels the Pacific Coast in Alaska. The western boundary of the belt is an erosional edge complicated in places by faults that separate it from the Alexander terrane. Recent fieldwork near Ketchikan suggests that the eastern boundary with Taku-Skolai terrane is a complex fault zone that locally has been intruded by Miocene quartz monzonite, granodiorite, and gabbro. Potentially economic porphyry molybdenum deposits occur in other Miocene granitic plutons near Ketchikan (Elliott and others, 1976). Strata of the Gravina-Nutzotin belt are intensely folded, regionally metamorphosed, probably overthrust by older rocks of Taku-Skolai terrane lying to the northeast, and intruded by upper Mesozoic granitic plutons and zoned ultramafic complexes. Gravina-Nutzotin belt is interpreted as part of an upper Mesozoic magmatic arc. Remnants of coeval arc-trench and trench assemblages occur to seaward in southeastern and southern Alaska (Berg and others, 1972), and back-arc sedimentary deposits probably accumulated in a marginal ocean basin to the north and east (Eisbacher, 1976).

The Taku-Skolai terrane consists of a structurally complex assemblage of upper Paleozoic to Cenozoic metamorphic and intrusive rocks, including those of the Coast Range plutonic complex. The oldest faunally dated rocks in the assemblage are Permian or Carboniferous; fossiliferous Upper Triassic rocks also occur. Much of the assemblage is metapelite and minor greenstone lithically similar to parts of the Gravina-Nutzotin belt. The upper Paleozoic and Triassic rocks probably occur as discontinuous, structurally dismembered blocks enclosed by the widespread, relatively continuous metapelite and minor greenstone. Intrusive rocks range in age from Late Cretaceous to Miocene and in composition from ultramafite to quartz monzonite. Recent field studies near Ketchikan indicate that the regional structure of Taku-Skolai terrane is characterized by southwestward-overturned to semirecumbent isoclinal folds. Zones of imbricate thrusts dip moderately northeastward parallel to the axial surfaces of the folds. Axial surfaces and thrusts both are complexly refolded and cut by high-angle faults. The Taku-Skolai terrane is interpreted as an upper Paleozoic magmatic arc built on presumed oceanic crust (Richter and Jones, 1973; Berg and others, 1972). Overlying this basement are diverse upper Paleozoic and Mesozoic sedimentary and volcanic sequences. Recent stratigraphic and paleomagnetic studies of these sequences indicate that, like Alexander terrane, they originated at low latitudes relative to the present North American continent (Jones and others, 1977; Hillhouse, 1977) and reached their present position by late Mesozoic time. If the widespread metapelite and minor greenstone are upper Mesozoic and are coeval with the Gravina-Nutzotin arc, they probably accumulated in a back-arc marginal ocean basin now occupied partly by Coast Range plutonic complex.

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Coast Range megalineament and Clarence Strait lineament on west edge of Coast Range batholithic complex, southeastern Alaska

By David A. Brew and Arthur B. Ford

The Coast Range megalineament is a prominent, nearly continuous topographic and structural feature that extends southeastward about 500 km from its junction with the Chatham Strait-Lynn Canal fault north of Berners Bay to Tongass Passage near the mouth of Pearse Canal where it leaves southeastern Alaska (fig. 31). It probably extends still farther southeastward into British Columbia along Work Channel and Chatham Sound-Grenville Channel.

The megalineament is a zone, a few hundred meters to 10 km wide, in which closely spaced joints, foliation, compositional layering, and small faults parallel the megalineament trend. The zone usually coincides with topographic depressions apparently caused by glacial erosion of less resistant rocks.

Studies in the Juneau (D. A. Brew and A. B. Ford, unpub. data, 1964–77), Tracy Arm-Fords Terror Wilderness (D. A. Brew and others, unpub. data, 1976), and Granite Fiords Wilderness (Berg and others, 1977) areas indicate that the megalineament: (1) is locally the site of lateral and vertical separations on a kilometer scale; (2) does not mark a major structural discontinuity in the near-surface rocks; (3) may be located near premetamorphic and preintrusive discontinuities; (4) is consistently associated with and parallel to steep gradients in both the gravity and aeromagnetic fields; and (5) probably is the surface expression of the western contact, at depth, of the dominant intrusive rocks and gneisses of the Coast Range batholithic complex with the schists to the southwest.

In northern southeastern Alaska the megalineament and the western limit of batholithic rocks exposed at the surface are close to each other. To the south, however, the western limit of discontinuous intrusive rocks is irregular and extends well to the west of the megalineament and the main batholithic complex (fig. 31). In the latter region, the enigmatic Clarence Strait (H. C. Berg, oral commun., 1969) and Ketchikan lineaments have a similar relation to the exposed batholithic rocks and may mark the western limit of this westward salient of the batholithic complex, whereas the Coast Range megalineament marks the limit of the main complex.

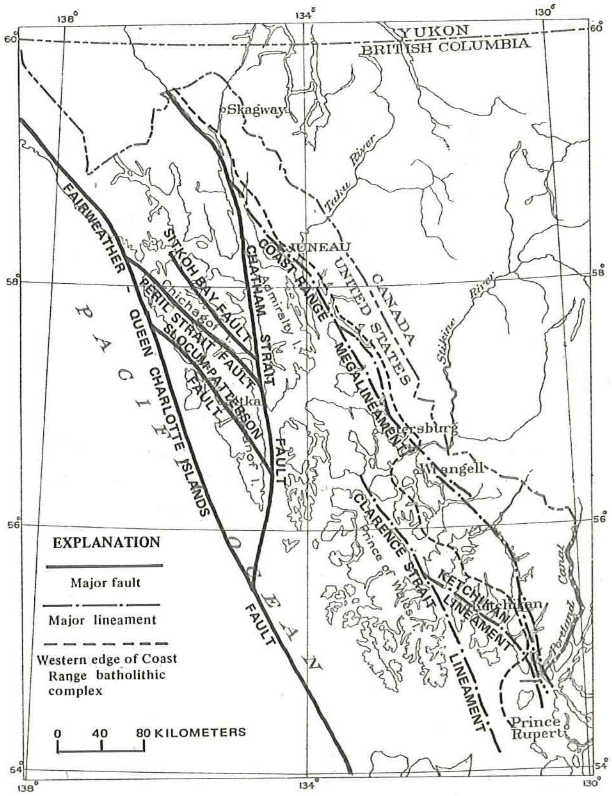

FIGURE 31.—Map of southeastern Alaska showing major faults and lineaments and the west edge of the Coast Range batholithic complex.

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Early Devonian conodonts found with a classical Upper Silurian brachiopod fauna, southeastern Alaska

By N. M. Savage, G. Donald Eberlein, and Michael Churkin, Jr.

Conodont studies by N. M. Savage, under a U.S.G.S. contract with the University of Oregon, show that the Karheen Formation at U.S.G.S. locality 2689 on the eastern end of Heceta Island contains the species *Eognathodus sulcatus* and *Pandorinellina exigua philipi*. The age of these beds is, therefore, considered to be early Pragian (middle Early Devonian). These conodonts come from the same beds that yielded brachiopids described by Kirk and

Amsden (1952) as Late Silurian. Discovery of the conodonts requires a drastic revision in the age of these brachiopods, which have been monographically studied by Kirk and Amsden and subsequently reported from other localities in the Cordillera.

Corroborative evidence of the Early Devonian age of the conodonts was obtained by Savage who found the same two species of conodonts together with *Pelekysgnathus serratus* in the Port St. Nicholas section, Prince of Wales Island. In the Port St. Nicholas section, the conodonts occur in limestone (U.S.G.S. locality 66ACn243) that is overlain directly by graptolitic shale containing *Monograptus yukonensis*, *M. craigensis*, and *M. pacificus* (fig. 32). These graptolites represent the highest zones of *Monograptus* and are of late Siegenian to early Emsian (Pragian) age.

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Geochemical sampling of stream sediments, Tracy Arm, southeastern Alaska

By Bruce R. Johnson, Carl L. Forn, James D. Hoffman, David A. Brew, and Constance J. Nutt

A stream-sediment sampling experiment was developed as a part of the U.S. Geological Survey wilderness resource evaluation program in the Tracy Arm-Fords Terror Wilderness Study Area, southeastern Alaska (D. A. Brew and others, unpub. data, 1976). The primary objective of the experiment was to develop sampling plans and techniques that make the most effective use of the time and resources available to obtain a maximum of useful information from samples of active stream sediments. These techniques may be useful in improving the quality of further resource evaluation programs in southeastern Alaska and other areas of similar terrain and bedrock geology.

The drainage basin chosen for this study lies on the north side of Tracy Arm and drains an area of approximately 150 km^2 (fig. 2(19)). The bedrock underlying the basin is composed primarily of hornblende-biotite granodiorite with associated migmatites and host rocks of amphibolite-grade gneiss and schist. Minor areas of marble and calc-silicate gneiss are included in the host rocks along with several small ultramafic bodies (D. A. Brew and others, unpub. data, 1976). Elevations in the basin range from boundary peaks approximately 2,000 m high to sea level at the mouth of the main stream. In addition to the main stream, eight first-order tributaries are contained within the basin.

Nearly 1,700 sample splits were analyzed for 30 elements by spectrograph and four elements by atomic absorption, using standard U.S.G.S. techniques. Since distributions with large numbers of data points above or below detection limits are not compatible with analysis of variance techniques, all sample distributions with more than 25 percent of the values outside detection limits were eliminated from the study. Thus spectrographic analyses of Ag, As, Au, B, Be, Bi, Cd, Mo, Nb, Sb, Sn, W, and Zn were eliminated as well as atomic absorption analysis of Au. The following 20 elements had less than 25 percent values outside detection limits and were used for the hierarchical analysis of variance: Fe, Mg, Ca, Ti, Mn, Ba, Co, Cr, Cu, La, Ni, Pb, Sc, Sr, U, Y, Zr by spectrographic analysis and Cu, Pb, and Zn by atomic absorption.

A four-level hierarchical design analysis of variance was run on the data for each element using the U.S.G.S. STATPAC program D0038. This program generates variance components for each element. A variance component is the amount of the total sample variance that can be attributed to variations at the level in question. The four levels used in this program are: (1) sampling locations (about 1.5 km separation); (2) sites (about 100 m separation); (3) sample points (less than 10 m separation); and (4) repeat analyses.

The most striking aspect of the variance components is the lack of uniformity from element to element. The variance distribution among levels differs greatly from one element to another and as does the total variation between elements. Some patterns, however, do emerge. In general about half the total sample variation is generated during the sample preparation and analysis. About one-quarter of the total sample variance is due to differences between sample

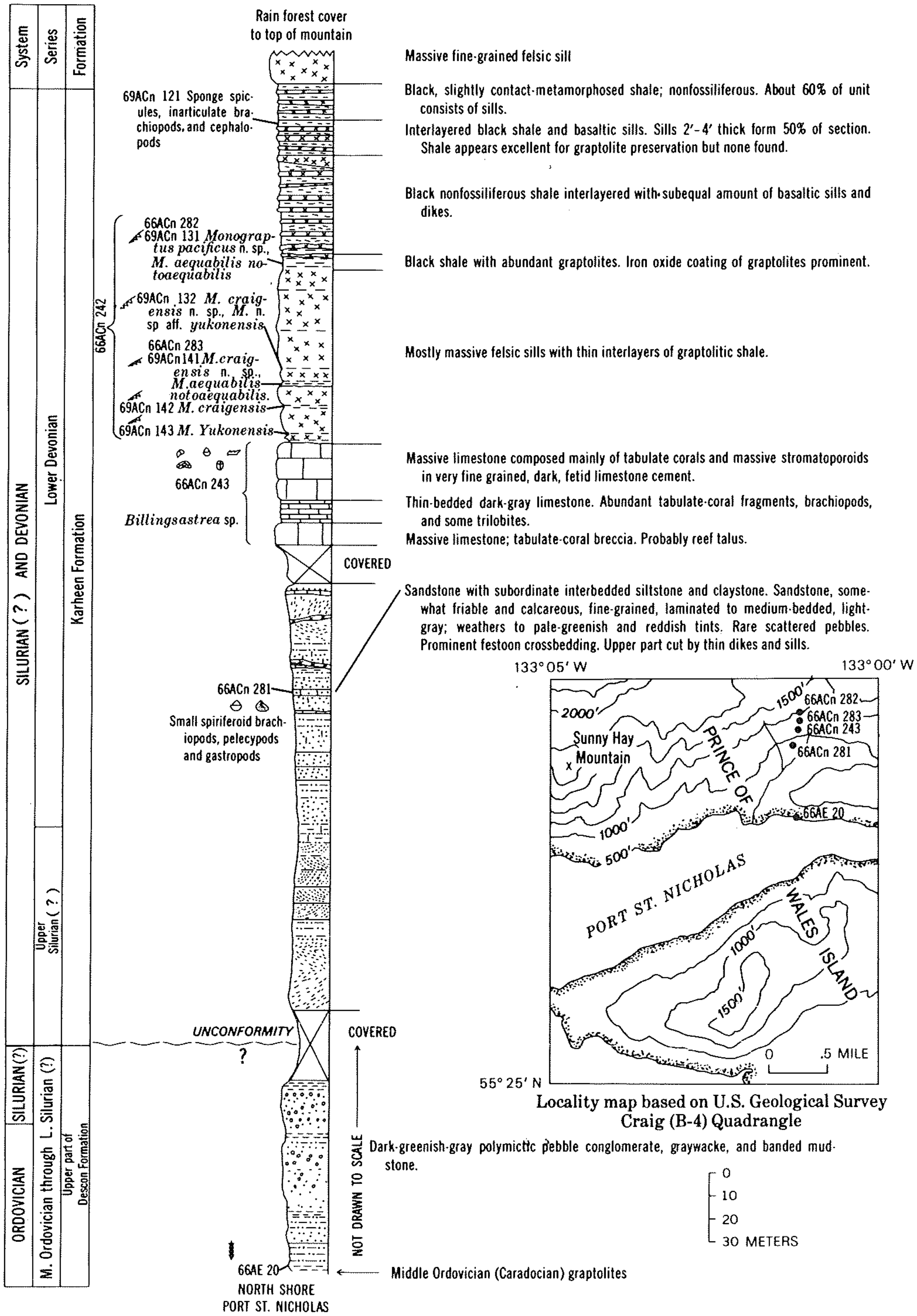

FIGURE 32.—Stratigraphic section exposed above Port St. Nicholas, southeastern Alaska.

locations, and the remaining one-quarter is due to differences between sites within sampling locations and between sample points within sites. The fact that components of variance for site and sample point levels generally are significantly smaller than the components for locations is encouraging since the sampling location spacings are on about the same scale (about 1.5 km) as the smallest geologically significant details needed for regional analysis.

Thus, sample locations need not be spaced closer than about 1.5 km for that purpose. The drainage basin sampled in this experiment apparently did not contain any small local sources for high concentrations of metallic elements. Because the existence of such sources may change the variance distribution significantly, variance distributions in previously unstudied areas should be determined by pilot studies prior to regional projects.

The generally large analytical variance may cause a great loss of information if the normal "one sample per location, one analysis per sample" techniques are used. Useful information may be lost in the "noise" of the analytical variance. Exceptions to these generalities make it necessary to consider each element and each analytical technique separately.

This stream-sediment experiment points out some problems inherent in the standard reconnaissance geochemical survey. Most of these problems are related to the sampling design of one sample per location and the lack of replicate analyses in the laboratory. This 1 × 1 sampling design produces geochemical anomaly maps that may be highly unstable. Maximum information can be obtained from a geochemical survey by careful analysis of the natural variations in samples and the expected analytical variation; and the choice of sample design that best fits these data.

The following are some recommended procedures for reconnaissance-type stream-sediment surveys aimed at delimiting areas of anomalous metal concentrations:

1. A small-scale pilot study in the area to be surveyed is invaluable. A hierarchical sampling design and an analysis of variance can be used to obtain variance components for each level of the sampling design, including the replicate analysis level. This study will produce the best possible data for determining the sampling design for the major study.
2. Set the sample location spacing on the basis of the variance components generated by the pilot study.
3. Choose a sampling design based on variance components and sample collection and analytical costs. At this point, the total cost of the survey can be estimated and adjustments made to the sample location spacing and (or) scope of the survey as necessary. For more help in establishing location spacings and calculating map stability, see Miesch (1976).
4. Before going into the field, write out a detailed description of sampling procedures for each geologist. The target population being sampled should be identified, and procedures for randomly selecting samples at each location should be standardized.
5. On anomaly maps, the most stable anomalies are those that occur in more than one element over areas of at least several sample locations. Anomalies generated by one element only or at one location only should be suspect and should not be considered significant until verified by re-sampling and (or) reanalysis.

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Ultramafic rocks in part of the Coast Range batholithic complex, southeastern Alaska

By Donald Grybeck, David A. Brew, Bruce R. Johnson, and Constance J. Nutt

Recent mapping in the Tracy Arm-Fords Terror Wilderness Study Area has revealed at least 30 bodies of ultramafic rock within the Coast Range batholithic complex (fig. 33). Several of these bodies along the shoreline are mentioned by Buddington and Chapin (1929), but most have not previously been reported nor, for that matter, has most of the batholithic complex in the area been mapped prior to this recent work. The geology of the area is only briefly summarized here.

The ultramafic bodies vary widely in mineralogy, and some might be better classified as mafic intrusions. Most are peridotite, but dunite is common, and pyroxenite is also present. Several of the bodies include gabbro, particularly the large body northeast of Port Snettisham. Although fresh rock is common, most of the bodies are pervasively altered to a mottled, dark-greenish-gray mass of felted tremolitic amphibole and anthophyllite. Serpentine is rare or entirely absent. The absence of serpentine and presence of tremolite and anthophyl-

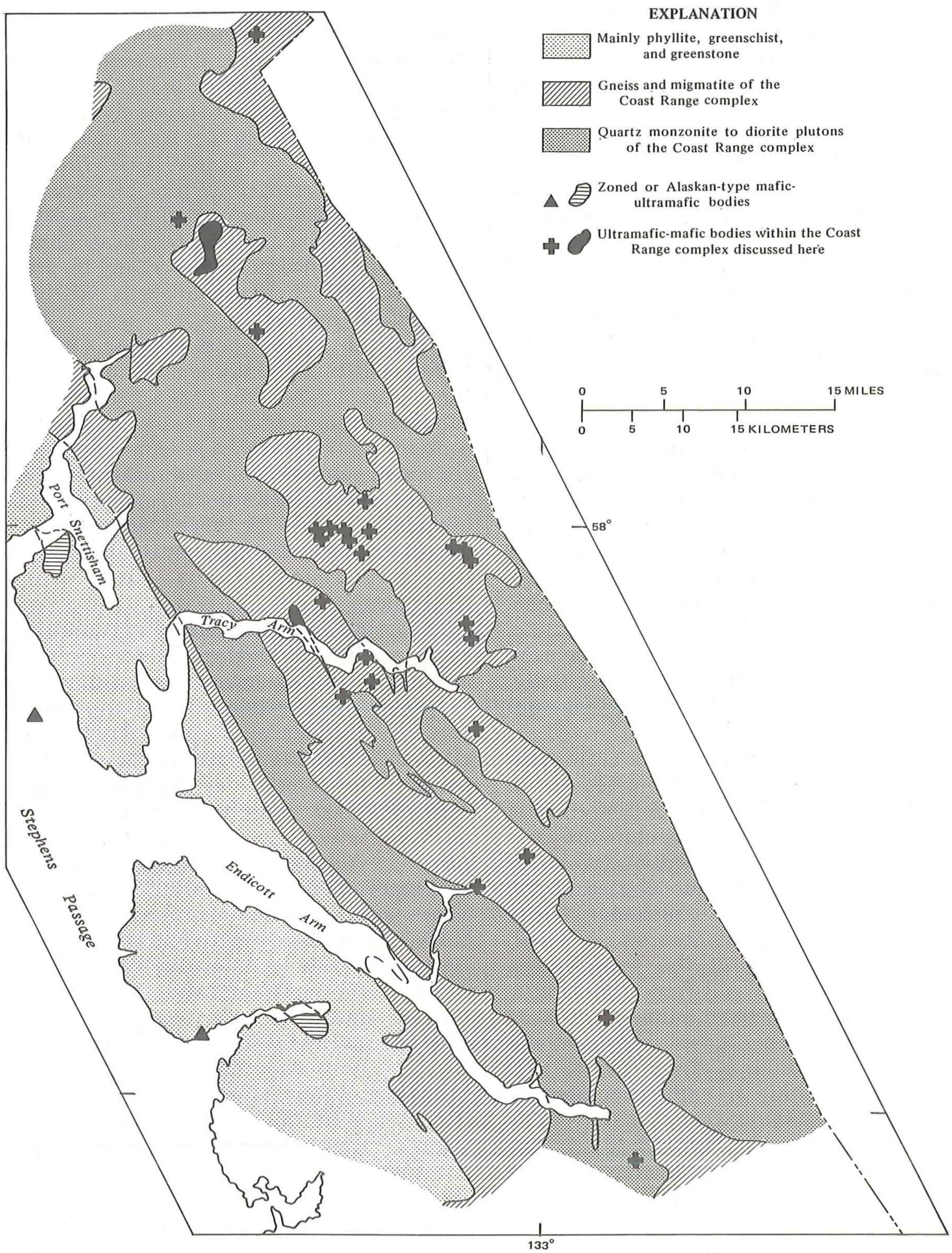

FIGURE 33.—Ultramafic rocks within the Coast Range batholithic complex, Endicott Arm area, southeastern Alaska.

lite suggest at least greenschist-facies metamorphism, according to Winkler (1974), but the mineralogy of the rocks has yet to be examined in detail. Striking, bright apple-green actinolite in gneiss or marble adjacent to the ultramafic bodies or a short distance away is a conspicuous indication of these bodies.

Most of the ultramafic bodies are small; several are less than 10 m in maximum dimension. With the exception of dunite, which weathers bright orange, they are also relatively inconspicuous; many more such bodies within the mapped area may have escaped our notice. Most occur as lenses in gneiss without any notable structural discontinuity along much of their contacts. Commonly at least part of their contact with the surrounding rocks is a discontinuity which can usually be traced out into the surrounding metamorphic rocks which are highly deformed and marked by noncontinuity of rock type. Some of the bodies are massive, but most are markedly foliated with the foliation invariably parallel to that of adjacent metamorphic rocks. The ultramafic rocks locally exhibit tight, almost isoclinal, folds that resemble those in the enclosing gneiss. Some of the bodies are so foliated as to resemble dark-greenish-gray tremolitic gneiss; their nickel and chromium content, however, is diagnostic. No contact metamorphic aureole surrounds the bodies; if such zones were present originally, they have been destroyed by later regional metamorphism.

With a single exception, the ultramafic rocks intrude almandine-amphibolite facies gneiss included in a highly deformed unit of granitic gneiss, marble, quartzite, amphibolite and migmatite that occurs as irregular masses or screens between the plutonic phases of the complex. The southernmost ultramafic body found in the area mapped occurs as a small, unmistakable xenolith at the border of a batholith-size body of a Cretaceous biotite-hornblende quartz diorite and thus establishes an upper limit for the age of the ultramafic rocks. The original age of the gneiss and ultramafic rocks within the batholithic complex can be given only as Cretaceous or older, on the basis of preliminary radiometric data. The phyllite, greenschist, and greenstone adjacent to the batholithic complex along the eastern side of Stephens Passage may be equivalent to the metamorphic rocks within the complex. Their age is uncertain, but they are considered to be Permian(?) and Triassic(?).

Unpublished mapping to the north in the Juneau and Taku River quadrangles (D. A. Brew and A. B. Ford, oral commun., 1976–77), has not indicated similar bodies. The batholithic complex to the south is largely unmapped; some reconnaissance geologic mapping to the south by A. L. Clark, D. A. Brew, and Donald Grybeck in 1969 did not reveal any ultramafic rocks. Because of their small size and relatively unconspicuous appearance, however, similar ultramafic rocks may be present but unrecognized in the adjacent parts of the batholithic complex.

The small size of most of these ultramafic bodies and the mountainous terrain in which they occur suggest that their economic significance is negligible. Their chromium and nickel contents show clearly in stream-sediment geochemical samples collected nearby, but the content is well within the normal geochemical abundance values for these types of rocks. No significant asbestos, magnetite, chromite, copper, or nickel mineralization was seen in any of the bodies.

The origin of these ultramafic and mafic rocks is enigmatic and largely obscured by their disruption and dismemberment during the Cretaceous and Tertiary Coast Range orogenic event. The diversity of rock types within the ultramafic bodies and their nickel and chromium content strongly suggest an igneous origin rather than a primary metamorphic origin. It is most convenient to correlate them with the zoned or Alaska-type bodies in southeastern Alaska (Taylor and Noble, 1969; Irvine, 1974). Three such bodies occur just west of the batholithic complex in the area: in Windham Bay, on Midway Islands, and Port Snettisham (fig. 33). Although the ultramafic bodies within the batholithic complex lack most of the characteristics of the Alaska-type bodies, these characteristics may have been destroyed during the Coast Range orogeny. Loney and others (1975) suggest that the ultramafic rocks on Baranof Island may be related to disrupted Alaska-type bodies. The bodies within the Coast Range complex could conceivably represent an extension of this sequence eastward. Whatever the place of these rocks in plate-tectonic models of western Canada and southeastern Alaska, their occurrence suggests original continuity of ultramafic rocks, even if of diverse origin, across the Coast Range batholithic complex.

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Truncation of regional metamorphic zonation pattern of the Juneau, Alaska, area by the Coast Range batholith

By Arthur B. Ford and David A. Brew

The existence of a regional metamorphic belt containing garnet-, staurolite-, kyanite-, and sillimanite-bearing micaschists has long been known along the west margin of the Coast Range batholithic complex in southeastern Alaska (Buddington and Chapin, 1929). The first systematic study of the distribution of key pelitic index minerals in this synkinematic Barrovian belt was undertaken by Forbes (1959), who identified first appearances of biotite, garnet, staurolite, kyanite and sillimanite successively northeastward from Juneau in a transect of the belt along Blackerby Ridge, at the east end of which appears a variety of migmatitic and other gneisses of the batholithic complex. The zonal sequence has now been extended westward across the transition from greenschist to subgreenschist facies on Douglas Island, and the distribution of metamorphic zones is known in detail (Ford and Brew, 1973; 1977b; Brew and Ford, 1977) or in reconnaissance over a broad area from Taku Inlet to Berners Bay and Lynn Canal (fig. 34).

The Juneau area affords a rarely equaled opportunity for study of regional metamorphism owing to its high local relief, in places exceeding 1,000 m, and to the great variety of intermixed lithologies across the belt. The mountainous terrain provides an abundance of excellent exposures and a third dimension for mapping traces of isogradic surfaces. As the first appearance of key index minerals depends on bulk composition of the parent rock as well as on conditions of temperature, pressure, and activity of such mobile components as H_2O and CO_2 during metamorphism, an intermixed variety of bulk compositions is required for mapped isograds to show the first possible appearance of index minerals. Parent rocks in the Juneau area range from upper Paleozoic basalt or andesite, shale, and sandstone to upper Mesozoic basalt, shale, and graywacke and locally include mixtures with calcareous sedimentary rocks. Lithologic types are generally well intermixed across the belt. Thus, the mapped isograds probably approximate fairly closely the first possible appearance, or disappearance, of the index minerals.

In the low-grade western part of the belt, on Douglas Island, metamorphic phases are those characteristic of the prehnite-pumpellyite metagraywacke facies. They commonly include albite, white mica, chlorite, pumpellyite, epidote and actinolite, and locally prehnite and stilpnomelane. The disappearance eastward, on the east side of Douglas Island, of pumpellyite and prehnite marks the transition into the greenschist facies. The rocks are chiefly metatuff-breccia of basaltic composition (Ford and Brew, 1977a), in places interlayered with metagraywacke and metapelite. Farther eastward, green pleochroic biotite first appears in metagraywacke and metavolcanic rock in the vicinity of Gastineau Channel, about 1.5 km west of the first appearance of brown biotite. Mapping of mineral zones of higher metamorphic rank is based on their first appearances in rocks of pelitic composition. The zonal sequence mapped in the Juneau area corresponds closely to those in other medium- to high-pressure regional metamorphic terranes, such as the Scottish Highlands and northern Appalachians (Turner, 1968).

Radiometric age data on the schist belt are interpreted by Forbes and Engels (1970) as showing probable Late Cretaceous or early Tertiary metamorphism thermally overprinted by Eocene (46.9–52.8 m.y.) emplacement of quartz monzonite in the batholithic interior.

The west margin of the batholithic complex is characterized by a varied assortment of

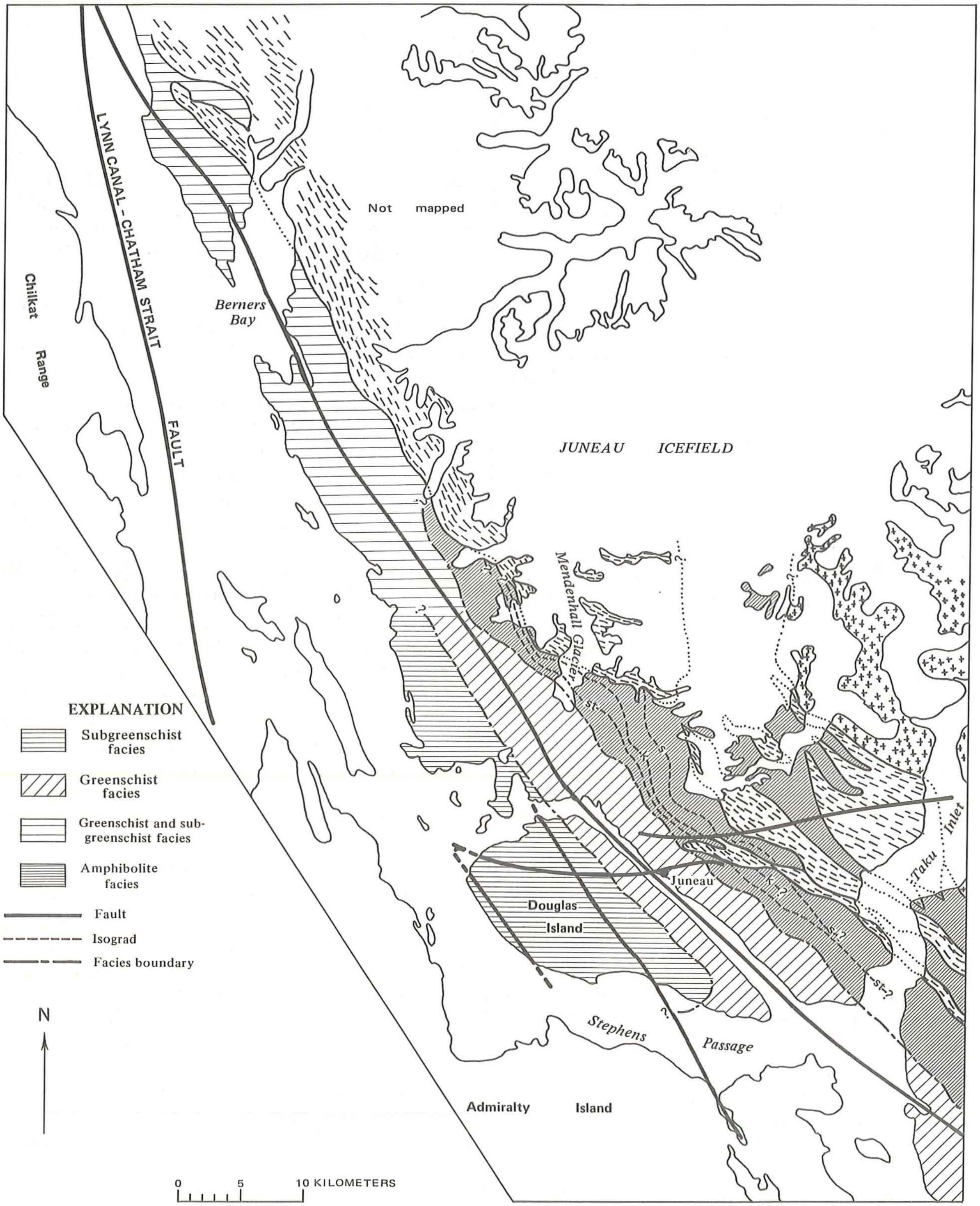

FIGURE 34.—Geologic sketch map of the Juneau area showing major faults, plutons, distribution of metamorphic facies, and metamorphic isograds (st, staurolite; k, kyanite; s, sillimanite). Dashed line pattern shows general foliation trends in orthogneiss plutons (J, Mount Juneau pluton). Crosses show little-foliated, posttectonic granitic pluton. Data in Berners Bay area from Knopf (1911, 1912).

gneisses, in places heterogeneously mixed with schist and in other places homogeneous. We interpret the larger homogeneous bodies of dominantly quartz dioritic to granodioritic gneiss as early orthogneiss phases of the batholith that were emplaced and solidified during a late stage of the metamorphism, after temperatures declined but before deformation ceased.

The close tie of regional metamorphism to early plutonism is particularly well documented by strucutral relations of a large body of garnet-biotite-hornblende quartz dioritic or tonalitic orthogneiss on Mount Juneau. This body, which was earlier mapped by Sainsbury (1953), may be the northern end of an elongate sill-like pluton traceable 225 km southeastward (Brew and others, 1976). It lies east of the schist belt near Taku Inlet, north of which it cuts westward across the metamorphic belt and reaches the garnet isograd on Mount Juneau. The body is clearly discordant to, and shows no apparent effect on, the regional synkinematic isograd pattern that was formed earlier. The well-developed foliation in the body parallels regional synkinematic northwest trends of the schist belt rather than the contact, thus showing that solidification preceded the end of regional penetrative deformation.

The relation of early batholithic activity to regional metamorphism shown on comparatively small scale near Mount Juneau appears to be present over a much larger area to the north. Between Mendenhall Glacier and the Berners Bay area, virtually the entire metamorphic zonal sequence is truncated by a 60-km-long transgressive batholithic contact. For most of this distance the batholithic margin consists mainly of orthogneiss plutons similar to the Mount Juneau pluton. These plutons also have internal foliation trends generally paralleling regional northwest trends. The metamorphic belt may reappear much farther to the north in the Yukon Territory (Forbes and others, 1974). We conclude from these relations that early phases of batholithic activity over a broad area accompanied a late stage of the regional metamorphism, namely after the thermal maximum and before the end of penetrative deformation. This conclusion is similar to that of Thompson and Norton (1968) for the New Hampshire Plutonic Series, in which the plutonic rocks are roughly contemporaneous with, or slightly younger than, the main regional metamorphism. Their conclusion (p. 325) that "A genetic relationship is thus highly likely, but it is by no means clear which is the primary and which is the secondary feature" also seems appropriate for the Juneau area.

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Chemical nature of Cretaceous greenstone near Juneau, Alaska

By Arthur B. Ford and David A. Brew

Metamorphosed mafic volcanic rocks are widely distributed along the apparent eastern edge of an upper Mesozoic sedimentary basin in northern southeast Alaska. They occur on the east side of Lynn Canal north of Juneau (Knopf, 1912; Barker, 1957; Irvine, 1973); on Douglas Island (Ford and Brew, 1973; 1977b); and on Glass Peninsula, Admiralty Island (Lathram and others, 1962). Though regionally metamorphosed in the subgreenschist and greenschist facies, the metavolcanic rocks are characterized throughout the belt by conspicuously large megacrysts of relict primary augite, the abundance of which led Knopf (1912) to name them "augite melaphyre." Volcanism is locally dated as Cretaceous by occurrences of *Inoceramus* in argillitic interbeds at two Douglas Island localities shown on the map of Ford and Brew (1973). The volcanic belt lies on the western fringe of a Barrovian synkinematic metamorphic terrane that, eastward from Juneau, ranges from the biotite to sillimanite zones (Ford and Brew, 1973, 1977a; Brew and Ford, 1977), the metamorphism of which is inferred by Forbes and Engels (1970) as Late Cretaceous and (or) early Tertiary.

The greenstones grade locally into greenschist. They are dominantly metatuff and metatuff-breccia, interlayered in places with metaflow-rock, which indicates that pyroclastic eruptions contributed the bulk of material to the 1,000-m- and possibly 3,000-m-thick volcanic pile. Subaqueous deposition, in part shallow marine, is only locally indicated by particle sorting, interbedding with metasedimentary rocks, which in places contain marine fossils, and by rare occurrence of pillows.

The tectonic setting of this volcanism is obscure. The occurrence of a large terrane of older rocks to the west, near the south of Glacier Bay (Brew and others, 1966; MacKevett and others, 1971; Loney and others, 1976), suggests that volcanism occurred some distance inland from the Cretaceous continental margin. Berg, Jones, and Richter (1972) proposed that the volcanism occurred in a late Mesozoic andesitic island arc that extended from southernmost southeast Alaska to the eastern Alaska Range, in which volcanism in an inland basin was related to trench subduction on the Pacific Ocean side of the older terrane. Volcanic centers have not been identified in the Juneau area, however, and therefore it is not known if the volcanism was generally associated with central conduits of an island-arc type, such as those of the present-day Aleutian arc; with central conduits of an oceanic seamount type; or with a volcanic-rift system of some other origin.

Because the geochemical nature of volcanic rocks can be used to identify distinct suites associated with different types of plate motions, even though the rocks may be metamorphosed as high as the greenschist facies (Pearce, 1975), we have undertaken a study of major- and trace-element chemistry of the Juneau-area metavolcanic rocks in an attempt to understand their tectonic setting. The average major-element chemistry of 28 analyzed samples from Douglas Island and Glass Peninsula shows that the greenstones are compositionally basaltic (table 4). The chemistry of the rocks from the two areas does not differ greatly.

Olivine and hypersthene occur in CIPW norms of the rocks, indicating an undersaturated olivine tholeiitic composition (Yoder and Tilley, 1962). Normative plagioclase and Al_2O_3 values show distinct tholeiitic rather than calc-alkaline characteristics, according to data of Irvine and Baragar (1971). The rocks are therefore chemically unlike upper Mesozoic andesitic metavolcanic rocks of the Ketchikan area, 350 km to the south (Berg and others, 1972), which are quartz normative and calc-alkaline. They also differ from probably correlative alkali olivine basalt, or ankaramite, near Berners Bay, 50 km to the north (Irvine, 1973). The available evidence thus indicates considerable diversity in this southeastern Alaskan volcanic belt.

Components of the greenstones obviously must have been redistributed to some extent during metamorphism. In particular, the alkali elements, H_2O and CO_2, show large standard deviations (table 4) that suggest mobility. The average of many samples, as in table 4, probably provides a reasonably close estimate of the original volcanic chemistry. Elements such as titanium, zirconium, and yttrium are more insensitive than others to secondary processes. Plots of the data from the Juneau area in Pearce's (1975) titanuim-zirconium-yttrium diagram suggest ocean-floor volcan-

TABLE 4.—*Average chemical composition, in weight percent, of metavolcanic rocks near Juneau compared to other southeast Alaskan occurrences*

	Juneau area		Ketchikan area	Berners Bay area
SiO_2	47.6	(1.5)	51.36	48.2
Al_2O_3	14.6	(1.8)	18.12	13.1
Fe_2O_3	2.9	(1.6)	3.66	3.30
FeO	7.4	(1.7)	5.47	7.39
MgO	7.7	(2.1)	4.52	9.0
CaO	11.0	(1.5)	8.76	10.1
Na_2O	2.3	(1.1)	2.70	2.6
K_2O	1.2	(0.9)	0.89	2.4
H_2O	3.1	(0.8)	2.71	...
TiO_2	0.73	(0.10)	0.73	0.70
P_2O_5	0.27	(0.09)	0.17	0.41
MnO	0.16	(0.02)	0.16	0.20
CO_2	0.4	(1.4)	0.39	0.33
Total	99.5		99.64	97.7

[1] Average of 28 rapid-rock analyses by Lowell Artis. Standard deviation in parentheses.

[2] Average of 26 analyses (Berg and others, 1972).

[3] Average of 7 analyses reported by Irvine (1973).

ism, but with some possibility of a volcanic-arc origin. The Juneau rocks may plot in Pearce's island-arc basalt field, in terms of titanium, zirconium, and strontium, because of significant enrichment in strontium during metamorphism.

The tectonic significance of this regional variation in chemistry is questionable. If the belt was an andesitic island arc, different levels or different lateral segments of the system may now be represented along its trend. An alternative view is that the andesitic arc existed only south of the Juneau area. If so, volcanism in the Juneau area and to the north was not related to trench subduction. The alkaline nature of basalt near Berners Bay makes a volcanic-rift or ocean-island origin more likely than a volcanic-arc one. Cretaceous volcanism in the Juneau area may have been transitional between the alkaline volcanism in Berners Bay and the calc-alkaline andesitic volcanism farther south in the belt.

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Newly discovered granitic and gabbroic bodies in the Fairweather Range, Glacier Bay National Monument, Alaska

By David A. Brew, Bruce R. Johnson, Constance J. Nutt, Donald Grybeck, and Arthur B. Ford

The available geologic information on the Fairweather Range (Brew and Ovenshine, 1974; MacKevett and others, 1971; Rossman, 1963; Plafker and MacKevett, 1970) is fragmentary. Current studies (related to investigation of the mineral resource potential as a factor in wilderness suitability), although brief, have added significantly to knowledge of the occurrence of granitic and gabbroic bodies in this remote, rugged, and almost inaccessible area.

Rossman (1963; unpub. data) mapped a few diorite and quartz diorite bodies between the southern peaks of the Fairweather Range and Cross Sound. Our recent work has refined Rossman's picture considerably: there are two groups of intrusions, each characterized by typical lithologies. The older group consists mostly of poorly to well-foliated, "messy"-appearing, biotite-hornblende quartz diorite and diorite of inferred Tertiary or Cretaceous age; the younger includes commonly foliated garnet-biotite granodiorite and slightly foliated garnet-muscovite-biotite granite, both of inferred Tertiary age. The younger group in particular has associated aureoles of andalusite-quartz-plagioclase-biotite hornfels.

In the upper reaches of Lituya glacier, about 5 km northwest of the poorly layered northernmost exposures of the Mt. Crillon-La Perouse layered gabbro body (Rossman, 1963), is a newly discovered, crudely layered gabbro body that is not yet completely mapped. The body may be only partially unroofed; the contact on the west side extends northward for about 7 km, to within about 11 km of the southernmost exposures of the poorly understood Mt. Fairweather gabbro body (Plafker and MacKevett, 1970). The eastern contact of the newly discovered body is as yet unknown. Where studied to date, this Lituya Glacier body consists of ½- to 1-m-thick layers of coarse-grained pyroxene-hornblende gabbro and pyroxene gabbro with discontinuous 2-cm-thick pyroxenite and 10-cm-thick hornblendite layers. The body appears to be relatively inaccessible because of extremely rugged topography.

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Probable Precambrian or lower Paleozoic rocks in the Fairweather Range, Glacier Bay National Monument, Alaska

By David A. Brew, Robert A. Loney, Ronald W. Kistler, Gerald K. Czamanske, C. Sherman Grommé, and Mitsunobu Tatsumoto

Several inconsistent but generally converging lines of evidence suggest that the rocks of the high part of the Fairweather Range, which have hitherto been interpreted to be either no older than late Paleozoic (Rossman, 1963a; Brew and others, 1966; MacKevett and others, 1971; Brew and Ovenshine, 1974) or, by distant lithologic correlation, middle Paleozoic (Hudson and others, 1977; Brew and others, 1976), may be as old as Precambrian. This hypothesis has significance for paleotectonic analysis of the northeastern rim of the Pacific.

The oldest rocks in the high part of the Fairweather Range are an apparently thick, complexly folded sequence of metamorphosed graywacke and shale (Brew, unpub. data). Few, if any, carbonate units are present; no fossils have been reported. Associated with the metagraywacke and metashale are a few 1-km-long thin lenses of metavolcanic rocks which, to the west and southwest, become the dominant rock type. These rocks have been correlated by Rossman (1963a, unpub. data) and Brew (Brew and others, 1966; MacKevett and others, 1971; Souther and others, 1974) with very sparsely fossiliferous rock units of Triassic through Early Cretaceous age on Chichagof Island to the south. Hudson, Plafker, and Lanphere (1977) and Plafker, Jones, Hudson, and Berg (1976), on the other hand, have described possibly correlative rocks in the Yakutat area, which are inferred to be at least as old as middle Paleozoic because they are intruded by plutons of late Paleozoic age.

There is thus no clear direct evidence of the age of metasedimentary and metavolcanic rocks of the high part of the Fairweather Range. The rocks are, however, intruded by a variety of plutons. The oldest that give consistent mineral ages in Glacier Bay National Monument are unfoliated leucocratic biotite granite and granodiorite of middle Tertiary age (Brew, Lanphere, and Smith, unpub. data). An apparently slightly older foliated granodiorite pluton in the Fairweather Range gives discordant mineral-pair ages that probably represent the revision of an emplacement age no older than mid-Cretaceous. As noted above, the oldest plutons recognized in the Yakutat area are apparently late Paleozoic.

The critical plutons in the Fairweather Range are the layered gabbros, the largest of which are the Mt. Fairweather (Plafker and MacKevett, 1970), Lituya Glacier (Brew and others, 1977), and Mt. Crillon-La Perouse (Rossman, 1963a) bodies. The Mt. Crillon-La Perouse body, the largest, is apparently at least 9,000 m thick and is about 27 x 13 km in plan view. All of these thick layered bodies appear to have developed contact aureoles in the metasedimentary and metavolcanic host rocks, as have the younger granite intrusions.

The one known good analog of these layered bodies elsewhere in the world is the Axelgold intrusion of British Columbia (Irvine, 1975), which is considered to be mid-Cretaceous in age and which intrudes late Paleozoic rocks. The Jabal Shayi intrusion in Saudi Arabia (Coleman and others, 1973), which intrudes Precambrian rocks and which is itself Precambrian, is also a possible analog. The Mt. Crillon-La Perouse body, however, differs from these bodies in that it is associated with a large copper-nickel-platinum deposit (Cornwall, 1966; MacKevett and others, 1971; Czamanske and others, 1977). Throughout the world, most of the known large nickel deposits that are associated with mafic and (or) ultramafic rocks are of Precambrian age (Naldrett and Cabri, 1976).

The Mt. Crillon-La Perouse body appears to have a relatively simple relation to the surrounding rocks and nearby younger intrusions; this simplicity, together with the lithologic correlations with rock units of Mesozoic age on northern Baranof Island, led to the initial interpretation that the body was Tertiary (Brew and others, 1966). Radiometric study shows, however, that this apparent simplicity is misleading. Potassium-argon dates of biotite, hornblende, pyroxene, and plagioclase from the body range from 36 to 250 m.y. Of eight specimens dated, no two dates are the same. Even though this study does not yield an age of emplacement for the body, it does demonstrate that the unit has a complex metamorphic history that was not apparent from the geologic studies. Further radiometric studies are underway using other isotopes. Preliminary results indicate that rocks from the body have extremely low strontium-87/86 ratios, like those of oceanic basalts rather than of continenetal crustal rocks, suggesting a relatively primitive nature.

Paleomagnetic study of the Mt. Crillon-La Perouse body likewise indicates a complicated history. Preliminary and incomplete results are compatible with a Precambrian age.

None of these lines of reasoning—field relations, associated sulfide deposits, radiometric data, isotopic data, or paleomagnetic data—point clearly to an age of emplacement for the Mt. Crillon-La Perouse and associated bodies or to an age of the host rocks. Most of these various studies are internally inconsistent, and most are not clearly consistent with each other. Taken together, however, they indicate a complexity that is best explained by a Paleozoic or older age of emplacement for the layered gabbros and a similarly older age for the host rocks. The hypothesis of an early Paleozoic or Precambrian age for both must be considered seriously.

If the rocks of the high part of the Fairweather Range are early Paleozoic or Precambrian, then the early history of the Alexander terrane (Berg and others, 1972) becomes even more complex. Precambrian rocks (Churkin and Eberlein, 1977) occur in the Wales Group on Prince of Wales Island to the south. Country rocks in the Fairweather Range do not appear to correlate lithologically or structurally with the highly mixed metavolcanic, metasedimentary, and metacarbonate rocks of the Wales Group, suggesting that, assuming a Precambrian age, more than one basement terrane may be present. Likewise, the lithologies of rocks high in the Fairweather Range do not correspond to those of the recently recognized Ordovician rocks nearby in the Yukon Territory (Read and Monger, 1975) or with the lower Paleozoic sections on Prince of Wales Island (Eberlein and Churkin, 1970), or elsewhere in Glacier Bay National Monument (Rossman, 1963b).

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Geophysical surveys in Glacier Bay National Monument

By David F. Barnes and Raymond D. Watts

A 1976 regional gravity survey of Glacier Bay National Monument was supported by radar measurements of ice thickness, which also showed that Brady Glacier is extremely deep and could limit the extent of an ore body on its margin. Earlier gravity measurements within the monument included a partial shoreline survey (Barnes and others, 1975), a study of the ice thickness of Casement Glacier (Peterson, 1970), and measurements to study elevation changes suggested by tide-gauge records (Rice, 1969). The 1976 gravity measurements were part of the U.S. Geological Survey and Bureau of Mines cooperative Glacier Bay Wilderness Study and were made in order to complete the regional coverage and study the anomalies caused by the Mt. La Perouse and associated ultramafic intrusions. These intrusions occur in terrain so mountainous that glaciers provide most of the opportunities for helicopter landings. The radar measurements of ice thickness were used primarily to correct the gravity measurements for the effect of the underlying ice, but the ice thicknesses measured on the Brady Glacier are independently significant and will be summarized after the gravity results.

Within Glacier Bay National Monument the usual association of lower Bouguer gravity anomalies with higher elevations is not consistently observed. Low gravity anomalies of -70 to -90 milligals were measured in the mountains, which have 1- to 2-km summits near the northeast edge of the monument. But the monument's highest mountains occur west of the Bay where several peaks with summits higher than 3 km occur between Mt. Fairweather, at the Canadian border, and Mt. La Perouse. Gabbroic stocks (Rossman, 1963) and high-density volcanic rocks in these mountains cause positive anomalies of more than 60 milligals near Mt. La Perouse. Anomalies of equal magnitude were also measured where another ultramafic stock crops out at the coastline. Infinite-slab calculations suggest that, with a density contrast of about 600 kg/m^3, both stocks have depths greater than 3 km, which would be increased by calculations based on mathematical models of realistic stock configurations. The available data also suggest that the breadth of the stocks increases at depth and that the two bodies could be different parts of a deep continuous ultramafic body. However, the data are still too scarce to prove such continuity. A pair of gravity measurements near the outcrops of similar ultramafic rocks on Mt. Fairweather (Plafker and MacKevett, 1970) showed lower positive anomalies of about +20 milligals, but the data are too limited to suggest the size or depth of this northern ultramafic unit. The data do indicate that the gravity field is generally high in these coastal mountains and suggest that the ultramafic and associated rocks may be more extensive than the geologic mapping indicates. Positive Bouguer anomalies predominate among the measurements in these mountains, and negative anomalies were measured primarily in the northeast corner of the peninsula where anomalies are below -40 milligals. The positive Bouguer anomalies at these elevations suggest large positive free-air anomalies and lack of isostatic adjustment.

The measurements of ice thickness were distributed primarily to support the regional gravity coverage and used the technique for radio-echo sounding of glaciers described by Watts and England (1976). The initial measurements were made on Finger, La Perouse, Crillon, Desolation, and Fairweather glaciers, which are valley glaciers flowing westward from the higher mountain summits towards the Gulf of Alaska. The measured ice thicknesses ranged from 100 m on their lower ice tongues to as much as 450 m in their upper cirques, and thicknesses of 200 to 300 m were typical of most valley parts of the glaciers.

The Brady Glacier (fig. 35) is the largest in the monument and drains much of the eastern flank of its higher mountains (La Perouse and Bertha). Its upper icefield is the accumulation area for several smaller glaciers as well as for Reid Glacier, which flows northward into Reid Inlet or upper Glacier Bay, and Brady Glacier, which flows southward into Taylor Bay and Icy Strait. The ice-surface contours and the several nunataks suggest a complex and rugged sub-ice topography, which was confirmed by the radio soundings. The two measurements near the main axis of the glacier (950 m and 910 m, fig. 35) both indicate a basement of about 200 m below sea level, which suggests that the glacier fills a deep fiord and that the western shore of Glacier Bay would be part of an island if the glacier, its outwash fan, and its terminal moraine were removed.

On the western arm of the glacier, about 200 km east of the shoulder of Mt. La Perouse, measurements indicated an ice thickness of 1,020 m and suggested that the bottom of the glacier is below sea level. The contrast between this elevation and the 3,000-m summit of the mountain indicates very rugged topographic relief. Furthermore, the probable directions of ice motion may be inferred from the ice surface contours and from crevasse patterns (fig. 35). The arrow nearest to the 1,020-m measurement indicates that the glacier may flow southeastward and suggests that a deep fiord may follow the approximate direction of this arrow. Such a fiord could underlie the ice on the north side of the small nunataks where the Brady Glacier nickel-copper prospect crops out (Cornwall, 1971). This mineralized prospect has been extensively drilled, but the proximity of a deep nearby glacier could restrict the ore body dimensions.

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OFFSHORE ALASKA

Seismicity patterns in the Cook Inlet-Prince William Sound region, Alaska

By Michael Blackford

An examination of hypocentral data from the U.S.G.S. seismic network in south-central Alaska has revealed a contrast in the distribution of earthquakes throughout the region. A pattern of uniform temporal and spatial seismicity in the Cook Inlet area grades into episodic activity in the Prince William Sound area. The entire region is underlain by a Benioff zone that marks the boundary between the American plate and the subducted Pacific plate. In the east, beneath Prince William Sound, where the westward dip of the Benioff zone is shallow and the American plate lithosphere and the Pacific plate lithosphere are in extensive contact, classical mainshock-aftershock earthquake sequences occurred, particularly in the upper plate. In the west, where the dip of the Benioff zone steepens and the Pacific lithosphere plunges into the asthenosphere beneath Cook Inlet, earthquakes with magnitudes of up to 6 have occurred with no evidence of aftershock activity. Shallow seismic activity, quite high in the east, dies out to the west except for occasional swarms of earthquakes related to active volcanoes on the west side of Cook Inlet. This contrast in seismicity may reflect the

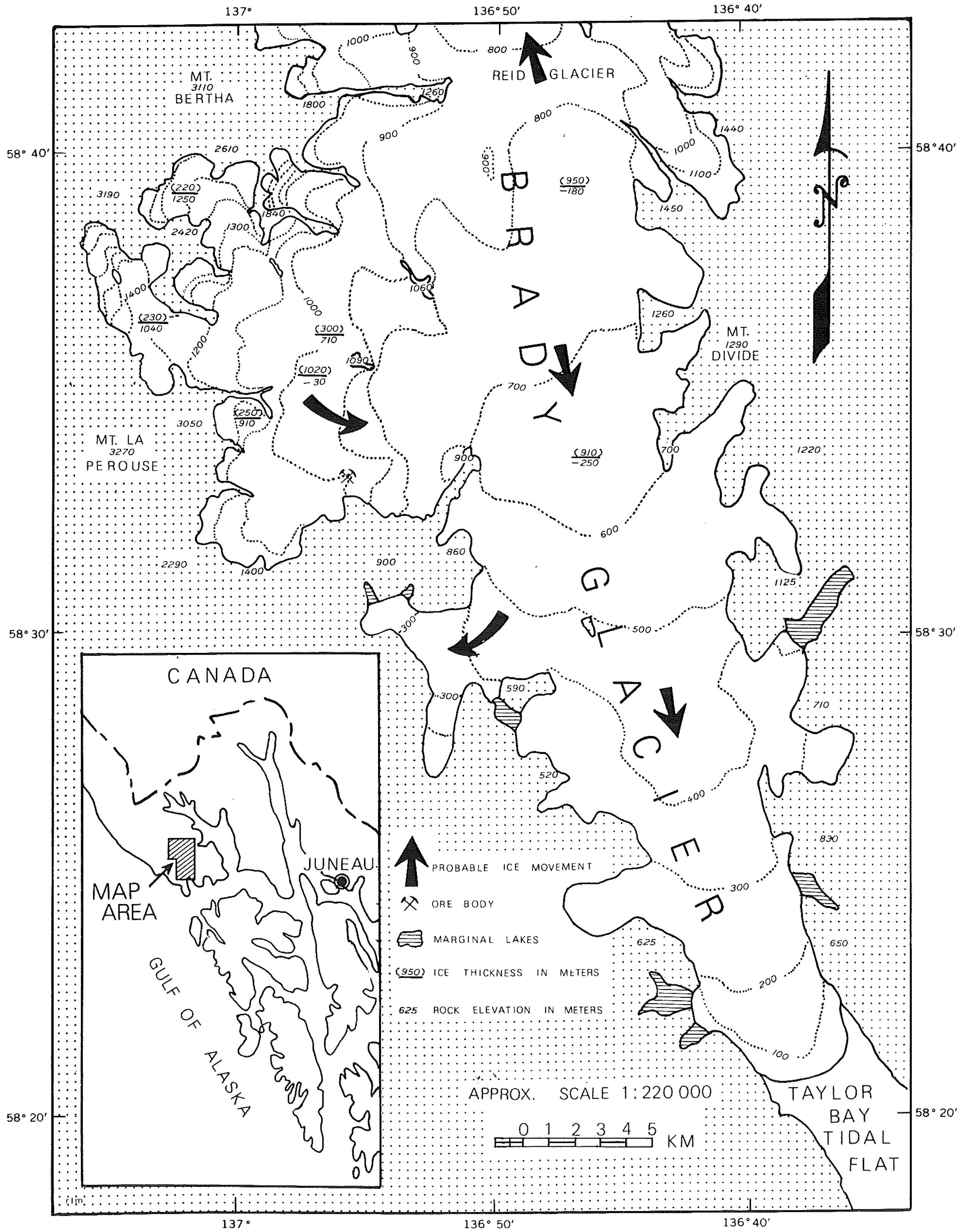

FIGURE 35.—Map of Brady Glacier area, Glacier Bay National Monument.

difference between stress accumulation and release due to plate motions in the shallow, rigid lithosphere, and stress due to the thermal regime within the plunging lithospheric slab.

Shelf-edge scarps in the northern Gulf of Alaska

By Paul R. Carlson, Bruce F. Molnia, Terry R. Bruns, and John W. Whitney

High-resolution seismic profiles in the northern Gulf of Alaska show numerous small scarps (fig. 36) cutting well-lithified strata near the edge of the continental shelf south of Kayak Island (fig. 2(20)). With this seismic control (3- to 5-km line spacings), we have not been able to correlate individual scarps from line to line. The scarps are found in two small clusters having areas of about 100-125 km² in water depths of 150-225 m. The relief of individual scarps ranges from 2 to 5 m, and the average distance between scarps on individual seismic lines is about 0.5 km.

Some of the blocks show evidence of backward rotation; however, the seismic records do not show outward (seaward) curvature of the normal fault or slip planes. The slip or glide planes can be traced to a maximum depth of about 150 m in the Tertiary strata. Along some of the seismic lines that continue seaward over the continental slope, masses of what appear to be slumped sediment are seen on the records. Both areas of these discontinuous scarps overlie complex anticlines that are oriented subparallel to the shelf edge (Bruns and Plafker, 1975).

The Gulf of Alaska is seismically active; numerous earthquakes of magnitude 6–7 have occurred since 1899, and epicenters near the shelf edge south of Kayak Island are common (Lahr and Page, 1976). Thus, the scarps can be readily explained by faulting, either associated with step faults formed by uplift and growth of the underlying anticlinal structures, or with gravity slumping at the shelf edge.

The faulted strata are almost certainly no older than late Pliocene and may be no older than Pleistocene, on the basis of seismic stratigraphy of the Gulf of Alaska (Bruns and Plafker, 1975; Carlson and Molnia, 1975; and Molnia and Carlson, 1975). It is not known, however, when the most recent movement has occurred or if the faults are currently active.

Regardless of their age or origin, the scarps represent a potential environmental hazard to petroleum exploration and development. Movement of the individual blocks could occur during seismically induced ground shaking or as a result of wave action, other natural phenomena, or the activities of man.

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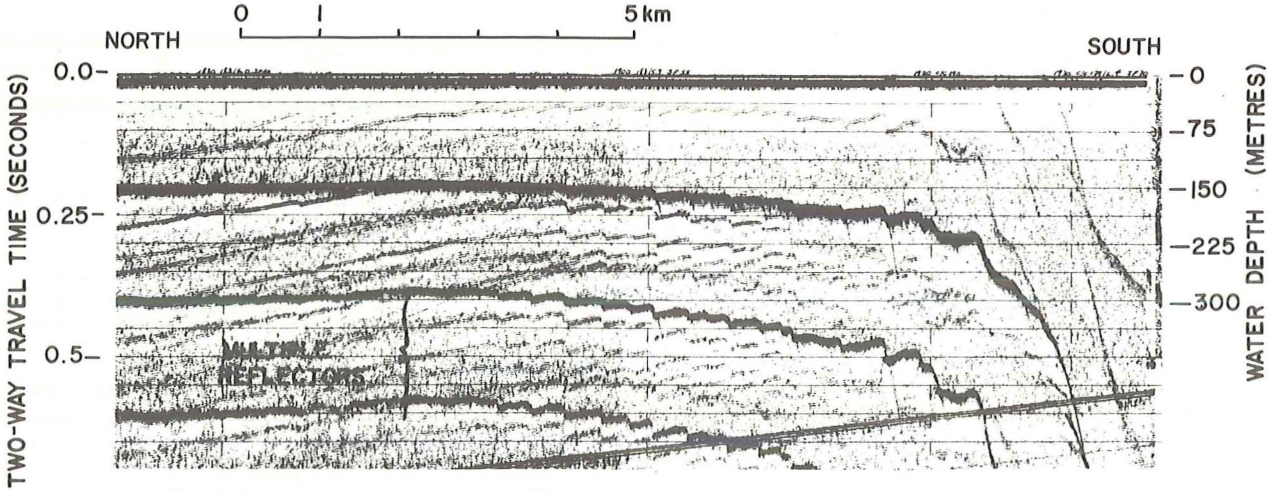

FIGURE 36.—Minisparker profile of scarps at edge of shelf south of Kayak Island (V.E. ≈ 10X).

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Sedimentary basins on the Shumagin shelf, western Gulf of Alaska

By Terry R. Bruns and Roland von Huene

Two previously undescribed structural basins are outlined by offshore geophysical data across the Shumagin continental shelf in the western Gulf of Alaska (fig. 2(21); Bruns and von Huene, 1977).

The first basin, informally named the Shumagin basin, is between the Semidi and Shumagin Islands and is roughly equidimensional with an area of about 3,800 km^2. It contains a presumed Cenozoic sedimentary section as much as 2,250 m thick, characterized acoustically by reflection horizons that show divergences in dip, local wedge-outs, and broad folds against the flanks of the basin. The section is underlain by what appear to be complexly deformed sedimentary beds of probable Late Cretaceous and early Tertiary age. Shumagin basin is therefore a structural depression in older deformed sedimentary rocks that has been filled by a relatively undeformed younger sequence.

The second basin, informally named Sanak basin, is an elongate, fault-bounded basin northeast of Sanak Island with an approximate area of 1,200 km^2. The basin contains sedimentary deposits of probable Cenozoic age with a maximum thickness of approximately 6,000 m. The northeast and southwest flanks of Sanak basin appear to be formed by extensions of uplifted Cretaceous turbidite and Tertiary intrusive sequences that crop out on the outer Shumagin Islands and on nearby Sanak Island. The sedimentary sequence along the flanks of the basin is broken by probable growth faults that indicate deposition contemporaneous with basin subsidence. Anticlinal folds and stratigraphic truncation also appear to have formed during basin subsidence.

Available data are insufficient to determine if additional basins are present on the Shumagin Shelf or to evaluate with certainty the number and size of potential hydrocarbon-bearing structures in the Shumagin and Sanak basins. However, existing data indicate that prospective stratigraphic and structural features may be present. Additional geologic data from adjacent onshore areas are needed to establish the possible existence of source or reservoir beds and to correlate the subsurface data with exposed sedimentary sequences along the Alaska Peninsula, where the petroleum potential is better known.

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Resource assessment and geophysical exploration of the southern Bering Sea shelf

By Michael S. Marlow

During the summer of 1976, over 5,000 km of geophysical data was collected in the Bering Sea (fig. 2(22)) on two cruises aboard the R/V *S. P. Lee.* The first 30-day cruise left Kodiak on July 28 and arrived in Nome on August 25, with an intermediate stop at Dutch Harbor. During this leg, 24-channel seismic-reflection data confirmed the existence of a previously unmapped basin, Amak basin, beneath the Bering shelf near the western end of the Alaska Peninsula. This basin is filled with 5-5.5 km of sedimentary section of probable Tertiary age. Amak basin is separated from the adjoining subshelf basins, St. George and Bristol Bay basins, by the offshore extension of the Black Hills structural trend exposed on the nearby Alaska Peninsula. Rocks exposed in the Black Hills are sandstone and siltstone of the Late Jurassic Naknek Formation. These anticlinally deformed rocks appear to extend some 220 km west of the peninsula as a subshelf basement ridge detected on seismic-reflection profiles. The existence of these rocks beneath the shelf is supporting evidence that a Mesozoic fore-arc and magmatic arc extended from southern Alaska to eastern Siberia by way of the Bering Sea shelf.

Data from the 1976 cruises are currently being processed and are to be published in mid- or late-1977. A preliminary assessment of the resource potential of the Bering Sea shelf, including the description of 11 basins that are prospective sites for hydrocarbon accumulations, was published in late 1976 (Marlow, McLean, and others, 1976). In addition, approximately 700 km of 24-channel seismic-reflection data, shot in 1975 aboard the R/V *S. P. Lee,* has been released (Marlow, Cooper, and others, 1976).

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Ice gouging and other environmental geologic problems of northern Bering Sea

By Hans Nelson

The following preliminary results have been noted from the Sept.-Oct. 1976 cruise to Norton Sound. Ice gouging has been found in all areas less than 20 m deep, but intensity of gouging is highly variable. Gouging is very intense where southward moving bergs first intersect the 18- to 20-m isobaths trending across the mouth of Norton Sound. Intense gouging also occurs around the shallow margin of the modern Yukon subdelta, where the outer edge of shorefast ice coincides with the counter-clockwise current gyre entering the southern side of Norton Sound. The state of preservation of ice gouges delimits regions of nondeposition and sites of rapid deposition, particularly around the modern Yukon subdelta. In some areas, both new and old gouges are well preserved, indicating nondeposition during recent time. In others, recent gouges are truncated by superposed sediment smoothing, showing recent rapid deposition. Fresh ice gouges in the nearshore parts of the sand wave fields near Pt. Clarence suggest that movement of the bedforms is intermittent and may be due mainly to periodic forcing by storm-related barotropic currents.

The sand wave fields near Pt. Clarence were found to be much more extensive than anticipated. All shoal crests out to and including the one on the lee side of King Island were covered by a wide variety of sand waves. All flanks and troughs between the sand ridges were covered by a thin veneer of marine sandy mud underlain by pretransgressive deposits of peaty limnitic mud. Fine-grained surface mud on the flanks and troughs but thin Holocene deposits overall indicate that periodic intense scouring must have generally prevented Holocene deposition between sand ridges.

New geophysical profiles suggest a logical explanation for an apparently large gas seep recently discovered by Dr. Joel Cline on a NOAA cruise to Bering Sea. A high gas concentration in the water column was detected 30 km directly south of Nome, and the anomaly was traced downcurrent in the water over 100 km to King Island. The seep appears to be related to updipping beds along the northern Norton Basin margin that are truncated by a near-surface fault. This structure creates a possible pathway to the sea floor for hydrocarbons.

Marine geophysical investigation in the Bering Sea basin

By Alan K. Cooper

The Bering Sea basin is a deep-water (3,800 m) sedimentary basin adjacent to the extensive western Alaskan continental margin. In area, the Bering Sea basin is the largest enclosed sedimentary basin contiguous with the continental shelves of the United States. Its size is comparable to the combined areas of the states of Texas and Oklahoma. The boundaries of the basin (fig. 37), which are the Aleutian Islands on the south, the Kamchatka peninsula on the west, and the Bering shelf on the east, enclose regionally thick (3–5 km) accumulations of nearly flat-lying Cenozoic sedimentary rocks (Scholl and others, 1972; Cooper and others, 1976).

The existence of similar deepwater sedimentary basins behind other island arc systems around the western perimeter of the Pacific Ocean suggests that all the marginal basins may have formed by a common mechanism. Regional crustal heating, resulting in part from the subduction of oceanic lithosphere, plays an important role in most models proposed for the evolution of marginal basins (Karig, 1971; Sclater, 1972; Cooper and others, 1977). In the Bering Sea basin, the combination of thick sedimentary deposits and potentially

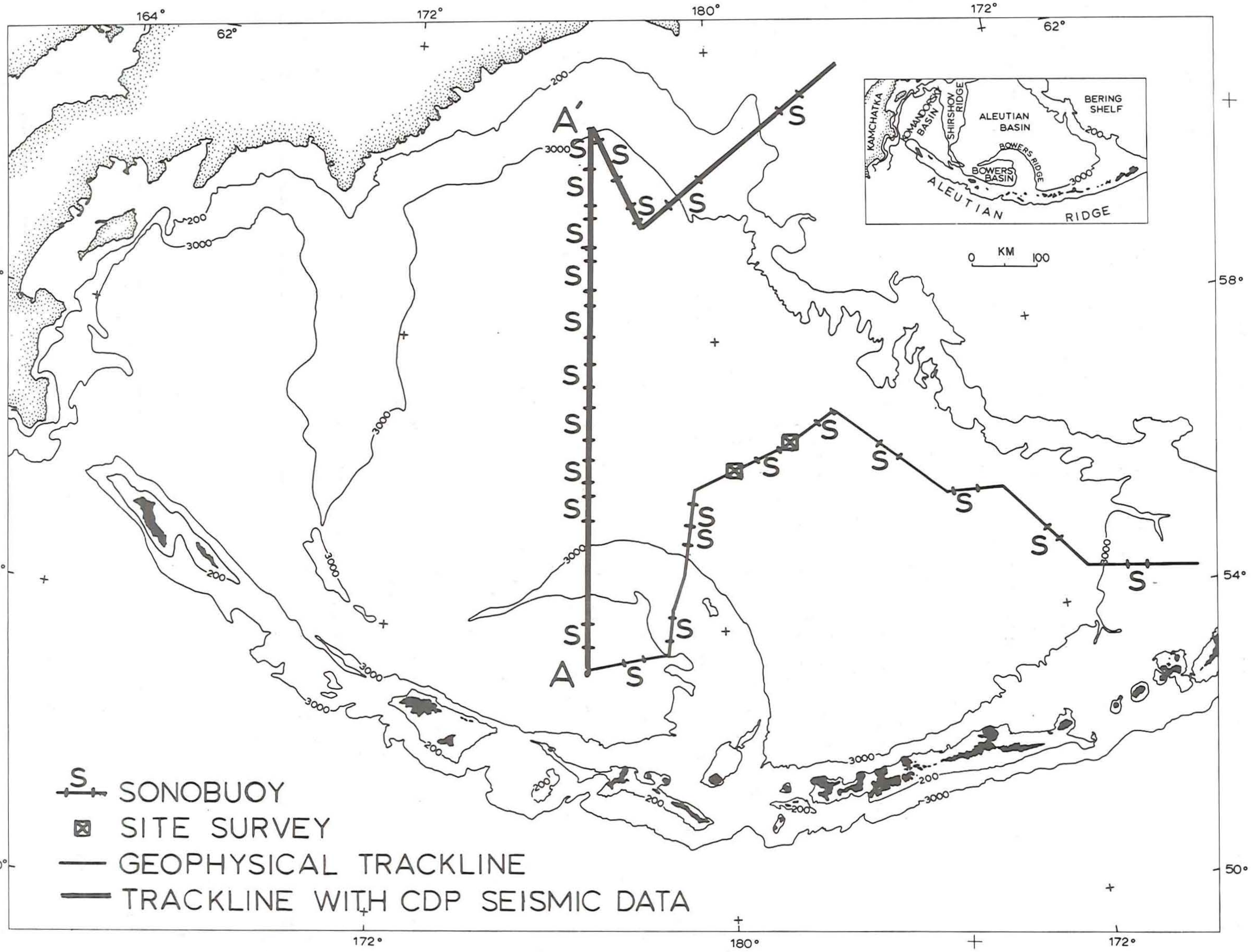

FIGURE 37.—Bathymetric map of the Bering Sea basin showing ship tracklines for geophysical work done during 1976. Bathymetric contours in meters.

high thermal gradients is a favorable indicator of the existence of significant hydrocarbon accumulations.

During two weeks in August 1976, the U.S.G.S. research vessel *S. P. Lee* conducted a regional geophysical survey across the Bering Sea basin to aid in evaluating the hydrocarbon resource potential of this vast area. The data collected included 2,800 km of gravity, magnetic, bathymetric, and single-channel seismic-reflection data, 1,200 km of multichannel CDP seismic reflection data, and crustal velocity information from 25 expendable sonobuoys (see fig. 37). The seismic source used for all underway reflection and refraction data was a tuned array of five airguns with a total capacity of 80.9 cm^3.

Two intensive site surveys (fig. 37) were conducted over areas that contained acoustic features believed to be caused by local hydrocarbon accumulations. Routine geophysical data were collected during these surveys.

Several new findings in the Bering Sea basin during the 1976 field season resulted primarily from the availability of new and advanced geophysical equipment on the *S. P. Lee*. A high-powered airgun array coupled with an advanced hydrophone system allowed recording of acoustic basement (Layer 2? basalt) across the Aleutian basin. The thickness of sediment along this profile ranges from 3 km in the center of the basin to 10 km on the north side of Bowes Ridge. Wide-angle sonobouy data collected along the same profile (A–A′; fig. 37) confirm the existence of an oceanic-type crust and show refraction arrivals from the crust-mantle boundary at several sites; these mantle refractions are the first to be recorded in the Bering Sea with a rapidly fired (once every 17 sec) airgun seismic system. Although mantle refractions were recorded at only one-third of the sonobuoy sites, the airgun seismic source provided sufficient power to give refraction arrivals from a shallower crustal layer (oceanic layer 3; $V_p \sim 6.8$ km/sec) at all sonobuoy sites.

Successful continuous recording of the acoustic basement (beneath 4 km of sediment) during both intensive site surveys permitted the delineation of narrow (8-km-wide) basement ridges with a relief of about 1.5 km. These ridges are associated with shallower (0.5 km subbottom) acoustic features, such as velocity pulldowns and structural bulges, indicative of possible hydrocarbon accumulations.

A highly successful 1976 field season has provided new insight into both the regional and local geophysical settings in the Bering Sea basin. Preliminary analysis of the data reveals the presence of potential hydrocarbon-bearing structures within the Bering Sea basin. These features are abundant in the center of the basin, in a deepwater area characterized by an oceanic-type crustal section covered by thick sedimentary rocks.

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Tectonic imprints on sedimentary deposits in Hope basin

By Stephen Eittreim, Arthur Grantz, and O. T. Whitney

Hope basin, in the southeast Chukchi Sea, is composed of young sediments that are in places more than 3,000 m thick. The basin morphologically terminates the Brooks Range, but the underlying basement exhibits an east-west ridge and trough morphology parallel to the general strike of the Brooks Range. The basin sediments are folded and faulted over these basement ridges. Although the age of the sediments cannot be specified, they are tentatively inferred to be mostly Tertiary and perhaps Cretaceous on the basis of outcrops around Kotzebue Sound and on Seward Peninsula. The total volume of sediments in the basin east of long 171° W. is conservatively estimated to be 100 x 10^3 km^3.

A strong and regionally persistent reflector, here called "reflector K," is inferred to be of mid-Tertiary age. Most of the faulting and folding associated with the Hope basin ridges and troughs occurred after deposition of this reflector. Before deposition of reflector K, little sediment accumulated in northeastern Hope basin. After this reflector was deposited, a triangular part of the crust south of Point Hope and north of the latitude of Cape Krusenstern subsided approximately 2,500 m. Hope basin is bounded on the south by Kotzebue Ridge, which is by far the largest of the east-west ridges in Hope basin (fig. 38). The seismic stratigraphy of the north flank of Kotzebue Ridge shows that the relief between basin floor and ridge crest was created by both basin subsidence (strata lapping onto the ridge) and ridge uplift (erosional truncation of beds against the ridge). Both kinds of unconformities occur in abundance in these sediments and produce a net divergence of beds and a thickening of the total section down the north flank of the ridge (see fig. 38). Because no onlapping is observed below reflector K, it appears to mark the onset of a new phase of vertical tectonics, characterized by basin subsidence in northeastern Hope basin and uplift along Kotzebue Ridge. This phase was superimposed on an earlier era of subsidence (Cretaceous?) which formed the outlines of the present Hope basin extending westward to offshore Siberia. This basin was located in Kotzebue Sound and the southernmost Chukchi Sea across the trend of the Brooks Range.

Kotzebue Ridge is the largest and seismically best explored of the east-west ridges of Hope basin. The ridges to the north, the first of which is shown on the north end of profiles 8 and 10 in figure 38, are deeply buried and have much lower relief. Kotzebue Ridge has been observed as a gravity high (Ostenso, 1968; Ruppel and McHendrie, 1976) trending westward from Cape Krusenstern across the basin to near Siberia where it curves northwestward parallel to the coast. The northern flank of the ridge is extensively broken by faulting (fig. 38), which accommodated the relative subsidence of the basin to the north. The most intense faulting occurs in the area of maximum curvature of the ridge flank. The faults are both normal and antithetic, the latter accommodating the rotation of blocks which are tilted down toward the north (e.g., profile 11-13). Reflector K and the underlying basement are offset by the faults in equal amounts. The faults are apparently due to arching and extension associated with uplift of the ridge and subsidence of the basin to the north. The minimum amount of absolute uplift can be gaged by the stratigraphic thickness of beds that have been truncated by erosion over the ridge. The amount of erosional truncation is as much as 900 m and is greatest on profiles 7, 11, and 12 in figure 38.

Offsets on the faults diminish upward in the uppermost part of the sediment column (upper few hundred meters) and locally as much as 100 m of conformable sediments at the top of the sediment column is unaffected by the faulting. In most places, however, the fault offsets end at an erosional unconformity that lies anywhere from 5 m to 50 m below the seafloor. High-resolution uniboom reflection records (fig. 38) taken over Kotzebue Ridge indicate that the faults have not been active since the Holocene flooding of the shelf. These records show a layer of acoustically transparent (homogeneous, with little internal layering) sediment unconformably overlying the erosional surface at which the fault offsets terminate. This homogeneous layer, which probably extends over the whole southern Chukchi Sea, has been dated as Holocene by Creager and McManus (1967). Thus the age of the faulting can only be bracketed as post-reflector K and pre-Holocene.

In summary, uplift of approximately 1 km along Kotzebue Ridge and associated subsidence of the basin to the north of approximately double that amount have occurred sometime in the late Cenozoic but are no longer active. The approximate alinement of Kotzebue Ridge with the southern Brooks Range peaks and the morphologic connection of the Baird Mountains to Kotzebue Ridge through the Igichuk Hills suggests a genetic relationship between Kotzebue Ridge and late Cenozoic uplift in the Brooks Range.

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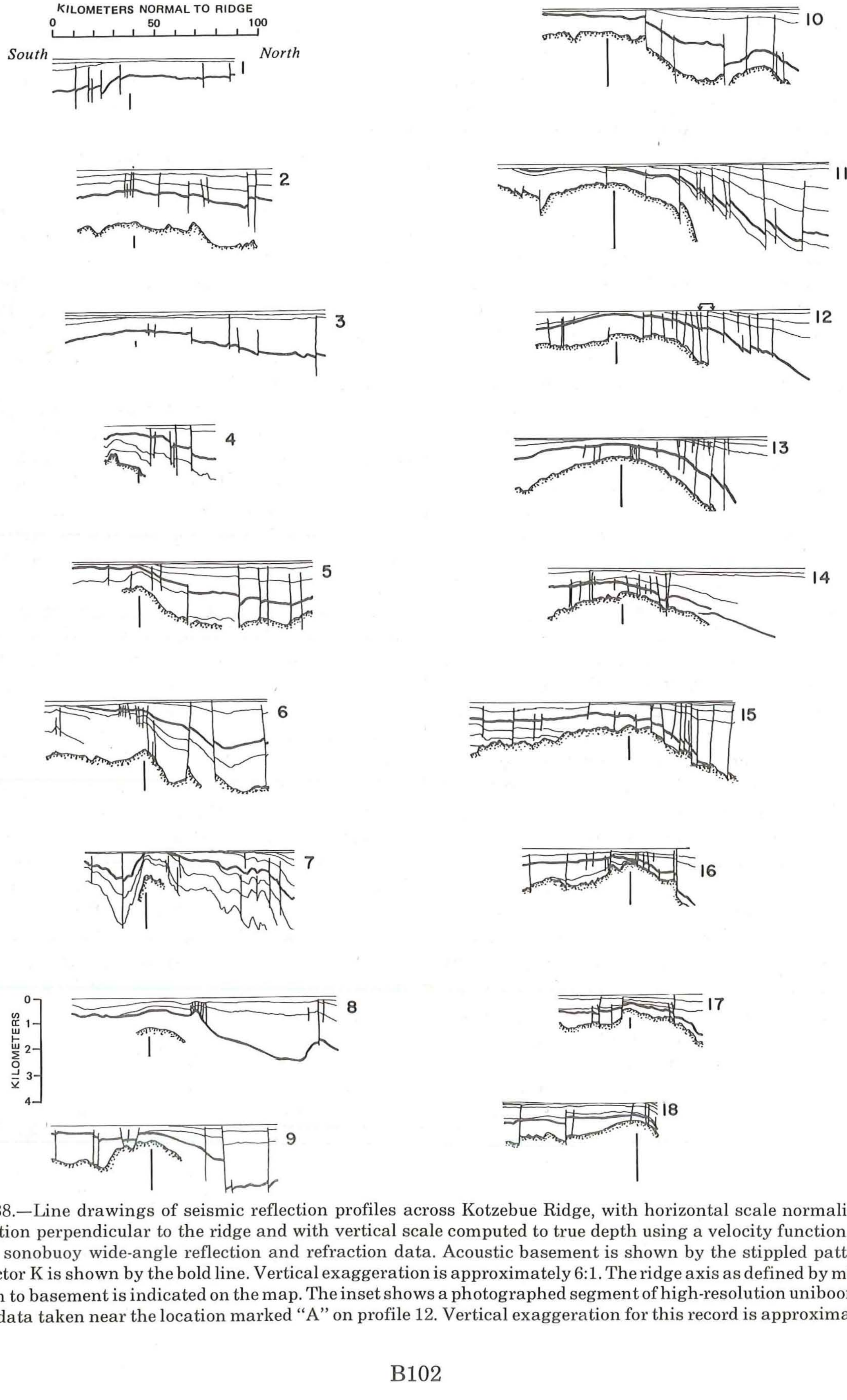

FIGURE 38.—Line drawings of seismic reflection profiles across Kotzebue Ridge, with horizontal scale normalized to a direction perpendicular to the ridge and with vertical scale computed to true depth using a velocity function derived from sonobuoy wide-angle reflection and refraction data. Acoustic basement is shown by the stippled pattern and reflector K is shown by the bold line. Vertical exaggeration is approximately 6:1. The ridge axis as defined by minimum depth to basement is indicated on the map. The inset shows a photographed segment of high-resolution uniboom reflection data taken near the location marked "A" on profile 12. Vertical exaggeration for this record is approximately 3:1.

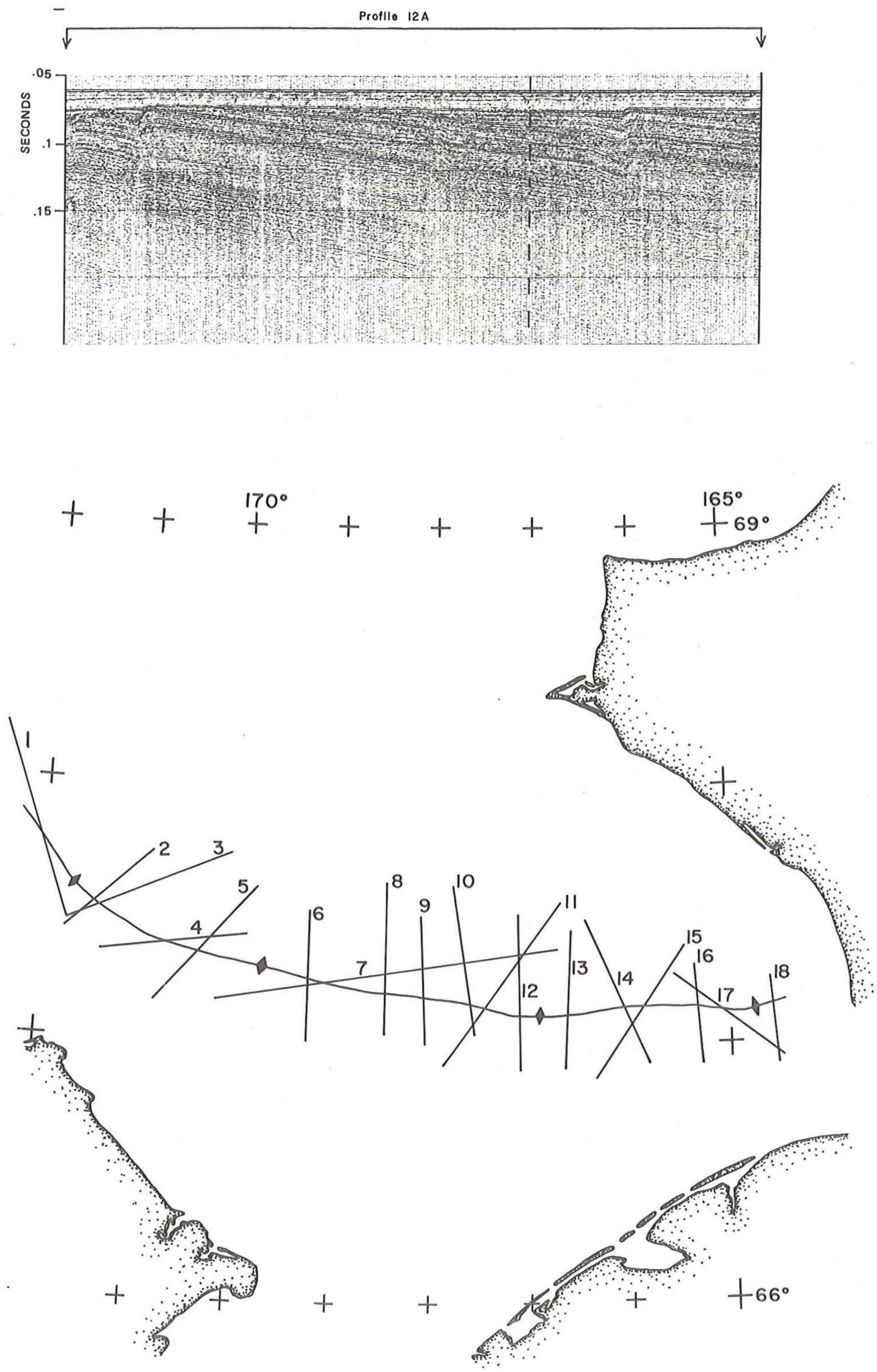

FIGURE 38.—Continued.

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