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1997 Guide to the Geology of the Kenai Peninsula, Alaska

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Field Guide to the Mesozoic Accretionary Complex Along Turnagain Arm and Kachemak Bay, South-Central Alaska

by

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Introduction

Turnagain Arm, just east of Anchorage, provides a readily accessible, world-class cross section through a Mesozoic accretionary wedge. Nearly continuous exposures along the Seward Highway, the Alaska Railroad, and the shoreline of Turnagain Arm display the two main constituent units of the Chugach terrane: the McHugh Complex and Valdez Group. In this paper we describe seven bedrock geology stops along Turnagain Arm, and two others in the Chugach Mountains just to the north (Stops 1-7 and 9), which will be visited as part of the May, 1997 field trip of the Alaska Geological Society. Outcrops along Turnagain Arm have already been described in two excellent guidebook articles (Clark, 1981; Winkler and others 1984), both of which remain as useful and valid today as when first published. Since the early 1980's, studies along Turnagain Arm have addressed radiolarian ages of chert and conodont ages of limestone in the McHugh Complex (Nelson and others, 1986, 1987); geochemistry of basalt in the McHugh Complex (Nelson and Blome, 1991); post-accretion brittle faulting (Bradley and Kusky, 1990; Kusky and others, 1997); and the age and tectonic setting of gold mineralization (Haeussler and others, 1995). Highlights of these newer findings will described both in the text below, and in the stop descriptions.

Superb exposures along the southeastern shore of Kachemak Bay show several other features of the McHugh Complex that are either absent or less convincing along Turnagain Arm. While none of these outcrops can be reached via the main road network, they are still reasonably accessible — all are within an hour by motorboat from Homer, seas permitting. Here, we describe seven outcrops along the shore of Kachemak Bay that we studied between 1989 and 1993 during geologic mapping of the Seldovia 1:250,000-scale quadrangle. These outcrops (Stops 61-67) will not be part of the 1997 itinerary, but are included here for the benefit of those who may wish to visit them later.

The Chugach Terrane

Alaska's Pacific margin is underlain by two parallel composite terranes — the Wrangellia composite terrane (consisting of the Peninsular, Wrangellia, and Alexander terranes), and farther outboard, the Chugach-Prince William composite terrane. During much of the Mesozoic, the two formed a magmatic arc and accretionary wedge, respectively, above a circum-Pacific subduction zone. The Border Ranges Fault forms the boundary between the two composite terranes; it began as a subduction thrust but has been reactivated in various places as a strike-slip or normal fault (for example, Little and Naeser, 1989). The rocks described here are part of the Chugach terrane (fig. 1), the name given to the Mesozoic part of the accretionary wedge.

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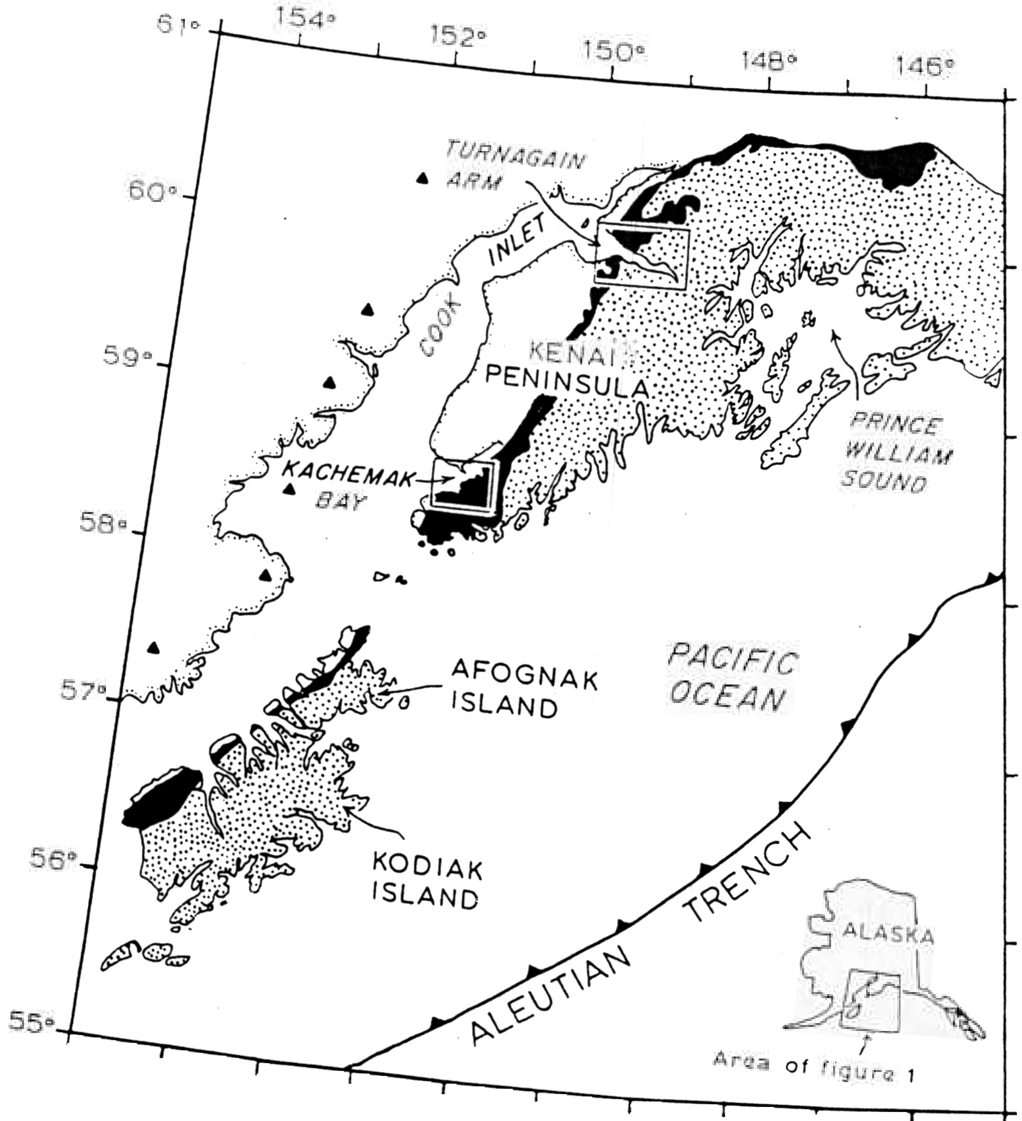

Figure 1. Locality map of south-central Alaska Showing detailed map-areas for Turnagain Arm (fig. 2) and Kachemak Bay (fig. 3). McHugh Complex and its equivalents are shown in black. Stippled area includes the remainder of the Chugach-Prince William composite terrane is underlain by rocks of the Peninsular terrane and younger strata of the Cook Inlet forearc basin. Volcanoes of the Aleutian Arc are shown as triangles.

The McHugh Complex constitutes the inboard part of the Chugach terrane in south-central Alaska. Along Turnagain Arm (fig. 2), the northwestern part of the McHugh Complex is a melange composed of fragments and disrupted beds of graywacke, mafic volcanic rocks, and chert, in a phacoidally cleaved matrix of argillite and tuff. The southeastern part is mainly composed of siliciclastic rocks, including boulder and cobble conglomerate, graywacke, and argillite.

The McHugh Complex is characterized by moderate to intense stratal disruption, which resulted in tectonic juxtaposition of varied rock types. In the Valdez (Winkler and others, 1981) and Seldovia (Bradley and others, unpublished) quadrangles, fault slices of chert, basalt, and graywacke have been traced tens of kilometers along strike. At the outcrop, hand-sample, and thin-section scale, these rock types occur as more competent objects in argillite matrix. The predominant mode of early deformation was layer-parallel fragmentation; breakup of relatively competent beds, such as chert and graywacke, was accompanied by flowage of argillite (± tuff) matrix into gaps. The resulting fragment foliation is the most conspicuous fabric element in the McHugh Complex; along Turnagain Arm, it strikes NNE and in most places dips steeply northwest. The foliation is commonly displaced across narrow (up to a few centimeters wide), early ductile shear zones. When the dominant foliation is restored to horizontal, the ductile shear zones show a consistent sense of slip, seaward side down (Bradley and Kusky, 1992). Clark (1972) reported prehnite-pumpellyite metamorphic facies assemblages in the McHugh Complex along Turnagain Arm. The primary melange foliation, ductile shear zones, and prehnite-pumpellyite metamorphism are all believed to have formed during subduction-accretion.

Many new fossil ages have been reported from the McHugh Complex since the two previous guidebooks were published in the early 1980's. In general, the new findings confirm and refine what Winkler and others (1984) were able to deduce from much slimmer evidence. The best paleontological control now available is from the Seldovia quadrangle. At several places, mostly in Kachemak Bay (fig. 3), radiolarian chert depositionally overlies pillow basalt (for example, Stop 62). Precise radiolarian age data show that the base of the chert varies in age from Ladinian (Middle Triassic) to Albian-Aptian (mid-Cretaceous)(C. Blome, written commun., 1994). Other chert sections, which are fault-bounded and have no stratigraphic context, also range from Ladinian to Albian. In 1989, two of us (DCB and SMK) discovered a depositional contact of graywacke overlying chert, which yielded Pliensbachian (Early Jurassic) radiolarians (C. Blome, written commun., 1994)(Stop 64).

The fossil ages are readily explained by a stratigraphic model developed by Connelly (1978) for the Uyak Complex, an equivalent of the McHugh Complex on Kodiak Island. According to this interpretation, the McHugh basalts were formed by seafloor spreading, the overlying cherts were deposited on the ocean floor as it was inexorably conveyed toward a trench, and the argillite and graywacke record deposition on the downgoing plate in the trench, just prior to subduction-accretion. In addition to the oceanic-plate component, it is possible that parts of the McHugh were deposited on the overriding plate, for example, on the inner trench slope. The timing subduction-accretion is not well known, but probably spanned much of the Jurassic and Cretaceous. High-pressure metamorphism of the Seldovia metamorphic complex took place during the Early Jurassic, as discussed under Stop 67. These metamorphic rocks lie along the landward margin of the McHugh Complex, which, considering its position further outboard, was probably accreted later.

Limestones within the McHugh Complex are of two types of very different origin: clasts in conglomerate and tectonic blocks in melange. A limestone clast in McHugh conglomerate has yielded conodonts with a possible age range of late Meramecian to early Morrowan (Late Mississippian to Early Pennsylvanian; Nelson and others, 1986). This clast could have been shed from the Strelna Formation of the Wrangellia terrane (Nelson and others, 1986). Most of the dated limestones, however, are tectonic blocks — typically occurring as severely extended strings of boudins — that have yielded Permian fusilinids, conodonts, or both (Stevens and others, 1997; B. Wardlaw and A. Harris, written commun., 1994). The fusilinids and conodonts are of shallow-water, tropical, Tethyan affinity; the fusilinids are quite distinct from those of Wrangellia. In terms of the Connelly (1978) model, the tectonic limestone blocks

GEOLOGIC MAP OF TURNAGAIN ARM

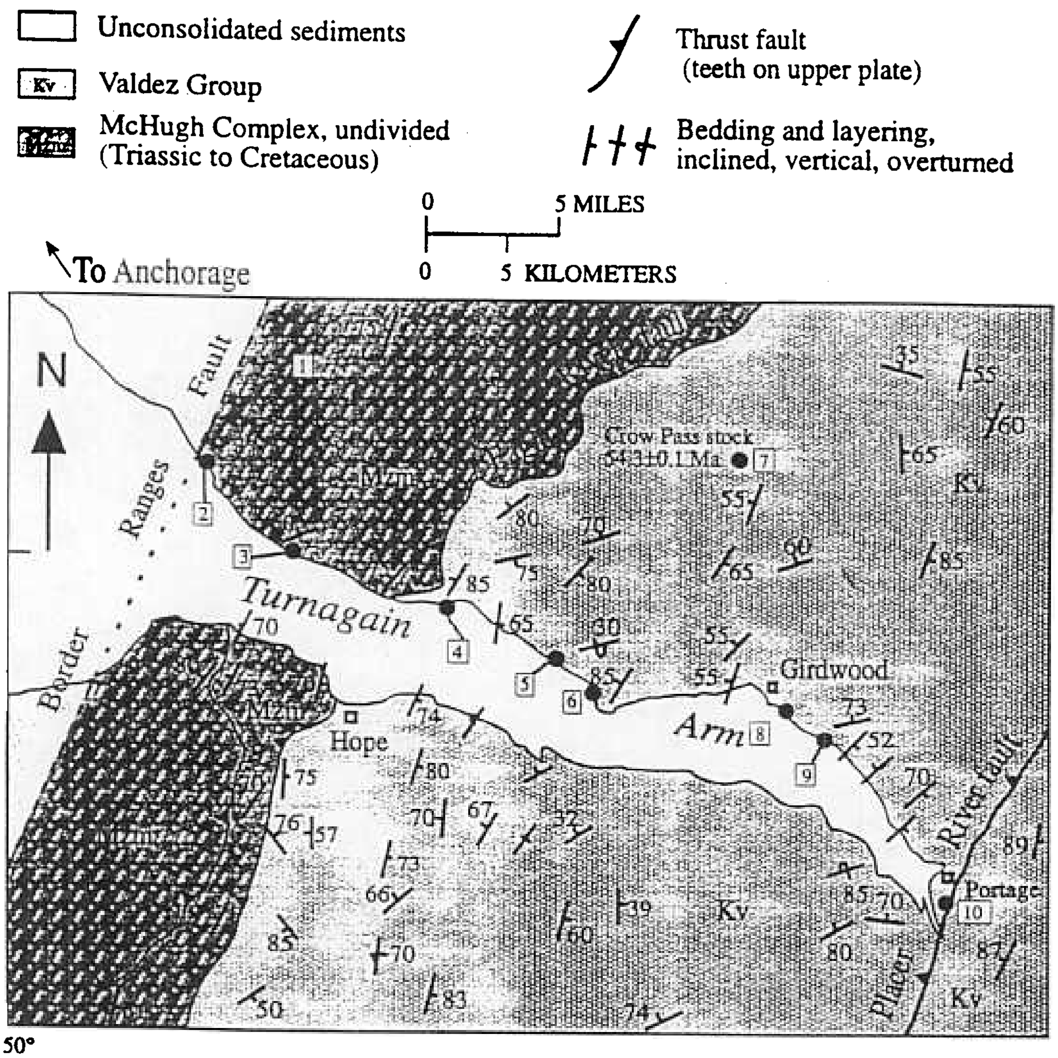

Figure 2. Generalized geologic map of Turnagain Arm, south-central Alaska. Field stops are labeled 1 through 10. Adapted from 1:250,000-scale map by Magoon and others (1976).

GEOLOGIC MAP OF KACHEMAK BAY

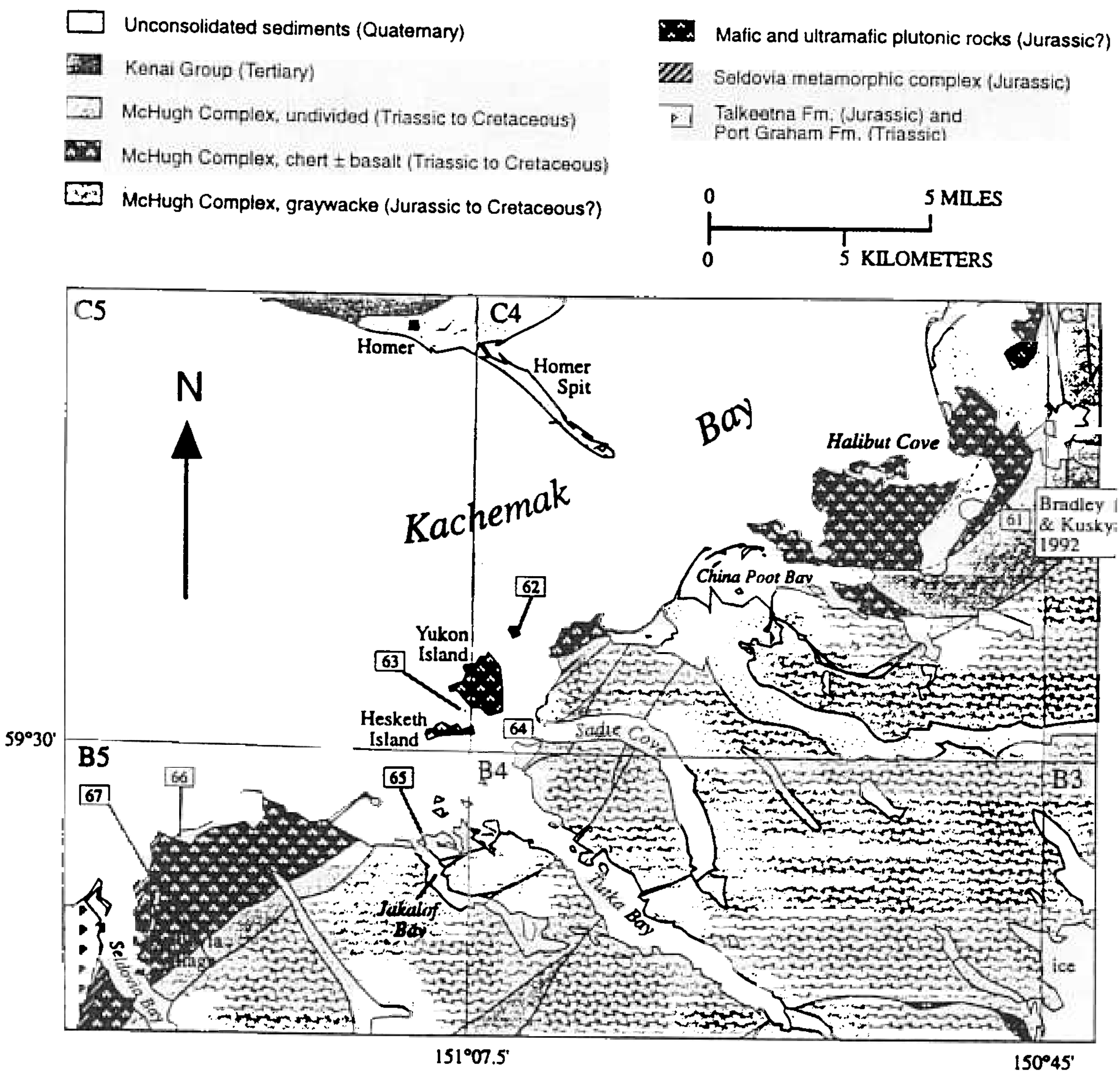

Figure 3. Generalized geologic map of Kachemak Bay, south-central Alaska. Field stops are labeled 61 to 67; also shown is the location at Grewingk Glacier of a detailed study of McHugh Complex melange (Bradley and Kusky, 1992). Gray grid lines are the boundaries between USGS 1:63,360-scale topographic maps, labeled B3, C3, etc. Adapted from an unpublished 1:250,000-scale geologic map by D. Bradley, P. Haeussler, T. Kusky, S. Karl, and T. Donley.

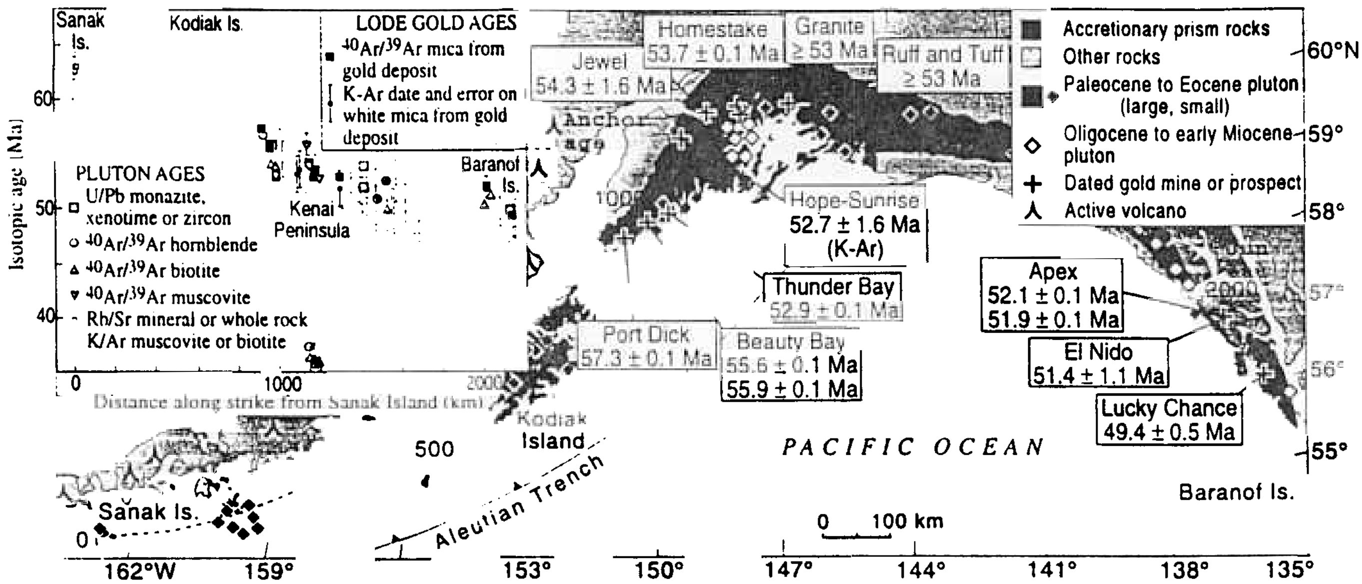

Figure 4. Map of southern Alaska showing accretionary prism, plutons of Sanak-Baranof plutonic belt, modern volcanoes, and $^{40}Ar/^{39}Ar$ isotopic ages of gold mineralization at specified mines, prospects, and mineral occurrences. Numbers along dashed reference line show distance in kilometers from southern tip of Sanak Island to Baranof Island. Anch.=Anchorage. Inset: Plot of isotopic ages of gold occurrences and intrusions vs. distance along strike around Sanak-Baranof plutonic belt (fig. 1). Error bars on $^{40}Ar/^{39}Ar$ and U/Pb ages are too small to be shown on plot. A few conventional K-Ar hornblende ages that fall above the trend at 1400-1800 km are not shown, because they show evidence of excess argon (see discussion in Bradley et al., 1993). From Haeussler et al. (1995).

might represent the tops of seamounts that were decapitated at the subduction zone. If so, some of the ocean floor that was offscraped to form the McHugh Complex must date back to the Paleozoic.

The seaward part of the Chugach terrane is underlain by the Valdez Group of Late Cretaceous (Campanian? to Maastrichtian) age. In the Kenai Peninsula area, it includes medium- and thin-bedded graywacke turbidites, black argillite, and minor pebble to cobble conglomerate. Sandstones of the Valdez Group are moderately well sorted, and consist mostly of quartz and feldspar, some volcanic fragments, and rare chert. These strata were probably deposited on the downgoing plate in a deep-sea trench (Nilsen and Zuffa, 1982), and accreted shortly thereafter. Most of the Valdez Group consists of relatively coherent strata, that have been deformed into regional-scale tight- to isoclinal folds, and cut by a slaty cleavage. The McHugh Complex and Valdez Group are juxtaposed along a thrust fault, which in the area of Turnagain Arm is called the Eagle River Fault. Beneath the fault is a melange of partially to thoroughly disrupted Valdez Group turbidites. This monomict melange, which is quite distinct from the polymict melanges of the McHugh Complex, can be traced for hundreds of kilometers in the footwall of the Eagle River Fault and its along-strike equivalents (Kusky and others, 1993).

Manifestations of Early Tertiary Ridge Subduction

Global plate reconstructions imply that a spreading center was subducted somewhere along the western margin of North America during the early Tertiary (Atwater, 1989). Although the triple junction (between the Kula, Farallon, and North American plates) cannot be located using marine magnetic anomalies, a series of near-trench plutons in the Chugach terrane probably tracks its position (Bradley and others, 1993 and references therein). These intrusions, the Sanak-Baranof belt of Hudson (1983), extend from Sanak Island on the west to Baranof Island on the east (fig. 4). The intrusions were emplaced 75-250 km seaward of the early Tertiary magmatic arc. The near-trench magmatic pulse migrated 2200 km along the continental margin, from Sanak Island in the west at about 63-65 Ma, to Baranof Island in the east at about 50 Ma (Bradley and others, 1993); in the Turnagain Arm area, the magmatism took place around 54 Ma (Haeussler and others, 1995). It is difficult to envision a plausible mechanism — other than ridge subduction — for generating intrusions in a near-trench setting with such a large-scale diachronous trend in ages. Several other lines of evidence support or are consistent with the ridge-subduction model. Geochemical evidence suggests that Paleocene granitoids on Kodiak Island formed by interaction between a parent magma similar to MORB and anatectically melted flysch (Hill and others, 1981). In the ~57 Ma Resurrection ophiolite, near Seward, pillow lavas are interbedded with flysch, suggesting that the spreading center was close to a continental margin, presumably the site of a trench, when it formed (Bol and others, 1992). Regional high-temperature, low-pressure metamorphism — opposite of what is normally expected in an accretionary prism — affected large areas in the eastern Chugach Mountains (Sisson and others, 1989; Pavlis and Sisson, 1995); metamorphic cooling ages are similar to the ages of nearby near-trench intrusions. This and other evidence for ridge subduction was discussed at greater length by Bradley and others (1993) and Pavlis and Sisson (1995).

Ridge subduction is also implicated in two other widespread events: gold mineralization and brittle faulting. The forearc setting of lode-gold deposits in the Chugach terrane is unusual; forearcs are normally relatively "cold" places noted for hydrothermal activity. The gold-bearing veins post-date accretion-related structures — mostly in the Valdez Group — and commonly occur along brittle faults. Quartz, calcite, and ankerite are the typical gangue minerals; arsenopyrite is the most abundant sulfide; tiny grains of native gold can still be found on many mine dumps. Goldfarb and others (1986) invoked a regional-scale ore-forming process because the vein mineralogy, isotopic data, and fluid inclusion composition, salinities, and homogenization temperatures are consistent over a very wide area. The mineralizing fluids were most

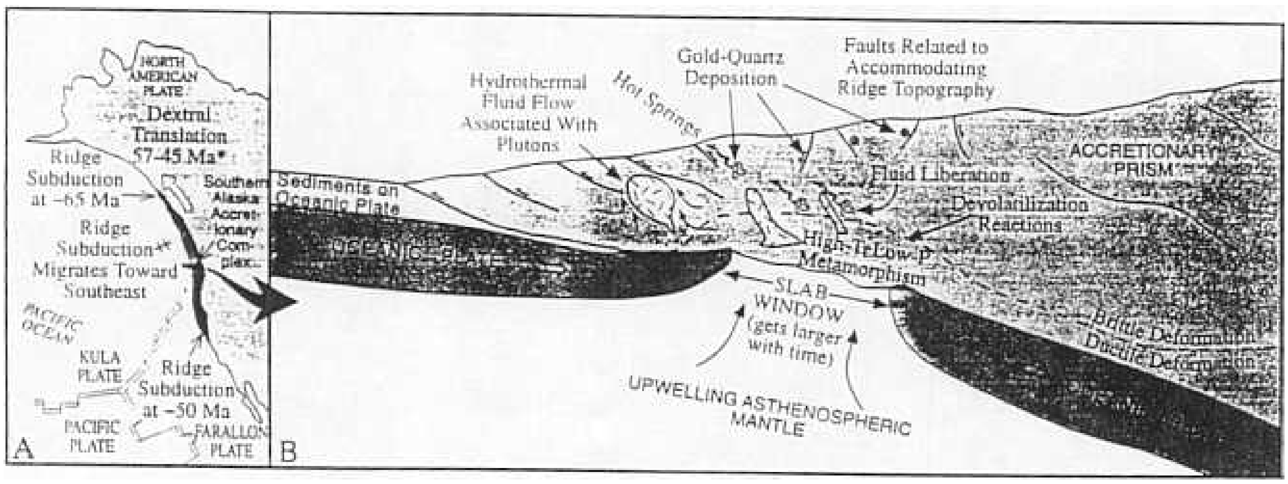

Figure 5. Tectonic setting of gold mineralization during ridge subduction in southern Alaska accretionary prism. A: Plate reconstruction. Kula-Farallon ridge location is constrained by ages of near-trench intrusions (Bradley et al., 1993). Asterisk refers to northward translation of accretionary prism inferred by paleomagnetic data. See Bol and others (1992) for discussion. B: Schematic cross section across accretionary prism showing processes involved during ridge subduction and gold mineralization. From Haeussler et al. (1995).

likely metamorphic in origin (Goldfarb and others. 1986). Recent $^{40}Ar/^{39}Ar$ dating of sericite from a number of gold mines has shown that mineralization took place at 57-53 Ma in the Kenai Peninsula area. and at 52-49 Ma in southeastern Alaska (Haeussler and others. 1995)(fig. 4). Near-trench gold mineralization thus was essentially coeval with the diachronous pulse of near-trench magmatism. and by implication. the two formed in the same tectonic setting.

Throughout southern Alaska. rocks of the Chugach terrane are cut by abundant late brittle faults (Bradley and Kusky. 1990; Kusky and others. 1997). Along Turnagain Arm. these late faults include sets of: (1) dextral and sinistral strike-slip faults. (2) synthetic and antithetic thrust faults. and (3) synthetic and antithetic normal faults. The faults are typically spaced every few meters to tens of meters. and can be seen at most of the outcrops visited on this trip. The thrust faults shortened the wedge subhorizontally nearly perpendicular to strike; then. the somewhat younger normal and strike-slip faults extended the wedge nearly parallel to orogenic strike. The three fault sets are characterized by quartz + calcite + chlorite + prehnite slickensides; curved slickenlines on some faults of each set reveal that displacement directions changed over time. We believe that this resulted from progressive changes in the orientation or magnitude of principal stresses during exhumation of the accretionary wedge, while the faults were active (Kusky and others, 1997). Although none of the brittle faults along Turnagain Arm have been dated. two lines of evidence suggest that they were active at the time of near-trench magmatism. As noted above. most of the gold-quartz veins in the Chugach terrane — including those that have been dated— occupy strike-slip and normal faults that resemble the ones along Turnagain Arm. At Grewingk Glacier near Kachemak Bay (fig. 3). Bradley and Kusky (1992) mapped mutually cross-cutting relationships between Tertiary mafic dikes and a set of ENE-striking dextral faults that have essentially the same orientation as the dextral faults along Turnagain Arm.

In summary. a number of geologic features in the Chugach terrane that post-date accretion can be interpreted as products of ridge subduction. According to this model (fig. 5). when the Kula-Farallon spreading center was subducted. an asthenosphere slab window opened in the ever-widening gap between the subducted — but still diverging — plates. This brought hot mantle into contact with the cold. wet base of the accretionary prism. causing. at various depths. partial melting. high-temperature metamorphism. hydrothermal fluid migration. and gold mineralization. As the high-standing spreading ridge approached a point along the continental margin. the accretionary prism was internally shortened along late thrust faults. in order to achieve a new critical taper. Then. as the triple junction migrated past and progressively older ocean floor was subducted. the accretionary prism was extended on normal and strike-slip faults. The late structures also may record different kinematic regimes associated with subduction of different oceanic plates. before and after ridge subduction. Prior to triple junction passage. subduction of the Farallon plate occurred at nearly right angles to the trench axis. whereas after triple junction migration. subduction of the Kula plate involved a significant component of dextral transpression and northward translation of the Chugach terrane.

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References Cited

Atwater, Tanya, 1989, Plate tectonic history of the northeast Pacific and western North America. *in* Winterer, E.L., Hussong, D.M., and Decker, R.W., editors, The geology of North America: The Eastern Pacific Ocean and Hawaii: Geological Society of America DNAG Series, v. N, p. 21-72.

Bol, A.J., Coe, R.S., Gromme, C.S., and Hillhouse, J.W., 1992, Paleomagnetism of the Resurrection Peninsula, Alaska: Implications for the tectonics of southern Alaska and the Kula-Farallon Ridge: Journal of Geophysical Research, v. 97, p. 17,213-17,232.

Boss, R. F., Lennon, R. B., and Wilson, B. W., 1976, Middle Ground Shoal oil field, Alaska: AAPG Memoir 24, p. 1-22.

Bradley, D.C., and T.M. Kusky, 1990, Kinematics of late faults along Turnagain Arm, Mesozoic accretionary complex, south-central Alaska: *in* Dover, J.H., and Galloway, J.P., eds., Geologic Studies in Alaska by the U.S. Geological Survey, 1989: U.S. Geological Survey Bulletin 1946, p. 3-10.

Bradley, D.C., and Kusky, T.M., 1992, Deformation history of the McHugh Complex, Seldovia quadrangle, south-central Alaska, *in* Bradley, D.C., and Ford, A.B., eds., Geologic Studies in Alaska by the U.S. Geological Survey, 1990: U.S. Geological Survey Bulletin 1999, p. 17-32.

Bradley, D.C., Haeussler, P.J., and Kusky, T.M., 1993, Timing of Early Tertiary ridge subduction in southern Alaska, *in* Dusel-Bacon, C., and Till, A.B., eds., Geologic Studies in Alaska by the U.S. Geological Survey, 1992: U.S. Geological Survey Bulletin 2068, p. 163-177.

Burns, L.E., 1985, The Border Ranges mafic-ultramafic complex, south-central Alaska: Cumulate fractionates of island-arc volcanics: Canadian Journal of Earth Science, v. 22, p. 1020-1038.

Clark, S.H.B., 1972, The McHugh Complex of south-central Alaska: U.S. Geological Survey Bulletin 1372-D, p. D1-D11.

Clark, S.H.B., 1981, Guide to bedrock geology along the Seward Highway north of Turnagain Arm: Alaska Geological Society, Pub. no. 1, 36 p.

Connelly, W., 1978, The Uyak Complex, Kodiak Islands, Alaska: A Cretaceous subduction complex: Geological Society of America Bulletin, v. 89, p. 755-769.

Cowan, D.S., and Boss, R.F., 1978, Tectonic framework of the southwestern Kenai Peninsula, Alaska: Geological Society of America Bulletin, v. 89, p. 155-158.

DeMets, Charles, Gordon, Richard G., Argus, Donald F., Stein, Seth, 1994, Effect of recent revisions to the geomagnetic reversal time scale on estimates of current plate motions: Geophysical Research Letters, v. 21, p. 2191-2194.

Goldfarb, R. J., Leach, D. L., Miller, M. L., and Pickthorn, W. J., 1986, Geology, metamorphic setting, and genetic constrains of epigenetic lode-gold mineralization within the Cretaceous Valdez Group, south-central Alaska, *in* Keppie, J. D. and others, eds., Turbidite-hosted gold deposits: Geological Association of Canada Special Paper 32, p. 87-105.

Haeussler, P.J., Bradley, Dwight, Golfarb, Richard, Snee, Lawrence, and Taylor, Clifford, 1995, Link between ridge subduction and gold mineralization in southern Alaska: Geology, v. 23, p. 995-998.

Haeussler, Peter J., and Bruhn, Ronald L., 1996, Evidence for Holocene or late Pleistocene folding in Cook Inlet, Alaska: EOS, v. 77, no. 46 p. F686.

Hill, M., Morris, J., and Whelan, J., 1981, Hybrid granodiorites intruding the accretionary prism, Kodiak, Shumagin, and Sanak Islands, southwest Alaska: Journal of Geophysical Research, v. 86, p. 10,569-10,590.

Hoekzema, Robert B., Fechner, Steven A., and Kurtak, Joseph M., 1987, Evaluation of selected lode gold deposits in the Chugach National Forest, Alaska: U.S. Bureau of Mines Information Circular 9113, 62 p.

Hudson, Travis, 1983, Calc-alkaline plutonism along the Pacific rim of southern Alaska: Geological Society of America, Memoir 159, p. 159-169.

Karl, Susan, Decker, John, and Jones, David L., 1979, Early Cretaceous radiolarians from the McHugh Complex, south-central Alaska, in Johnson, K.M., and Williams, J.R., The USGS in Alaska: Accomplishments during 1978: USGS Circular 804-B, p.B88-B90.

Karlstrom, T.N.V., 1964, Quaternary geology of the Kenai lowland and glacial history of the Cook Inlet region, Alaska: U.S. Geological Survey Professional Paper 443, p. 69.

Kelley, J.S., 1985, Geology of the southwestern tip of the Kenai Peninsula, Alaska: in Sisson, A., ed., Guide to the Geology of the Kenai Peninsula, Alaska, Alaska Geological Society Guidebook, p. 50-68.

Kelly, T.E., 1961, Photogeology—a quick, economical tool for oil hunters: The Oil and Gas Journal, November 20, 1961, p. 265-272.

Kelly, T.E., 1963, Geology and hydrocarbons in Cook Inlet basin, Alaska, in Backbone of the Americas: AAPG Memoir 2, p. 278-296.

Kirschner, C. E., and Lyon, C. A., 1973, Stratigraphic and tectonic development of Cook Inlet petroleum province, in Arctic Geology: AAPG Memoir 19, p. 396-407.

Kusky, T.M., Bradley, D.C., Haeussler, P.J., Karl, S.M., and Donley, D.T., 1993, The Chugach Bay thrust, a major tectonic boundary in the southern Alaska accretionary prism [abs.]: Geological Society of America, Abstracts with Programs, v. 25, no. 6, p. A-282.

Kusky, T.M., Bradley, D.C., and Haeussler, P.J., 1997, Progressive deformation of the Chugach accretionary complex, Alaska, during a Paleogene ridge-trench encounter: Journal of Structural Geology, v. 19, p. 139-157.

Little, T.A., and Naeser, C.W., 1989, Tertiary tectonics of the Border Ranges fault system, Chugach Mountains, Alaska: Deformation and uplift in a forearc setting: Journal of Geophysical Research, v. 94, p. 4333-4359.

Magoon, L.B., Adkison, W.L., and Egbert, R.M., 1976, Map showing geology, wildcat wells, Tertiary plant fossil localities, K-Ar age dates, and petroleum operations, Cook Inlet area, Alaska: U.S. Geological Survey Miscellaneous Investigations Series Map I-1019, scale 1:250,000.

Martin, G.C., Johnson, B.L., and Grant, U.S., 1915, Geology and Mineral Resources of Kenai Peninsula, Alaska, U.S. Geol. Surv. Bull., 587, 243 pp.

Nelson, S.W., Blome, C.D., Harris, A.G., Reed, K.M., and Wilson, F.H., 1986, Late Paleozoic and Early Jurassic fossil ages from the McHugh Complex: *in* Bartsch-Winkler, S., and Reed, K.M., eds., Geologic Studies in Alaska by the U.S. Geological Survey during 1985: U.S. Geological Survey Circular 978, p. 60-64.

Nelson, S.W., Blome, C.D., and Karl, S.M., 1987, Late Triassic and Early Cretaceous fossil ages from the McHugh Complex, southern Alaska, *in* Hamilton, T.D., and Galloway, J.P., eds., Geologic Studies in Alaska by the U.S. Geological Survey during 1986: U.S. Geological Survey Circular 998, p. 96-98.

Nelson, S.W., and Blome, C.D., 1991, Preliminary geochemistry of volcanic rocks from the McHugh Complex and Kachemak terrane, southern Alaska: U.S. Geological Survey Open-File Report 91-134, 14 p.

Nilsen, T.H., and Zuffa, G.G., 1982, The Chugach terrane, a Cretaceous trench-fill deposit, southern Alaska: Geological Society of London, Special Publication 10, p. 213-227.

Park, C.F., Jr., 1933, The Girdwood Distric Alaska: U.S. Geological Survey Bulletin 849- G, p. 381-424, plate, scale 1:62,500.

Pavlis, T.L., and Sisson, V.B., 1995, Structural history of the Chugach metamorphic complex in the Tana River region, eastern Alaska: A record of Eocene ridge subduction: Geological Society of America Bulletin, v. 107, p. 1333-1355.

Schmoll, Henry R., Szabo, B. J., Rubin, Meyer, and Dobrovolny, Ernest, 1972, Radiometric dating of marine shells from the Bootlegger Cove Clay, Anchorage area, Alaska: Geological Society of America Bulletin, v. 83, p. 1107-11.

Schmoll, Henry R., Yehle, Lynn A., Gardner, Cynthia A., and Odum, Jack K., 1984, Guide to surficial geology and glacial stratigraphy in the upper Cook Inlet basin: Alaska Geological Society, Anchorage, 89 p.

Silberman, M.L., Mitchell, P.A., and O'Neil, J.R., 1981, Isotopic data bearing on the origin and age of the epithermal lode gold deposits in the Hope-Sunrise mining district, northern Kenai Peninsula, Alaska: U.S. Geological Survey Circular 823-B, p. B81-B84.

Sisson, V. B., Hollister, L. S., and Onstott, T. C., 1989, Petrologic and age constraints on the origin of a low-pressure/high-temperature metamorphic complex, southern Alaska: Journal of Geophysical Research, v. 94, p. 4392-4410.

Stevens, C.H., Davydov, V.I., and Bradley, D.C., 1997, Permian Tethyan fusilinids from the Kenai Peninsula, Alaska: Journal of Paleontology, 25 MS pp., 4 figs., 1 table, in press.

Tysdal, R.G., 1976, A preliminary evaluation of selected earthquake-related geologic hazards in the Kenai Lowland, Alaska: U.S. Geological Survey Open-File Report 76-270, 30 p.

Updike, R.G., and Ulery, C. A., 1986, Engineering-geologic map of southwest Anchorage, Alaska: Alaska Division of Geological and Geophysical Surveys Professional Report 89, 1 plate, scale 1:15,840.

Winkler, G.R., Silberman, M.L., Grantz, A., Miller, R.L., and MacKevett, E.M., Jr., 1981, Geologic map and summary geochronology of the Valdez quadrangle, southern Alaska: U.S. Geological Survey Open-File Report 80-892-A, 2 sheets, scale 1:250,000.

Winkler, G.R., Miller, M.L., Hoekzema, R.B., and Dumoulin, J.A., 1984, Guide to the bedrock geology of a traverse of the Chugach Mountains from Anchorage to Cape Resurrection: Alaska Geological Society, 40 p.

Road Log
for the 1997 Guide to the Geology of the Kenai Peninsula

by

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Introduction

This road log is built on three previous road logs (Clark, 1981; Winkler and others, 1984; and Triplehorn and others, 1985). This road log does not duplicate all of the information from the previous road logs, but the key stops from those logs have been included here, and also previous stops that have new information have been updated here. This guide is intended to be a self-sufficient resource for trips to see the geology of the Kenai Peninsula. The older field guides are not necessary to accompany this guide, but they do include useful information that is not repeated here. Other complementary field guides that dicuss surficial geology not addressed in this guide are Bartsch-Winkler and Schmoll, 1984, and Crossen, 1992.

The mileage used in this field guide starts from the U.S. Geological Survey office on Alaska Pacific University campus in Anchorage because that is the location of the start of the May 1997 field trip that inspired the compilation of this guide. However the mileage is reset to 0 at the weigh station by Potter's Marsh in order to coordinate with the previous logs. Both the Seward and Sterling Highway markers are noted for calibration purposes. Both highways are actively under construction. Straightening and rerouting since 1985 has changed some of the distances between stops. Mile markers on both highways now range from 0.4 to 1.6 miles apart. As of May 1, 1997, the distance from the weigh station to the Seward -Sterling highway junction is one mile shorter than it was in 1985. Inevitably, the mileages in this guide will soon be inaccurate. To alleviate this unavoidable problem, stream crossings, road junctions, and other landmarks are noted frequently in the log. We also highly recommend complementing this log with the following 1:63,360 scale topographic maps:

Anchorage A-8
Kenai A-4, A-6, B-1, B-3, B-4, C-1, C-2, C-3
Seldovia B-4, B-5, C-4, C-5, D-5
Seward B-8, C-7, C-8, D-6, D-7, D-8

The Kenai Peninsula has outstanding fishing, hiking and boating oppurtunities, in addition to interesting and resource-full geology. Rubber boots and tidebooks are a must for trips on the Kenai Peninsula. Be prepared for frigid water and cold, wet weather. Most of the stops in this guide are on state or federal land, but access to outcrops in Falls Creek, Diamond Gulch, Fritz Creek, and McNeil Canyon is through private property.Permission for access is advised.

Overview of the Geology Covered in the Road Log

The Kenai Peninsula is part of the South Central Alaska Region, one of the most tectonically active areas on the earth. The young topography offers a unique opportunity to observe geologically "immediate" depositional and structural responses to active tectonic processes. The tectonic setting of the Kenai Peninsula has remained an interplay of compressional and translational tectonic processes for more than 150 million years. The view from Glen Alps (stop 1) looking down Cook Inlet, is a cross-section of a plate boundary collisional arc, and provides a chance to appreciate the scale of a geologic phenomenon we more commonly see in structurally telescoped exposures of older rocks.

Because of the rapid uplift of South Central Alaska resulting from modern subduction of the Pacific plate, we can see modern structures and deposits conveniently superposed for comparison on ancient lithified and deformed deposits derived from the same tectonic processes, with the added bonus of the rugged and spectacular scenery that accompanies such young topography.

On this field trip, we'll observe the components of collisional and translational tectonic environments in the Mesozoic and Cenozoic, spiked by unique and intriguing events like the subduction of an active spreading ridge. Stop 2 is in the McHugh Complex, a Cretaceous accretionary complex, consisting of a tectonic mixture of subducted oceanic, arc, and continental margin sedimentary and volcanic rocks. Our next stops are in the Valdez Group, which represents trench-fill deposits. Stops 4, 7, and 9 have examples of post-accretionary granitic dikes and gold-quartz veins (Bradley and others, this volume), that have been linked to the subduction of the Kula spreading ridge approxiamtely 54 million years ago.

Superposed on these rocks, at stops 8 and 10, are modern deposits resulting from accretionary tectonic processes, namely the 1964 earthquake and analogous paleoseismic events (Combellick, this volume). These stops offer a rare opportunity to observe the unique interplay of glacial, fluvial, and tidal deposits punctuated by seismic eventsand volcanic ash deposits. In Turnagain Arm we observe the interaction of climatic and tectonic processes, including uplift and subsidence, glacial scouring and deposition, fluvial erosion and aggradation.

In the Tertiary deposits of the Kenai Peninsula,at stops 46, 47, 50, 53-60, we'll see fluvial deposits indicating the Cook Inlet fore-arc basin was entirely nonmarine from approximately 65 to 2 million years ago (Swenson, this volume; Flores and others, this volume; Brimberry and others, this volume). Pleistocene glaciation intermittently extended across the Cook Inlet basin, and the basin was dominantly marine by approxiamately 16,000 years ago. Repeated glacial advances significantly modified the Tertiary topography on the Kenai Peninsula (Reger and Pinney, this volume), and modern tectonics has played an important role in the distribution and flow directions of these glaciers. Stops 14 and 19-55 describe various young features that developed from combined tectonic and climatic processes.

The Kenai Peninsula contains abundant energy and mineral resources, from gold and chromite to coal, oil, and gas. The Kenai also has outstanding timber, fishing, and recreational resources. All of these natural resources require investigation upgrades as access and technology increase and improve. The continuing investigations by private industry and state and federal agencies lead to new insights on the sources and distribution of resources at local and regional scales, and also lead to new questions and opportunities. The rewards of a better understanding of Kenai Peninsula geology are more than economic; they also include recognition of natural hazards, and improved community planning and development.

Road Log

Mile 0.0 Begin at the parking lot behind the USGS offices at 4200 University Drive. Head west (left out of the parking lot) on University Drive, which eventually becomes 36th Ave. You are in the Anchorage A-8 1:63,360 quadrangle.

Mile 2.1 Turn left at the 6th traffic light onto the New Seward Highway. If visibility is good, a side trip t the Glen Alps overlook is highly recommended, for a geologic overview of the Anchorage area.

Mile 6.8. Take the O'Malley Road exit. Turn left at the end of the ramp onto O'Malley. If visibility is poor on the day of the 1997 AGS field trip, we will skip stop 1 and go straight to Turnagain Arm. In that case, skip ahead to the entry for mile 21.2.

Mile 8.8 Alaska Zoo on the left.

Mile 10.4 Turn righ nto Hillside.

Mile 11.5 Turn left onto Upper Huffman.

Mile 12.1 Turn right onto Toilsome Hill Road.

Mile 14.0 Turn left into the Glen Alps parking lot. A sign reads "Entering Chugach State Park'

Stop Glen Alps Overlook

Walk to the scenic overlook. It can be very windy here.

The subduction of the Pacific Plate beneath the North American Plate controls the tectonics of southern Alaska. The Pacific Plate is about 40 km beneath our feet, and is currently subducting beneath Anchorage at a rate of 54.3 ± 1.4 mm/yr toward an azimuth of 344° (using the relative motion poles of Demets and others, 1994). Three main parts of a classic subduction zone can be seen from here: the Aleutian volcanic arc, the Cook Inlet forearc basin, and the Chugach terrane accretionary complex.

The Aleutian volcanic arc is located approximately 100 km above the subducting Pacific Plate, and it stretches about 2500 km from Hayes Volcano (north of Mt. Spurr) almost to the end of the Aleutians. The distance between the toe of the accretionary complex and the magmatic arc is a wider-than-average 460 km. Forty-two volcanoes have been active since 1760, accounting for more than 265 eruptions during that time. Eighty volcanic centers show evidence for Holocene activity. Arc magmas range from basalts to rhyolites, but are dominantly andesites.

The Chugach and Kenai Mountains consist of ocean-floor rocks of the Chugach terrane. As discussed above, these rocks originated in the paleo-Pacific, and were accreted to the continental margin, by offscraping and underplating, during the Jurassic and Cretaceous. The Border Ranges fault (originally a subduction-zone thrust, subsequently reactivated) lies in the lowlands along the mountain front.

Between the volcanic arc and the accretionary complex is the Cook Inlet forearc basin, which has a long, discontinuous history of sedimentation since Triassic time. Tertiary strata in Cook Inlet have been deformed into open, assymetric, and fault-cored folds that Haeussler and Bruhn (1996) have attributed to transpression. This most recent phase of deformation in the Cook Inlet basin probably began in the late Miocene, and may extend into Quarternary (Boss and others, 1976) or even Holocene time (Kelley, 1961, 1963; Kirschner and Lyon, 1973; Tysdal, 1976). The folds are important structural traps of oil and gas in the Cook Inlet basin — the first petroleum province extensively developed in Alaska. Haeussler and Bruhn (1996) argued these folds are still active and may be important seismic hazards in the Anchorage area.

The oldest known glaciation in the Anchorage area is thought to have covered the top of Mt. Susitna (4,396 ft.)(Karlstrom, 1964) and possibly the top of nearby Flattop Mountain (3,510 ft.)(Schmoll and others, 1984) — both summits should be visible from this overlook. The lowlands of the Anchorage bowl are largely underlain by sediments of the Bootlegger Cove Formation, dated at 13,690 to 14,900 radiocarbon yr. B.P. (Schmoll and others, 1972). Updike and Ulery (1986) regarded these sediments as fan-delta deposits, related to an ice lobe located just west of Anchorage. The Elmendorf Moraine, is visible to the north as a band of low, hummocky hills, formed during the last glacial maximum between 12,000 and 14,000 radiocarbon yr. B.P., when a large ice lobe extended down the Matanuska Valley (Schmoll and others, 1984).

Retrace path to the New Seward Highway.

Mile 21.2 Turn southbound onto the New Seward Highway, and continue toward Turnagain Arm.

GEOLOGIC MAP OF TURNAGAIN ARM

Unconsolidated sediments

Kv Valdez Group

McHugh Complex, undivided (Triassic to Cretaceous)

Thrust fault (teeth on upper plate)

Bedding and layering, inclined, vertical, overturned

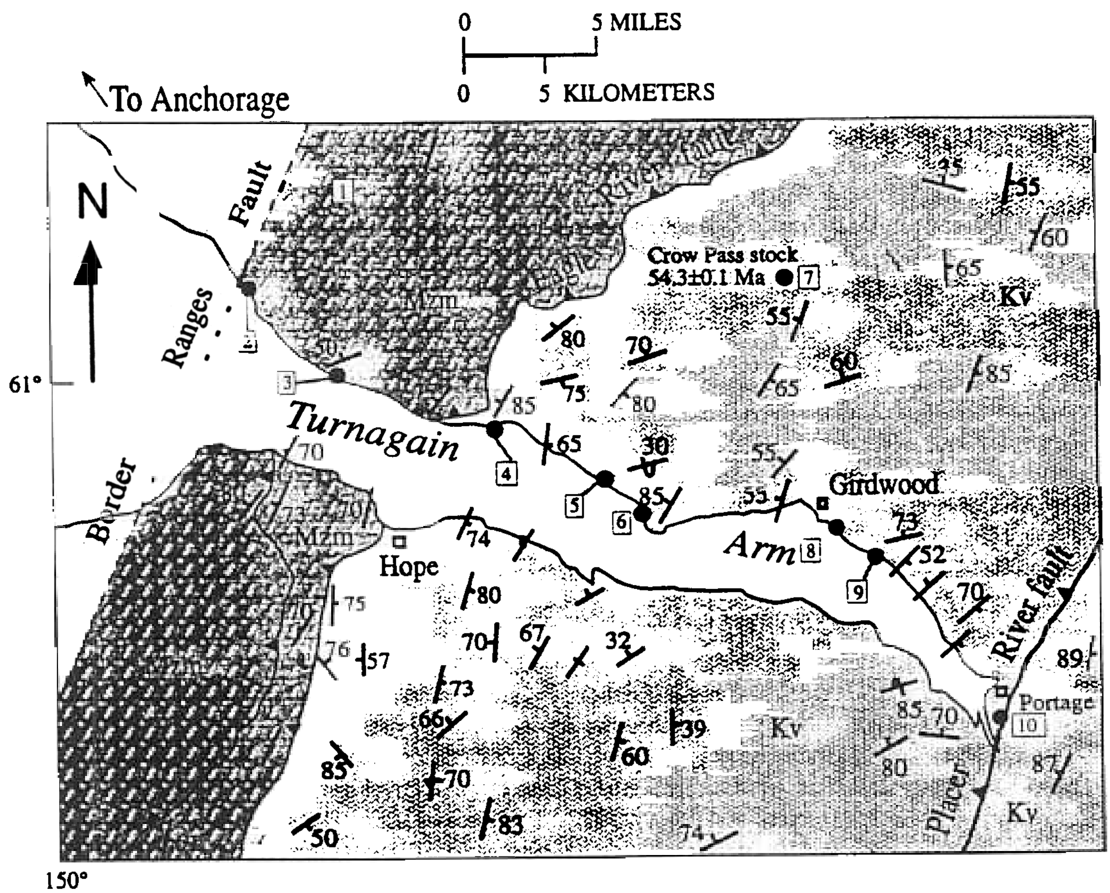

Figure 1. Generalized geologic map of Turnagain Arm, south-central Alaska. Field stops are labeled 1 through 10. Adapted from 1:250,000-scale map by Magoon and others (1976).

Mile 23.8 Rabbit Creek Road overpass on the New Seward Highway

Mile 26.3 Approximate buried trace of the Knik fault (a segment of the Border Ranges fault system), which bounds the Peninsular and Chugach terranes (fig. 1).

Mile 27.1 (Seward Highway mile 114.7). Turn left into Weigh Station. Reset trip meter to 0 to coordinate with previously published road logs of Turnagain Arm.

Stop 2. Mchugh Complex Pillow Basalt and Melange

Park at the west end of weigh station parking lot, and cross the Seward Highway to an outcrop of pillow basalt along the shoreline, opposite the stop sign. This is about as good as pillows get in Turnagain Arm; in Kachemak Bay there are dozens of more spectacular exposures of probably correlative rocks. This basalt has not been dated, but is probably Middle Triassic to mid-Cretaceous, by extrapolation from the Seldovia quadrangle.

From here, walk westward along the shore a few hundred feet to the next outcrop, which consists of mesoscale melange. Enclosed in a phacoidally cleaved argillite matrix are isolated blocks, and variably pulled-apart layers of greenstone, chert, limestone, and graywacke. The tall roadcut opposite this outcrop also consists of mesoscale melange, but is not as well weathered to bring out details. Note the large limestone block in the roadcut.

Return to cars, continue along Seward Highway. The type locality of the McHugh Complex extends from here at the Weigh Station, past the next stop at Beluga Point, to a short distance west of Falls Creek.

Mile 0.7 (Seward Highway mile 114; Benchmark BM 39). In roadcuts on the left is a conspicuous lozenge of red, ribbon-bedded radiolarian chert. Five species of radiolarians indicate a Berriasian to Valanginian (Early Cretaceous) age for this chert (Karl and others, 1979).

Mile 1.5 (Seward Highway mile 113.2). There are several different paleontologically dated cherts at this location. A gray chert lens in a 150-meter road cut of predominantly massive greenstone with minor chert and argillite yielded Berriasian to Valanginian radiolarians (Nelson and others, 1987). A hundred meters or so to the south is a 10-meter-thick lens of red and gray ribbon-bedded chert, in basalt, that yielded radiolarians of late Pleinsbachian to Toarcian (Early Jurassic) age (Nelson and others, 1986). Four meters to the south is another block of red ribbon chert containing Berriasian to Hauterivian (Early Cretaceous) radiolarians (Nelson and others, 1987).

Mile 1.7 (Seward Highway mile 113). Gray chert in centimeter-scale lenses and boudins occur in a sheared argillite matrix. This chert contains radiolarians of late Carnian to early Norian (Late Triassic) age (Nelson and others, 1987).

Mile 3.1 Cross McHugh Creek, from which the McHugh Complex took its name.

Mile 4.6 (Seward Highway mile 110.1). Turn right into parking lot at Beluga Point, and park at the east end of the lot.

Stop 3. Beluga Point

Cross the highway to cliffs of McHugh Complex boulder conglomerate. Clasts found here include greenstone, argillite, chert, limestone, siltstone, and gabbro. A plutonic clast from a nearby outcrop yielded a hornblende K/Ar age of 146±7 Ma (M.A. Lanphere, quoted in Clark, 1981). Elsewhere in the

Anchorage quadrangle. Clark (1981) reported conglomerate clasts of glaucophane schist and serpentinite in conglomerate of the McHugh Complex. Conodonts from a limestone cobble in McHugh conglomerate 2 km southeast of Beluga Point are Meramecian to Morrowan in age (Late Mississippian to Early Pennsylvanian; Nelson and others, 1986). Sandstones of the McHugh Complex typically are poorly sorted, matrix-supported, and consist mostly of chert and volcanic rock, plus less abundant quartz and feldspar. A comprehensive study of the McHugh Complex conglomerate clasts — using the full arsenal of modern techniques such as U/Pb and $^{40}Ar/^{39}Ar$ geochronology, conodont and radiolarian paleontology, and sedimentary petrography and geochemistry — would be of enormous value in plate reconstructions.

On the lower cliff face, about opposite the information kiosk, are the slickensided surfaces of several late brittle faults that are widespread throughout Chugach terrane on the Kenai Peninsula (Bradley and Kusky, 1990; Kusky and others, 1997). The most conspicuous of these is an oblique dextral-normal fault.

Return to cars, continue along Seward Highway

<u>Mile 6.6</u> Rainbow Creek crossing. There was minor placer gold production near here in the early 1900's Entering Seward D-7 quadrangle.

<u>Mile 9.2</u> (Seward Highway mile 104.7). Falls Creek. Here we cross the Eagle River Fault, a low-angle thrust; driving eastward we leave the McHugh Complex in the hangingwall and enter the Valdez Group in the footwall. For about the next mile, the Valdez Group is quite disrupted. Bedding, where preserved, is generally inverted, suggesting that disruption may be the consequence of shearing on the overturned limb of a recumbent footwall syncline. In the same structural position in the Seldovia quadrangle, the belt of "melanged" Valdez Group has been mapped as the "Melange of Iceworm Peak" (Kusky and others, 1993). All roadcuts for the next 100 or so miles on the road to Homer will be Valdez Group.

<u>Mile 10.6</u> (Seward Highway mile 103.3). Park on the right at a pullout, located in the middle of a broad bend to the left.

Stop 4. Valdez Group Near Indian

Scramble down a footpath, cross the railroad track, head left a few hundred feet, and descend toward the water's edge, keeping to the left of the prominent headland. The wave-washed outcrops are of thin- and medium-bedded turbidites of the Valdez Group, most of which display partial Bouma sequences (Tcde). Sedimentary structures are quite well preserved, to a degree seldom seen in the McHugh Complex, but fairly common in parts of the Valdez Group. Paleocurrents here, based on single-tilt restoration of seven cross laminae, are toward about 215°, roughly parallel to the present structural grain and to the inferred paleotrench axis. Outcrops to the left and right are of thick, locally conglomeratic sandstones.

Structural elements here are distinctly different from what we saw earlier in the McHugh Complex. The strata are well bedded, and are preserved in coherent sections amenable to sedimentological study and bed-by-bed section logging. Slaty cleavage is well developed; it is strongly refracted in the sandstone layers. Thin sandstone dikes locally cut the slates; they are nearly parallel to cleavage and have been interpreted to show that the Valdez Group was not well lithified when deformation commenced (Clark, 1981).

Around the point toward the west is a felsic dike belonging to the Sanak-Baranof near-trench intrusive suite. The dike shows a pronounced tectonic foliation; of hundreds of dikes that we have examined in the Chugach terrane, only a handful are foliated. The dike is undated but presumed to be about 54 Ma. This stop can serve as a substitute for Stop 9, where parking is restricted.

Return to cars, continue along Seward Highway.

Mile 12.0 Cross Indian Creek

Mile 13.5 Cross Bird Creek

Mile 14.9 (Seward Highway mile 100)

Mile 15.8 (Seward Highway mile 99). Park in a pullout on the right under powerlines, just in front of the sign that reads "Avalanche area next 2 miles, do not stop." (Sign is folded over in summer).

Stop 5. Valdez Group at BM 29

Scramble down on a footpath that begins between the sign and the triple power pole. Walk to the right a few hundred feet along the railroad tracks to a headland capped by gnarly spruce trees. This is a textbook exposure of a channel sandstone, tens of meters thick, cut into thin-bedded turbidites. Note the stepwise base of the sandstone. Unless the tide is in all the way, it will be worthwhile to follow the shoreline rather than the railroad tracks back to the footpath. The wave-washed outcrops are of thin-bedded Valdez Group turbidites, which have been disharmonically folded and faulted. Is this deformation soft-sediment or tectonic in origin?

Stop 6. Fossil Locality in Valdez Group

Southernmost outcrops below the railroad track have yielded the Late Cretaceous (Maastrichtian) pelecypod *Inoceramus kusiroensis*. The outcrop is dominantly mudstone with thin beds of sandstone. Note that places where the cleavage is close to, or parallel to bedding, original sedimentary features in the mudstone are better preserved. This corresponds to Stop 12 of Clark (1981). Inoceramus fragments are reported from outcrops along the beach for a mile or so to the north of this locality (Clark, 1981), which would include stop 5 of this guide.

Mile 19.2 Bird Point on the right is a thick channel sandstone of Valdez Group that juts out into the middle of Turnagain Arm. Gold was mined here from 1916-1919, from quartz-carbonate veins in the Valdez Group, exposed below high-tide level.

Mile 20.2 Entering Seward D-6 quadrangle.

Mile 25.5 Turnoff for Girdwood. A stop description of the Crow Pass area is included, but, for lack of time, the AGS field trip will continue on the Seward Highway here. Skip ahead to the entry for Mile 25.8.

Stop 7. Crow Pass

Turn left toward Girdwood for an interesting half-day side-trip up to Crow Pass to see small near-trench intrusions and gold mineralization related to the subduction of the Kula-Farallon ridge. Two references are helpful: the geologic map and report by Park (1933), and a description of the mine workings by Hoekzema and others (1987). Drive northeast 2 miles and turn left onto the Crow Creek Road where the main road swings toward the east. It is about 5.8 miles farther to the parking lot for the Crow Pass Trail. Placer gold operations are still active near the point where the road narrows to a single lane. From the parking area, the trail switchbacks up a moderate grade to Crow Pass, about 3 miles.

Along the way, you will see remarkably undeformed sediments of the Valdez Group, and on the mountainsides above, light-colored felsic dikes and small intrusions of the Sanak-Baranof belt. At 1.7 miles from the parking area you will reach the ruins of the Monarch Mine, a lode gold mine that operated from 1906-1948. A number of characteristics of the gold-quartz veins can be seen at the entrance to the collapsed upper adit of the Monarch Mine, a short distance above the trail. The mineralized structure is a right-lateral strike-slip fault, with a brecciated zone between 40 cm and 2 m in width. Faulting probably occurred during and after mineralization, as is indicated by slickensides on quartz-vein surfaces. Visible free gold has been found in outcrop here. Haeussler and others (1995) reported a 40Ar/39Ar plateau age of 54.1±0.1 Ma on white mica from the Crow Pass intrusion, uphill from the Monarch Mine, and a plateau age of 54.3±0.1 Ma on white mica from a gold-quartz vein at the nearby Jewel Mine. These dates provide a clear link between near-trench magmatism and gold mineralization. Orientations of all the structures in the Crow Pass area, including faults hosting the gold-quartz veins, are roughly 90° clockwise of equivalent structures along Turnagain Arm and in the Prince William Sound region. Thus, some vertical-axis rotation appears to have affected this region after gold mineralization.

Retrace path to the Seward Highway in Girdwood. Turn left to rejoin the field trip log at mile 25.5.

Mile 25.8 Turn onto access road to gravel pit. Park at gate.

Stop 8. Gravel Pit Southeast of Girdwood Tidal Marsh

Nearly all of the trees visible on this marsh were killed by saltwater intrusion as a result of subsidence during the great 1964 earthquake. Most of the buildings in the part of Girdwood near the present intersection of Seward Highway and Alyeska Road were inundated, and many were subsequently moved to higher ground up Alyeska Road.

The most extensive tidal flooding occurred about two weeks after the earthquake during the next high spring tides. During the following two decades, repeated tidal flooding resulted in deposition of several tens of centimeters of silt, restoring the flats to near pre-earthquake levels (Bartsch-Winkler and Garrow, 1982). Salt-tolerant grasses now dominate the vegetation on Girdwood flats, and the marsh surface is flooded by sea water only at extreme high tides.

Visible in the tidal-bank exposure directly opposite the gravel pit is a stratigraphic record of the 1964 event, where postearthquake marine silt overlies freshwater vegetation that was killed by saltwater flooding. This pre-earthquake vegetation appears as a 10-15 cm thick peat layer and associated rooted stumps of dead trees, many of which are still standing. Also visible about 1 m below the 1964 peat layer is a second layer of stumps rooted in peat, yielding radiocarbon ages with an average range of 730-900 cal yr B.P. (Combellick, 1993, 1994). This forest layer was probably buried as a result of the previous 1964-style earthquake. Depending on exposure and accessibility (these active tidal flats are constantly changing), an older buried peat layer may be visible 1-2 m vertically below the 730-900-yr layer. This older layer has a radiocarbon age of 1,930-2,310 yr B.P. and probably records another previous submergence event (Combellick, this volume, fig. 4, eastern marsh). Still older peat layers, ranging to a maximum age of 4,000 yr B.P., are visible at low tide along the western portion of the marsh and in samples from a 19-m-deep borehole (Combellick, this volume, fig. 4). Evidence of as many as five pre-1964 great earthquakes appears in the tidal-marsh stratigraphy at Girdwood. All of these freshwater peat layers are well below present mean higher-high water (the approximate seaward limit of freshwater vegetation). The peat layers are also below corresponding late-Holocene lower sea-level stands (assuming 1.5 mm/yr average sea-level rise during this period).

Mile 28.1 Turn left to park by utility poles. Look ahead through the utility poles across the marsh to an old road cut on this abandoned section of the Seward Highway. You can see a light-colored dike cutting the dark sedimentary rocks. This outcrop with the dike is stop 9, and there is no longer a good pull-out to park at stop 9.

Mile 28.6 Park on shoulder and be careful of traffi

Stop 9. Valdez Group Intruded By Tertiary Dike.

Park and walk west about 100 feet along roadcuts to two aphanitic felsic dikes. The less prominent of the two comes to a bulbous end partway up the face. The dikes discordantly cut steeply dipping, dark argillite of the Valdez Group; a few dismembered siltstone beds can be seen in the argillite. Neither dike has been dated; a 1991 paleomagnetic study by Al Bol (Univ. of California, Santa Cruz) proved inconclusive, and was never published. This outcrop is admittedly not all that impressive — Crow Pass is far more revealing — but it is the most accessible exposure of a near-trench intrusion of the Sanak-Baranof suite. Although dikes are uncommon along Turnagain Arm, they are abundant not far to the north in the valley of Eagle River, to the south in the Hope-Sunrise mining district, and to the east in the Port Wells area of Prince William Sound. Silberman and others (1981) reported a K-Ar whole-rock age of 52.7±1.6 Ma from one such dike near Hope.

Mile 31.6 Peterson Creek

Mile 35.1 'wenty-Mile River

Mile 35.7 Old Portage townsite. The townsite marks the location of the main route through the mounains to Prince William Sound used by native Alaskans, and developed by miners in 1902. The Alaska Central Railway surveyed the route in 1904. The buildings west of the road were partially destroyed by high water during the March 1964 earthquake. The dead trees and remaining old buildings are protected artifacts of the earthquake.

Mile 36.6 Parking area adjacent to bridge at Portage Creek No. 2 (north channel of Portage Creek).

Stop 10. Portage Creek

At this location, near the axis of maximum subsidence during the 1964 earthquake, the postearthquake silt deposit (Placer River Silt of Ovenshine and others, 1976) is up to 2 m thick. Numerous abandoned buildings in the vicinity are partially filled with silt and, as at Girdwood, most of the trees on Portage flats were killed by saltwater intrusion during high tides following the earthquake. The pre-1964 ground surface, associated peat layer, and numerous artifacts such as milled wood, cables, and pallets are visible in the bank exposures downstream from the bridge. Also visible are clastic dikes of sand and gravel that erupted to the former ground surface as a result of earthquake-induced liquefaction (Walsh and others, 1995; Combellick, this volume, fig. 6). Postearthquake tidal flooding eroded most of these dikes to a depth of about 0.5 m below the 1964 ground surface and replaced the eroded portion with silt. Consequently, few sand boils were preserved. However, nearly every dike is associated with a break in the peat that does not extend into the overlying silt, indicating that the sand erupted after the peat formed but before the silt was deposited. These relationships effectively place the dike formation at the time of the 1964 earthquake.

No evidence of pre-1964 earthquake-related subsidence is visible in the tidal banks at Portage, because any remaining older peat layers are buried under modern tidal-channel deposits. Additionally, most boreholes drilled in the vicinity of Portage show that tidal sediments have been eroded by streams and replaced with alluvium over much of the area. However, continuous core samples from one borehole in unreworked tidal deposits south of Portage show evidence of as many as seven pre-1964 events during the past 5,000 yr (Combellick, this volume, fig. 5). The stratigraphic record at Portage, Girdwood, and other tidal marshes along upper Cook Inlet suggests that 1964-style (Mw 8-9) earthquakes have occurred in the region an average of every 600-800 yr. This generally agrees with the record of uplift events preserved at Copper River Delta and Middeton Island (Plafker and others, 1992).

the sea cliffs. This is a very important outcrop for stratigraphic purposes, as described by Triplehorn and others (1985):

> Although the Beluga-Sterling contact is mapped here, it is not based on outcrop character, but is projected from the subsurface to the surface (Adkison and others, 1975). On the other hand, Wolfe (in Adkison and others, 1975) placed his boundary between the Homerian and Clamgulchian stages here at a prominent coal, the B coal of Barnes and Cobb, (1959). Triplehorn and others, (1977), and Turner and others, (1980), reported a number of radiometric ages from volcanic ashes in the coal beds above and below the B coal. The average of these ages is about 8 million years, which is taken as the age of the Homerian-Clamgulchian boundary here. As pointed out by Rawlinson, (1984), the Beluga Formation along Kachemak Bay roughly corresponds to the Homerian stage type section.

Petrographic anlalyses and analysis of measured sections by Rawlinson (1984) indicate pyroclastic deposits are more abundant in Clamgulchian stage rocks than in the Homerian stage rocks. The pyroclastic debris occurs in discrete ash beds, and is also commonly preserved in coal beds. Alteration of glass in the ash layers and in the sandstones contribute to the poor porosity observed in these rocks (Hayes and others, 1976; Rawlinson, 1984).

These exposures were studied in detail by Rawlinson (1984). He applied a Markov analysis to channel and overbank deposits and his resulting interpretation was that beds deposited during the Homerian stage represent facies of braided-meandering streams, and beds deposited during the Clamgulchian stage represent facies of meandering streams (Rawlinson, 1984). Facies analysis of the Beluga and Sterling formations by Flores and others (1992) suggest the streams that deposited the Beluga Formation were lower sinuosity anastomosing braided and meandering streams, and the streams that deposited the Sterling Formation were higher sinuosity meandering streams. Pyroclastic deposits are more abundant in Clamgulchian stage rocks. The pyroclastic debris occurs in discrete ash beds, and is also commonly preserved in coal beds. Alteration of glass in the ash layers and in the sandstones contribute to the poor porosity observed in these rocks (Hayes and others, 1976; Rawlinson, 1984).

East End Road continues 9 miles further. The Sterling Formation is exposed in the stream cuts, and there are excellent views of Kachemak Bay and the glaciers of the Kenai Mountains to enjoy.

End of Road Log

FIELD STOPS IN KACHEMAK BAY

The stops are arranged from north to south (fig. 9), but there is no set itinerary.

Stop 61. Halibut Cove. The Halibut Cove gabbro crops out in a tall cliff at the northeastern end of Halibut Cove. It is presumed to be part of the Jurassic-aged Border Ranges mafic-ultramafic complex, which Burns (1985) interpreted as the roots of a magmatic arc. Most of the body consists of altered, chloritized, gabbro cut by innumerable microfaults. The gabbro is fault-bounded. The surrounding McHugh Complex shows no sign of contact metamorphism, implying that the gabbro was "cold" when emplaced into its present structural position. At the southern margin of the gabbro are bands (fault slices?) of serpentinite and garnet pyroxenite. Just south of the gabbro, the McHugh Complex is cut by an intermediate porphyritic dike, presumably of the Sanak-Baranof near-trench intrusive suite.

Stop 62. Cohen Island. Beautiful exposures of contorted chert of the McHugh Complex can be seen just south of the northeastern corner of the island; boats can be landed on the gravel beach a short distance to the south. Radiolarians from this outcrop are of Middle Triassic, Ladinian age (C. Blome, written commun., 1994). Seaward-verging, chevron- and sheath folds exposed here are typical of bedded chert

GEOLOGIC MAP OF KACHEMAK BAY

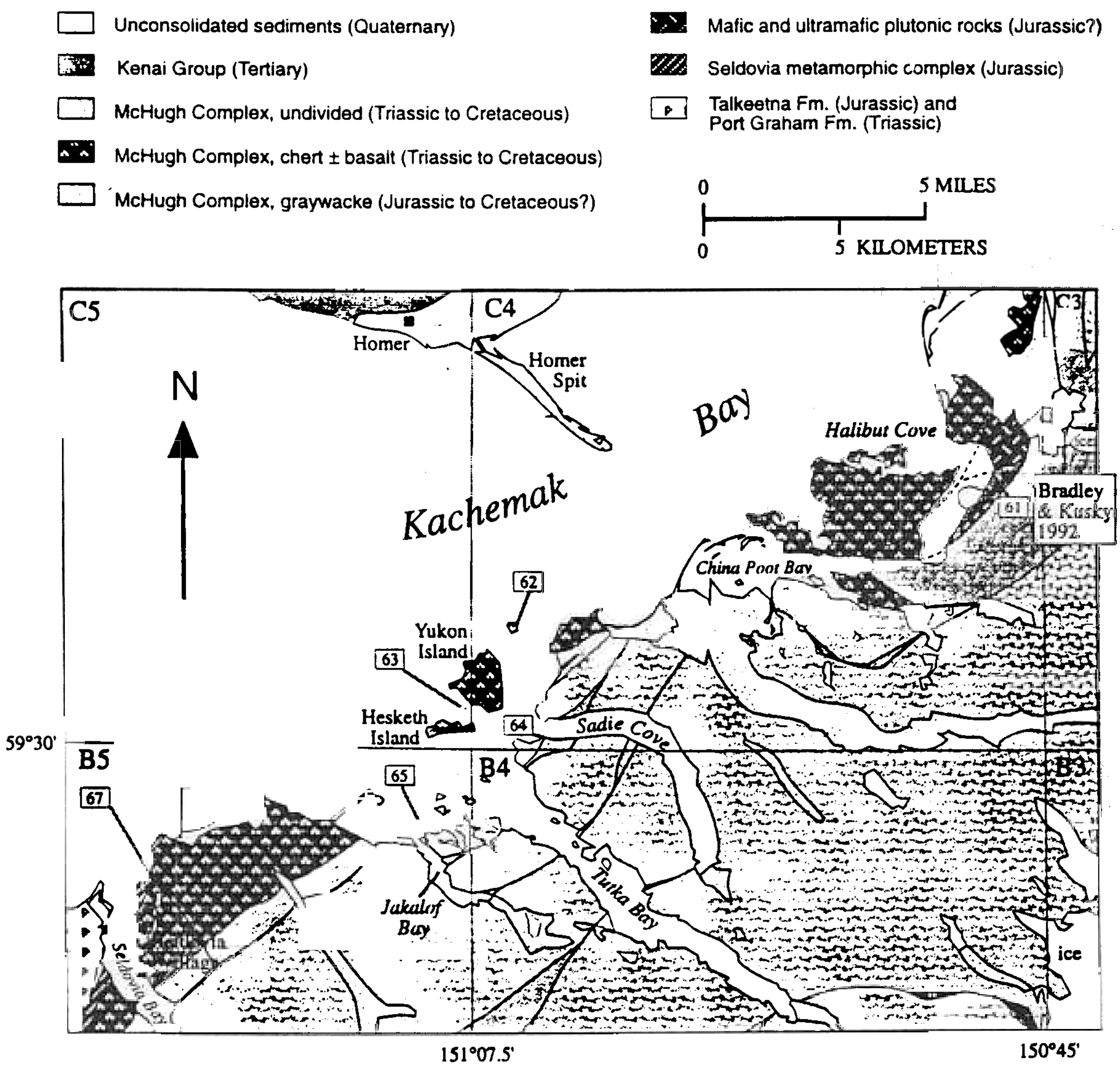

Figure 9. Generalized geologic map of Kachemak Bay, south-central Alaska. Field stops are labeled 61 to 67; also shown is the location at Grewingk Glacier of a detailed study of McHugh Complex melange (Bradley and Kusky, 1992). Gray grid lines are the boundaries between USGS 1:63,360-scale topographic maps, labeled B3, C3, etc. Adapted from an unpublished 1:250,000-scale geologic map by D. Bradley, P. Haeussler, T. Kusky, S. Karl, and T. Donley.

that forms an internally complex but mappable tract within the McHugh Complex, which extends about 50 km along strike northeast from Seldovia village. Similar chert exposures can be seen in many places along the shores of Yukon and Hesketh Islands, and along Peterson and China Poot Bays.

Stop 63. "Aardvark Rock" — a small island between Yukon and Hesketh Islands. Bedded radiolarian chert depositionally overlies pillow basalt. The contact is inverted. Here the basal chert has yielded radiolarians of earliest Jurassic, Hettangian age (C. Blome, written commun., 1994). Several other depositonal contacts of chert over pillow basalt can be seen in Kachemak Bay, for example, at the southwestern tip of Hesketh Island, and at the end of MacDonald Spit. However, as noted earlier, the age of the lowest chert varies from place to place, ranging from as old as Ladinian to as young as Albian-Aptian.

Stop 64. Sadie Cove, south shore. This key outcrop is located 1.1 km due east of the westernmost point of land at the entry to Sadie Cove, and 100-200 m west of power lines that cross the water. Boats can be landed in a small cove just west of the exposures of interest, which are at a point of land. Graywacke depositionally overlies radiolarian chert that has yielded Pliensbachian (Early Jurassic) radiolarians (C. Blome, written commun., 1994). This relationship completes the classic "oceanic-plate stratigraphy" for the McHugh Complex (basalt-chert-graywacke/argillite), in support of Connelly's (1978) stratigraphic model. The chert-graywacke contact is inverted. The graywacke section, which is about 12 meters thick, is "stratigraphically" overlain (but structurally underlain) by mesoscale melange interleaved with fault slices of greenstone, graywacke, and bedded chert.

Stop 65. Jakalof Bay. Nice exposures of a thick graywacke succession within the McHugh Complex extend from opposite the boat launch to well beyond the point to the northwest. The graywacke is many tens of meters thick. Bedding within it is revealed by conglomeratic horizons (a rarity in most graywacke bodies in the McHugh Complex); it dips about 45° to the north and is upright. The outcrop is cut by a recessive, ~9-meter-thick basaltic dike of presumed early Tertiary age.

Stop 66. Barabara Point, Miocene Tyonek Formation (Kenai Group) overlying the McHugh Complex. Bluffs of weakly consolidated sandstone and conglomerate extend about 4 km from the mouth of Barabara Creek toward the southwest. Plant fossils from four localities here are of early to middle Miocene age; on this basis, the strata have been assigned to the Tyonek Formation (Magoon and others, 1976). At the southwest end of this exposure, the Tyonek Formation overlies greenstone of the McHugh Complex along a high-relief, profound unconformity. The presence of conglomerate clasts of McHugh Complex suggests that the Tyonek Formation here was derived from the ancestral Kenai Mountains.

Stop 67. Outside Beach. This stop can be reached by roads from Seldovia Village, but Seldovia itself can only be reached by air or sea. The main purpose of this stop is to examine shoreline outcrops of high-pressure metamorphic rocks of the Seldovia metamorphic complex (Seldovia schist terrane of Cowan and Boss, 1978). These stretch from the picnic area at Outside Beach to Watch Point in Seldovia, a linear distance of about 1.5 km. A variety of metamorphic rocks are exposed, including greenstone, mica schist, glaucophane schist, thin-bedded quartzite, and marble. Several metamorphic grades are represented and the various rock types are typically separated by faults. Hornblende and white-mica separates from two schist samples have yielded $^{40}Ar/^{39}Ar$ plateau ages of 191-192 Ma (A. Till, U.S. Geological Survey, 1995, written commun.). This age falls in the Early Jurassic (Pliensbachian according to the DNAG time scale) and is believed to date an episode of subduction-zone metamorphism. Considering the evidence from Stop 64 and 67 together, we suggest that during the Pliensbachian, the chert and graywacke at Sadie Cove were being deposited in the outer trench, while the Seldovia metamorphic complex was being metamorphosed at depth in the accretionary wedge.

Eastward from the picnic area at Outside Beach are exposures of mesoscale melange of the McHugh Complex, and of bedded radiolarian chert. The fault that juxtaposes the Seldovia metamorphic complex with the McHugh Complex lies buried beneath beach gravels.

South of Seldovia are many miles of beautiful but largely inaccessible coastal exposures of the Jurassic Talkeetna Formation (volcaniclastics and volcanics, the Triassic Port Graham Formation (impure limestone plus other rock types, including minor volcanic rocks), and a Jurassic diorite pluton. In a 1985 field-trip guide, Kelley (1985) described these rocks, but did not identify specific stops. All of these rocks are assigned to the Peninsular terrane magmatic arc. The ruins of a Russian-era (1850's) coal mine can be seen at Coal Cove, at the northern entry to Port Graham. According to Martin and others (1915, p. 108), American operators who briefly reopened the mine around the turn of the century found old rusted leg-irons, suggesting that convict labor had been employed! (The mine entry is now below sea level, a result of subsidence during the great 1964 earthquake).

References Cited

Adkison, W.L., Kelly, J.S., and Newman, K.R., 1975, Lithology and palynology of the Beluga and Sterling Formations exposed near Homer, Kenai Peninsula, Alaska: U.S. Geological Survey Open-File Report 75-383, 240 p.

Anderson, G.S., 1972, Aquifer test, Soldotna, Alaska: U.S. Geological Survey Water Resources Division (Alaska District) Open-File Report 519, 17 p.

Anderson, G.S., and Jones, S.H., 1972, Water resources of the Kenai-Soldotna area, Alaska: U.S. Geological Survey Water Resources Division (Alaska District) Open-File report, 81 p, 2 sheets, scale 1:134,810.

Atwater, Tanya, 1989, Plate tectonic history of the northeast Pacific and western North America, *in* Winterer, E.L., Hussong, D.M., and Decker, R.W., editors, The geology of North America: The Eastern Pacific Ocean and Hawaii: Geological Society of America DNAG Series, v. N, p. 21-72.

Barnes, F.F., 1967, Coal resources of Alaska: U.S. Geological Survey Bulletin 1242-B, p. B1-B36, scale 1:2,500,000.

Barnes, F.F., and Cobb, E.H., 1959, Geology and coal resources of the Homer district, Kenai coal field, Alaska: U.S. Geological Survey Bulletin 1058-F, p. 217-260.

Bartsch-Winkler, S.R., and Garrow, H.C., 1982, Depositional system approaching maturity at Portage Flats, *in* Coonrad, W.L., ed., The U.S. Geological Survey in Alaska: Accomplishments during 1980: U.S. Geological Survey Circular 844, p. 115-117.

Batsch-Winkler, Susan, and Schmoll, H.R., 1984, Guide to the Late Pleistocene and Holocene deposits of Turnagain Arm, 1984: Alaska Geological Society, 70 p.

Begét, J.E., and Kienle, Juergen, 1992, Cyclic formation of debris avalanches at Mount St Augustine volcano: Nature, v. 356, p. 701-704.

Begét, J.E., and Nye, C.J., 1994, Postglacial eruption history of Redoubt Volcano, Alaska: Journal of Volcanology and Geothermal Research, v. 62, no. 1-4, p. 31-54

Begét, J.E., Stihler, S.D., and Stone, D.B., 1994, A 500-year-long record of tephra falls from Redoubt Volcano and other volcanoes in upper Cook Inlet, Alaska: Journal of Volcanology and Geothermal Research, v. 62, no. 1-4, p. 55-67.

Bol, A.J., Coe, R.S., Gromme, C.S., and Hillhouse, J.W., 1992, Paleomagnetism of the Resurrection Peninsula, Alaska: Implications for the tectonics of southern Alaska and the Kula-Farallon Ridge: Journal of Geophysical Research, v. 97, p. 17,213-17,232.

Boss, R. F., Lennon, R. B., and Wilson, B. W 1976, Middle Ground Shoal oil field, Alaska: AAPG Memoir 24, p. 1-22.

Bradley, D.C., and Kusky, T.M., 1992, Deformation history of the McHugh Complex, Seldovia quadrangle, south-central Alaska, *in* Bradley, D.C., and Ford, A.B., eds., Geologic Studies in Alaska by the U.S. Geological Survey, 1990: U.S. Geological Survey Bulletin 1999, p. 17-32.

Bradley, D.C., and T.M. Kusky, 1990, Kinematics of late faults along Turnagain Arm, Mesozoic accretionary complex, south-central Alaska: *in* Dover, J.H., and Galloway, J.P., eds., Geologic Studies in Alaska by the U.S. Geological Survey, 1989: U.S. Geological Survey Bulletin 1946, p. 3-10.

Bradley, D.C., Haeussler, P.J., and Kusky, T.M., 1993, Timing of Early Tertiary ridge subduction in southern Alaska, *in* Dusel-Bacon, C., and Till, A.B., eds., Geologic Studies in Alaska by the U.S. Geological Survey, 1992: U.S. Geological Survey Bulletin 2068, p. 163-177.

Burns, L.E., 1985, The Border Ranges mafic-ultramafic complex, south-central Alaska: Cumulate fractionates of island-arc volcanics: Canadian Journal of Earth Science, v. 22, p. 1020-1038.

Childers, M., 1970, Flood frequency in Alaska: U.S. Geological Survey Open-File Report 70-63, 30 p.

Clark, S.H.B., 1972, The McHugh Complex of south-central Alaska: U.S. Geological Survey Bulletin 1372-D, p. D1-D11.

Clark, S.H.B., 1981, Guide to bedrock geology along the Seward Highway north of Turnagain Arm: Alaska Geological Society, Pub. no. 1, 36 p.

Combellick, R.A., 1984, Surficial-geologic map of the Seward D-6 quadrangle, Alaska: Alaska Division of Geological & Geophysical Surveys Report of Investigations 84-15, scale 1:63,360.

Combellick, R.A., 1993, The penultimate great earthquake in southcentral Alaska: Evidence from a buried forest near Girdwood, *in* Solie, D.N., and Tannian, Fran, eds., Short notes on Alaskan geology 1993: Alaska Division of Geological & Geophysical Surveys Professional Report 113, p. 7-15.

Combellick, R.A., 1994, Investigation of peat stratigraphy in tidal marshes along Cook Inlet, Alaska, to determine the frequency of 1964-style great earthquakes in the Anchorage region: Alaska Division of Geological & Geophysical Surveys Report of Investigations 94-7, 24 p.

Combellick, R.A., 1994, Investigation of peat stratigraphy in tidal marshes along Cook Inlet, Alaska, to determine the frequency of 1964-style earthquakes in the Anchorage area: Alaska Division of Geological & Geophysical Surveys Report of Investigations 94-7, 24 p.

Combellick, R.A., and Pinney, D.S., 1995, Radiocarbon age of probable Hayes tephra, Kenai Peninsula, Alaska, *in* Combellick, R.A., and Tannian, Fran, eds., Short Notes on Alaska Geology 1995: Alaska Division of Geological & Geophysical Surveys Professional Report 117, p. 1-9.

Combellick, R.A., and Reger, R.D., 1994, Sedimentological and radiocarbon-age data for tidal marshes along eastern and upper Cook Inlet, Alaska: Alaska Division of Geological & Geophysical Surveys Report of Investigations 94-6, 60 p.

Connelly, W., 1978, The Uyak Complex, Kodiak Islands, Alaska: A Cretaceous subduction complex: Geological Society of America Bulletin, v. 89, p. 755-769.

Cowan, D.S., and Boss, R.F., 1978, Tectonic framework of the southwestern Kenai Peninsula, Alaska: Geological Society of America Bulletin, v. 89, p. 155-158.

Crossen, K.J., 1992, Guide to the Little Ice Age landforms and glacial dynamics in Portage Valley and Portage Pass: Alaska Geological Society, 46 p.

DeMets, Charles, Gordon, Richard G., Argus, Donald F., Stein, Seth, 1994, Effect of recent revisions to the geomagnetic reversal time scale on estimates of current plate motions: Geophysical Research Letters, v. 21, p. 2191-2194.

'leisher, P.J., 986, Dead-ice sinks and moats: Environments of stagnant ice deposition: Geology, v. 4, no 1, p. 39-4

Flores, R.M., and Stricker, G.D., 1992, Some facies aspectsof the upper part of the Kenai Group, southern Kenai Peninsula, Alaska, in Bradley, D.C., and Dusel-Bacon, Cynthia, eds., Geologic studies in Alaska by the U.S. Geological Survey, 1991: U.S. Geological Survey Bulletin 2041, p. 160-170.

Goldfarb, R. J., Leach, D. L., Miller, M. L., and Pickthorn, W. J., 1986, Geology, metamorphic setting, and genetic constrains of epigenetic lode-gold mineralization within the Cretaceous Valdez Group, south-central Alaska, in Keppie, J. D. and others, eds., Turbidite-hosted gold deposits: Geological Association of Canada Special Paper 32, p. 87-105.

Haeussler, P.J., Bradley, Dwight, Golfarb, Richard, Snee, Lawrence, and Taylor, Clifford, 1995 ink between ridge subduction and gold mineralization in southern Alaska: Geology, v. 23, p. 995-998.

Haeussler, Peter J., and Bruhn, Ronald L., 1996, Evidence for Holocene or late Pleistocene folding in Cook Inlet, Alaska: EOS, v. 77, no. 46 p. F686.

Hayes, J.B., Harms, J.C., and Wilson, T.W., 1976, Contrasts between braided and meandering stream deposits, Beluga and Sterling Formations (Tertiary), Cook Inlet, Alaska, in Miller, T.P., ed., Recent and Ancient Sedimentary Environments in Alaska: Alaska Geological Society Symposium Proceedings, p. J1-J27.

Hill, M., Morris, J., and Whelan, J., 1981, Hybrid granodiorites intruding the accretionary prism, Kodiak, Shumagin, and Sanak Islands, southwest Alaska: Journal of Geophysical Research, v. 86, p. 10,569-10,590.

Hoekzema, R.B., 1985, Mineral Deposits and Mining History of the Kenai Peninsula Area, in: Guide to the Geology of the Kenai Peninsula, Alaska, A. Sisson, editor, Alaska Geologic Society guidebook, pp. 73-87.

Hoekzema, R.B., and S.F. Fechner, 1986, *Placer Gold sampling in and near the Chugach National Forest, Alaska:* U.S. Bureau of Mines Circular 9091, 42 p.

Hoekzema, Robert B., Fechner, Steven A., and Kurtak, Joseph M., 1987, Evaluation of selected lode gold deposits in the Chugach National Forest, Alaska: U.S. Bureau of Mines Information Circular 9113, 62 p.

Huber,C., J.M. Kurtak, and N. Rathbun, 1997, *A Guide to Recreational Gold Panning on the Kenai Peninsula, Chugach National Forest, Alaska:* U.S. Forest Service Special Publication, 26 p.

Hudson, Travis, 1983, Calc-alkaline plutonism along the Pacific rim of southern Alaska: Geological Society of America, Memoir 159, p. 159-169.

Kari, James, 1983, Kalifornsky, the Californian from Cook Inlet, *in* Antonson, M ed. Alaska perspective: Alaska Historical Commission, v. 5, no. 1, p. 1-9.

Karl, Susan, Decker, John, and Jones, David L., 1979, Early Cretaceous radiolarians from the McHugh Complex, south-central Alaska, in Johnson, K.M., and Williams, J.R., The USGS in Alaska: Accomplishments during 1978: USGS Circular 804-B, p.B88-B90.

Karlstrom, T.N.V., 1964, Quaternary geology of the Kenai lowland and glacial history of the Cook Inlet region, Alaska: U.S. Geological Survey Professional Paper 443, p. 69.

Karlstrom, T.N.V., 1964, Quaternary geology of the Kenai Lowland and glacial history of the Cook Inlet region, Alaska: U.S. Geological Survey Professional Paper 443, 69 p., 2 pls., 5 map sheets, scales 1:63,360, 1:250,000, 1:1,594,490, and 1:500,000.

Kelley, J.S., 1985, Geology of the southwestern tip of the Kenai Peninsula, Alaska: in Sisson, A., ed., Guide to the Geology of the Kenai Peninsula, Alaska, Alaska Geological Society Guidebook, p. 50-68.

Kelly, T.E., 1961, Photogeology—a quick, economical tool for oil hunters: The Oil and Gas Journal, November 20, 1961, p. 265-272.

Kelly, T.E., 1963, Geology and hydrocarbons in Cook Inlet basin, Alaska, in Backbone of the Americas: AAPG Memoir 2, p. 278-296.

Kienle, Jürgen, 1990, Augustine, Cook Inlet, Alaska, *in* Wood, C.A., and Kienle, Jürgen, eds., Volcanoes of North America: Cambridge, Cambridge University Press, p. 79-80.

Kirschner, C. E., and Lyon, C. A., 1973, Stratigraphic and tectonic development of Cook Inlet petroleum province, in Arctic Geology: AAPG Memoir 19, p. 396-407.

Kusky, T.M., Bradley, D.C., and Haeussler, P.J., 1997, Progressive deformation of the Chugach accretionary complex, Alaska, during a Paleogene ridge-trench encounter: Journal of Structural Geology, v. 19, p. 139-157.

Kusky, T.M., Bradley, D.C., Haeussler, P.J., Karl, S.M., and Donley, D.T., 1993, The Chugach Bay thrust, a major tectonic boundary in the southern Alaska accretionary prism [abs.]: Geological Society of America, Abstracts with Programs, v. 25, no. 6, p. A-282.

Little, T.A., and Naeser, C.W., 1989, Tertiary tectonics of the Border Ranges fault system, Chugach Mountains, Alaska: Deformation and uplift in a forearc setting: Journal of Geophysical Research, v. 94, p. 4333-4359.

Magoon, L.B., Adkison, W.L., and Egbert, R.M., 1976, Map showing geology, wildcat wells, Tertiary plant fossil localities, K-Ar age dates, and petroleum operations, Cook Inlet area, Alaska: U.S. Geological Survey Miscellaneous Investigations Series Map I-1019, scale 1:250,000.

Magoon, L.B., Adkison, W.L., and Egbert, R.M., 1976, Map showing geology, wildcat wells, Tertiary plant fossil localities, K-Ar dates, and petroleum operations, Cook Inlet area, Alaska: U.S. Geological Survey Miscellaneous Investigations Map I-1019, 3 sheets, scale 1:250,000.

Martin, G.C., Johnson, B.L., and Grant, U.S., 1915, Geology and Mineral Resources of Kenai Peninsula, Alaska, U.S. Geol. Surv. Bull., 587, 243 pp.

Moffit,F.H., 1907, *Mineral Resources of the Kenai Peninsula, Alaska-Gold Fields of the Turnagain Arm:* U.S. Geological Survey Bull. no. 277, pp. 7-52.

Nelson, S.W., and Blome, C.D., 1991, Preliminary geochemistry of volcanic rocks from the McHugh Complex and Kachemak terrane, southern Alaska: U.S. Geological Survey Open-File Report 91-134, 14 p.

Nelson, S.W., Blome, C.D., and Karl, S.M., 1987, Late Triassic and Early Cretaceous fossil ages from the McHugh Complex, southern Alaska, *in* Hamilton, T.D., and Galloway, J.P., eds., Geologic Studies in Alaska by the U.S. Geological Survey during 1986: U.S. Geological Survey Circular 998, p. 96-98.

Nelson, S.W., Blome, C.D., Harris, A.G., Reed, K.M., and Wilson, F.H., 1986, Late Paleozoic and Early Jurassic fossil ages from the McHugh Complex: *in* Bartsch-Winkler, S., and Reed, K.M., eds., Geologic Studies in Alaska by the U.S. Geological Survey during 1985: U.S. Geological Survey Circular 978, p. 60-64.

Nilsen, T.H., and Zuffa, G.G., 1982, The Chugach terrane, a Cretaceous trench-fill deposit, southern Alasl Geological Society of London, Special Publication 10, p. 213-227.

Ovenshine, A.T., Lawson, D.E., and Bartsch-Winkler, S.R., 1976, The Placer River Silt–An intertidal deposit caused by the 1964 Alaska earthquake: Journal of Research of the U.S. Geological Survey, v. 4, no. 2, p. 151-162.

Park, C.F., Jr., 1933, The Girdwood District, Alaska: U.S. Geological Survey Bulletin 849—G, p. 381-424, plate, scale 1:62,500.

Pavlis, T.L., and Sisson, V.B., 1995, Structural history of the Chugach metamorphic complex in the Tana River region, eastern Alaska: A record of Eocene ridge subduction: Geological Society of America Bulletin, v. 107, p. 1333-1355.

Plafker, George, Lajoie, K.R., and Rubin, Meyer, 1992, Determining recurrence intervals of great subduction zone earthquakes in southern Alaska by radiocarbon dating, *in* Taylor, R.E., Long, Austin, and Kra, R.S., eds., Radiocarbon after four decades: An interdisciplinary perspective: New York, Springer-Verlag, p. 436-452.

Post, Austin, and Mayo, L.R., 1972, Glacier dammed lakes and other outburst floods in Alaska: Geological Survey Hydrologic Investigations Atlas HA-455, 10 p., 3 sheets, scale 1:1,000,000.

Rawlinson, S.E., 1984, Environments of deposition, paleocurrents, and provenance of Tertiary deposits along Kachemak Bay, Kenai Peninsula, Alaska: Sedimentary Geology, v. 38, p. 421-442.

Rawlinson, S.E., 1986, Peat-resource and surficial-geologic map of the southern Kenai area, Kenai Peninsula, Alaska: Alaska Division of Geological & Geophysical Surveys Report of Investigations 86-15, 1 sheet, scale 1:31,680.

Reger, D.R., 1982, Preliminary archaeological investigations at the Clam Gulch Site, Cook Inlet, Alaska: Alaska Division of Geological and Geophysical Surveys, Open-File Report 172, 14p.

Reger, R.D., 1977, Photointerpretive map of the surficial geology of the southern Kenai lowlands, Alaska: Alaska Division of Geological & Geophysical Surveys Open-File Report 111A, 1 sheet, scale 1:63,360.

Reger, R.D., 1979, Bluff Point landslide, a massive ancient rock failure near Homer, Alaska, in Short Notes on Alaskan Geology: Alaska Division of Geological & Geophysical Surveys Geologic Report 61, p. 5-9.

Reger, R.D., and Carver, C.L., 1977, Photointerpretive map of the geologic materials of the southern Kenai lowlands, Alaska: Alaska Division of Geological & Geophysical Surveys Open-File Report 111B, 1 sheet, scale 1:63,360.

Reger, R.D., and Petrik, W.A., 1993, Surficial geology and late Pleistocene history of thge Anchor Point area, Alaska: Alaska Division of Geological & Geophysical Surveys Public-Data File 93-50b, 8 p., 1 sheet, scale 1:25,000.

Reger, R.D., and Pinney, D.S., 1996, Late Wisconsin glaciation of the Cook Inlet region with emphasis on Kenai Lowland and implications for early peopling, *in* Davis, N.Y., and Davis, W.E., eds. Adventures through time: Readings in the anthropology of Cook Inlet, Alaska: Anchorage, Cook Inlet Historical Society, p. 15-35.

Reger, R.D., and Updike, R.G., 1983, Upper Cook Inlet region and the Matanuska Valley, *in* Péwé, T.L., and Reger, R.D., eds., Guidebook to permafrost and Quaternary geology along the Richardson and Glenn Highways between Fairbanks and Anchorage, Alaska: Alaska Division of Geological & Geophysical Surveys Guidebook 1, p. 185-263, 1 sheet, scale 1:250,000.

Reger, R.D., Combellick, R.A., and Brigham-Grette, Julie, 1995, Update of latest Wisconsin events in the upper Cook Inlet region, southcentral Alaska, *in* Combellick, R.A., and Tannian, Fran, eds., Short Notes on Alaska Geology 1995: Alaska Division of Geological & Geophysical Surveys Professional Report 117, p. 33-45.

Reger, R.D., Combellick, R.A., and Brigham-Grette, Julie, 1995, Late-Wisconsin events in the upper Cook Inlet region, southcentral Alaska, *in* Combellick, R.A., and Tannian, Fran, Short notes on Alaska geology 1995: Alaska Division of Geological & Geophysical Surveys Professional Report 117, p.33-45.

Reger, R.D., Pinney, D.S., Burke, R.M., and Wiltse, M.A., 1996, Catalog and initial analyses of geologic data related to middle to late Quaternary deposits, Cook Inlet region, Alaska: Alaska Division of Geological & Geophysical Surveys Report of Investigations 95-6, 188 p., 5 sheets, scale 1:250,000.

Riehle, J.R., 1985, A reconnaissance of the major Holocene tephra deposits in the upper Cook Inlet region, Alaska: Journal of Volcanology and Geothermal Research, v. 26, no. 1-2, p. 37-74.

Riehle, J.R., Bowers, P.M., and Ager, T.A., 1990, The Hayes tephra deposits, an upper Holocene marker horizon in south-central Alaska: Quaternary Research, v. 33, no. 3, p. 276-290.

Riehle, J.R., Kienle, Jeurgen, and Emmel, K.S., 1981, Lahars in Crescent River valley, lower Cook Inlet, Alaska: Alaska Division of Geological & Geophysical Surveys Geologic Report 51, 10 p.

Schmoll, Henry R., Szabo, B. J., Rubin, Meger, and Dobrovolny, Ernest, 1972, Radiometric dating of marine shells from the Bootlegger Cove Clay, Anchorage area, Alaska: Geological Society of America Bulletin, v. 83, p. 1107-11.

Schmoll, Henry R., Yehle, Lynn A., Gardner, Cynthia A., and Odum, Jack K., 1984, Guide to surficial geology and glacial stratigraphy in the upper Cook Inlet basin: Alaska Geological Society, Anchorage, 89 p.

Scott, K.M., 1982, Erosion and sedimentation in the Kenai River, Alaska: U.S. Geological Survey Professional Paper 1235, 35 p.

Silberman, M.L., Mitchell, P.A., and O'Neil, J.R., 1981, Isotopic data bearing on the origin and age of the epithermal lode gold deposits in the Hope-Sunrise mining district, northern Kenai Peninsula, Alaska: U.S. Geological Survey Circular 823-B, p. B81-B84.

Sisson, V. B., Hollister, L. S., and Onstott, T. C., 1989, Petrologic and age constraints on the origin of a low-pressure/high-temperature metamorphic complex, southern Alaska: Journal of Geophysical Research, v. 94, p. 4392-4410.

Stevens, C.H., Davydov, V.I., and Bradley, D.C., 1997, Permian Tethyan fusilinids from the Kenai Peninsula, Alaska: Journal of Paleontology, 25 MS pp., 4 figs., 1 table, in press.

Triplehorn, D.M., Sisson, Alexander, Krameer, M.C., Reger, R.D., and Reger, D.R., 1985, Road Log -- Anchorage to Homer via the Seward and Sterling Highways, in Sisson, Alexander, ed., Guide to the Geology of the Kenai Peninsula, Alaska: Alaska Geological Society, p. 98-138.

Triplehorn, D.M., Turner, D.L., and Naeser, C.W., 1977, K-Ar and fission track dating of ash partings in Tertiary coals from the Kenai Peninsula, Alaska -- A radiometric age for the Homerian Clamgulchian stage boundary: Geological Society of America Bulletin,, v. 88, p. 1156-1160.

Tuck, R., 1933, The Moose Pass-Hope District, Kenai Peninsula, Alaska: U.S. Geological Survey Bull. 849-I pp. 469-530.

Turner, D.L., Triplehorn, D.M., and Naeser, C.W., 1980, Radiometric dating of ash partings in Alaskan coal beds and upper Tertiary botanical stages: Geology, v. 8, no. 2, p. 92-96.

Tysdal, R.G., 1976, A preliminary evaluation of selected earthquake-related geologic hazards in the Kenai Lowland, Alaska: U.S. Geological Survey Open-File Report 76-270, 30 p.

U.S. Army Corps of Engineers, 1967, Flood plain information, Kenai River, Kenai-Soldotna, Alaska, 12 p.

U.S. Army Corps of Engineers, 1973, Flood plain information, Kenai River, phase Kenai Peninsula Borough, Alaska: 25 p.

U.S. Army Corps of Engineers, 1975, Flood plain information, Kenai River, phase II, Kenai Peninsula Borough, Alaska: 25 p.

Updike, R.G., and Ulery, C. A., 1986, Engineering-geologic map of southwest Anchorage, Alaska: Alaska Division of Geological and Geophysical Surveys Professional Report 89, 1 plate, scale 1:15,840.

Utermohle, G.E., Jr., and Munson, R.J., 1972, Foundation report, Kenai River crossing at Kenai (Bridge No. 1149), Project No. S-0463(10): Alaska Department of Highways Engineering Geology Section Engineering Geology & Foundation report, 17 p.

Walsh, T.J., Combellick, R.A., and Black, G.L., 1995, Liquefaction features from a subduction zone earthquake: Preserved examples form the 1964 Alaska earthquake: Washington Division of Geology and Earth Resources Report of Investigations 32, 80 p.

Walsh, T.J., Combellick, R.A., and Black, G.L., 1995, Liquefaction features from a subduction zone earthquake: Preserved examples from the 1964 Alaska earthquake: Washington Division of Geology and Earth Resources Report of Investigations 32, 80 p.

Wiles, G.C., and Calkin, P.E., 1994, Late Holocene, high-resolution glacial chronologies and climate, Kenai Mountains, Alaska: Geological Society of America Bulletin, v. 106, no. 2, p. 281-303.

Winkler, G.R., M.L. Miller, R.B. Hoekzema, and J.A. Dumoulin, 1984, Guide to the Bedrock Geology of a Traverse of the Chugach Mountains from Anchorage to Cape Resurrection, Alaska Geologic Society, 40 p.

Winkler, G.R., Miller, M.L., Hoekzema, R.B., and Dumoulin, J.A., 1984, Guide to the bedrock geology of a traverse of the Chugach Mountains from Anchorage to Cape Resurrection: Alaska Geological Society, 40 p.

Winkler, G.R., Silberman, M.L., Grantz, A., Miller, R.L., and MacKevett, E.M., Jr., 1981, Geologic map and summary geochronology of the Valdez quadrangle, southern Alaska: U.S. Geological Survey Open-File Report 80-892-A, 2 sheets, scale 1:250,000.

Wolfe, J.A., Hopkins, D.M., and Leopold, E.B., 1966, Tertiary stratigraphy and paleobotany of the Cook Inlet region, Alaska: U.S. Geological Survey Professional Paper 398-A, p. A1-A29.

Yount, M.E., 1990, Redoubt, Cook Inlet, Alaska, *in* Wood, C.A., and Kienle, Jürgen, eds., Volcanoes of North America: Cambridge, Cambridge University Press, p. 81-82.Barry, M., 1973, A History of Mining on the Kenai Peninsula: Alaska Northwest Publishing Co., 214 p.