GEOLOGICAL SURVEY RESEARCH 1972

Chapter D

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CONTENTS

GEOLOGIC STUDIES

HYDROLOGIC STUDIES

Limnology

Quality of water

Relation between ground water and surface water

Hydrologic techniques

INDEXES

GEOLOGICAL SURVEY RESEARCH 1972

This collection of 30 short papers is the third published chapter of "Geological Survey Research 1972." The papers report on scientific and economic results of current work by members of the Geologic and Water Resources Divisions of the U.S. Geological Survey.

Chapter A, to be published later in the year, will present a summary of significant results of work done in fiscal year 1972, together with lists of investigations in progress, cooperating agencies, and Geological Survey offices.

"Geological Survey Research 1972" is the thirteenth and last volume of the annual series Geological Survey Research. The short-papers chapters (B, C, and D) will be replaced in 1973 by the "Journal of Research of the U.S. Geological Survey," and the summary chapter (A) will be published as a separate professional paper. The twelve volumes already published are listed below, with their series designations.

Geological Survey Research	*Prof. Paper*
1960	400
1961	424
1962	450
1963	475
1964	501
1965	525
1966	550
1967	575
1968	600
1969	650
1970	700
1971	750

GRAVINA-NUTZOTIN BELT—TECTONIC SIGNIFICANCE OF AN UPPER MESOZOIC SEDIMENTARY AND VOLCANIC SEQUENCE IN SOUTHERN AND SOUTHEASTERN ALASKA

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Abstract.—Rocks of the Gravina-Nutzotin belt in southern and southeastern Alaska consist dominantly of marine flyschlike argillite and graywacke, minor nonmarine strata, and interbedded andesitic volcanic rocks. Fossils from the belt range in age from Late Jurassic (Oxfordian) to late Early Cretaceous (Albian), although some may be as old as Bajocian. The volcanic rocks comprise thick lenses that intertongue with and overlie both the oldest and youngest sedimentary beds known in the belt. Gravina-Nutzotin strata depositionally overlie upper Paleozoic and Triassic rocks (Taku-Skolai terrane) in the northwestern and central parts of the belt, and lower Paleozoic to Triassic rocks (Alexander terrane) in the central and southeastern parts. They are in fault contact with metamorphosed Paleozoic rocks (Yukon terrane) along the Denali fault. Rocks in the northern part of the belt are moderately deformed and relatively unmetamorphosed. In the southeastern part they are intensely folded and regionally metamorphosed, and probably overthrust by older rocks of the Taku-Skolai terrane. Upper Mesozoic and Cenozoic granitic plutons and zoned ultramafic complexes have intruded the belt and adjacent terranes. The Gravina-Nutzotin belt is part of a deformed upper Mesozoic magmatic arc. In southern Alaska, partly coeval shallow-marine (Matanuska-Wrangell terrane) and deep-marine (younger Chugach terrane) sedimentary rocks may correspond respectively to an arc-trench gap assemblage formed on the continental shelf and slope and an oceanic trench assemblage formed at the continental margin. The relatively strong deformation of the Gravina-Nutzotin belt in southeastern Alaska may be the result of northeastward movement of the Alexander terrane, a displaced fragment of older continental crust.

A narrow belt of Middle(?) Jurassic to middle-Cretaceous sedimentary and volcanic rocks extends almost continuously from southeastern Alaska to the eastern Alaska Range, a distance of over 700 miles. This belt, herein called the Gravina-Nutzotin belt after geographic features at its presently known extremities, comprises a thick prism of flyschlike sedimentary rocks, subordinate andesitic volcanic and volcaniclastic rocks, and minor granitic and ultramafic rocks. Rocks throughout the belt are moderately to intensely deformed and, in the southeastern part, metamorphosed in the greenschist facies.

The existence of this belt in southeastern Alaska has long been known (Buddington and Chapin, 1929; Brew and others, 1966), but its continuation across the Chatham Strait fault through the southwest corner of Yukon Territory and into the eastern Alaska Range hitherto has not been recognized. The near continuity of this belt from southeastern Alaska to the Alaska Range thus is highly important in linking the geologic history of these large areas that had previously been treated as separate geologic provinces.

This report describes the sedimentary and volcanic rocks of the Gravina-Nutzotin belt in several places in order to document their gross similarity throughout the belt, compares these rocks with two other upper Mesozoic terranes of coeval, but dissimilar, bedded rocks in nearby parts of southern and southeastern Alaska, and, finally, speculates on the origin and relations of these three sequences in terms of plate-tectonic theory.

During our analysis of the late Mesozoic history of this region, it became apparent that great differences exist in the character and age of basement rocks that underlie or abut the Gravina-Nutzotin belt. In order to express these differences more clearly, we have found it useful to organize these rocks into discrete tectonic units. In the first part of this report, we summarize the salient features of these subjacent terranes and speculate briefly on their origin; in the second part, we consider their significance in the evolution of the three upper Mesozoic superjacent terranes.

This report is a direct outgrowth of a reconnaissance by Berg and Jones in 1971 of Mesozoic and upper Paleozoic rocks from Ketchikan to Juneau and also draws on detailed work by Berg in the Ketchikan area, by A. B. Ford and D. A. Brew in the Juneau area, by E. M. MacKevett, Jr., and G. D. Robinson near Haines, and by Richter and Jones in the eastern Alaska Range.

SUBJACENT TERRANES

Upper Mesozoic rocks of the Gravina-Nutzotin belt were deposited on two different basement terranes and are in fault contact with a third terrane. Those in depositional contact are herein informally designated the Taku-Skolai terrane and the Alexander terrane. The third is called the Yukon terrane. Distribution of these terranes is shown on figure 1.

Taku-Skolai terrane.—Upper Paleozoic (mainly Permian) andesitic and minor basaltic volcanic and volcaniclastic rocks are the oldest known in the Taku-Skolai terrane. They have been extensively studied by Richter (1971a, 1971b, and unpub. data) in the eastern Alaska Range and by Smith and MacKevett (1970) in the adjoining Wrangell Mountains. These volcanic rocks are associated with abundant mafic and alpine-type ultramafic rocks in the central Alaska Range (Clark and others, 1972) and in the Kluane Ranges in Canada (Muller, 1967) and have been interpreted by Richter and Jones (1972b) as vestiges of an upper Paleozoic island arc formed directly on oceanic crust.

Overlying the Permian volcanic rocks is a thick sequence of Permian sedimentary rocks and Triassic volcanic and sedimentary (mainly calcareous) rocks (MacKevett, 1970, 1971; Richter, 1971a, 1971b). Similar rocks crop out to the southeast near Kluane Lake (Muller, 1967) and Dezadeash Lake (Kindle, 1953), and they probably occur in the Squaw Creek—Rainy Hollow area (Watson, 1948).

Distribution and character of the Taku-Skolai terrane in southeastern Alaska are poorly known. The presence there of this terrane is substantiated by Permian and Triassic fossils associated with volcanic rocks, argillite, and marble in a number of localities (fig. 1) along the eastern margin of the Gravina-Nutzotin belt. Throughout much of this region, however, intense deformation and metamorphism have obliterated the preorogenic history.

Metamorphosed bedded and intrusive rocks of late(?) Paleozoic or early Mesozoic age on southern Duke, Annette, and Gravina Islands in southeastern Alaska (figs. 1 and 2) are provisionally assigned to the Taku-Skolai terrane because they are grossly similar in lithology to other rocks of this terrane. The Gravina Island occurrence is too small to show on figure 1.

A depositional contact between Gravina-Nutzotin rocks and the Taku-Skolai terrane can be observed in the northwest part of the belt (Richter and Schmoll, 1972) but cannot be demonstrated in the southeast part where Late Cretaceous or Cenozoic deformation has emplaced older rocks on top of Gravina-Nutzotin rocks in what may be an eastward-dipping thrust zone (fig. 1).

Alexander terrane.—The Alexander terrane, well exposed throughout the Alexander Archipelago of southeastern Alaska, comprises an extremely heterogeneous assemblage of sedimentary, volcanic, and metamorphic rocks ranging in age from Ordovician, or older, to Late Triassic. It contains granitic plutons at least as old as Silurian, indicating that it was by then a terrane of continental crust. It is also intruded by numerous other granitic bodies of Paleozoic, Mesozoic, and Cenozoic age (Lanphere and others, 1965; Loney and others, 1967), and near its southern terminus, by ultramafic plutons of Silurian and Ordovician age (M. A. Lanphere, oral commun., 1971).

In many places rocks of the Alexander terrane are gently folded and only slightly metamorphosed. Locally, however, they are complexly folded and have undergone at least two periods of metamorphism, one of which is probably of early Paleozoic age (A. L. Clark and G. D. Eberlein, oral commun., 1971). Structure of the terrane is still poorly known and is undoubtedly complex. On southern Prince of Wales and Dall Islands, and probably elsewhere in the terrane, juxtaposition of roughly coeval bedded rocks of contrasting structure and metamorphic grade may be due to large-scale thrust faulting (Berg, 1972b).

The oldest fossiliferous rocks in the Alexander terrane are Lower Ordovician graptolitic chert and shale exposed on western Prince of Wales and nearby islands (Eberlein and Churkin, 1970). These beds, whose base has not been seen, are in the lowermost part of a well-preserved, nearly continuous sequence of Ordovician to Pennsylvanian marine sedimentary and volcanic rocks at least 35,000 feet thick. Partly correlative rocks have also been mapped on Kuiu and Kupreanof (Muffler, 1967), Annette and Gravina (Berg, 1972a,c), Chichagof (Loney and others, 1963), and Admiralty (Lathram and others, 1965) Islands, in the Chilkat Mountains (Lathram and others, 1959), and in the St. Elias Mountains in Yukon Territory (Muller, 1967).

On Kuiu, Kupreanof, and southern Admiralty Islands, Permian marine sedimentary and minor volcanic rocks depositionally overlie lower and middle Paleozoic rocks and in turn are unconformably overlain by Upper Triassic marine strata, the youngest bedded rocks assigned to the Alexander terrane.

Upper Mesozoic sedimentary rocks of the Gravina-Nutzotin belt in unconformable contact with Paleozoic and lower Mesozoic rocks of the Alexander terrane have been observed in several places along the present western margin of the belt in southeastern Alaska, and in the St. Elias Mountains west of Dezadeash Lake in Yukon Territory (Kindle, 1953). Although several workers (Monger and Ross, 1972; Jones and others, 1972; Monger and others, 1972) have proposed that rocks of the Alexander terrane are allochthonous, the deposition of Gravina-Nutzotin belt rocks by this terrane establishes that it was contiguous to the belt by late Mesozoic time.

Yukon terrane.—The region north of the Denali fault is underlain by phyllite, quartz-mica schist, marble, and other metasedimentary and metavolcanic rocks. Upper Mesozoic and lower Tertiary granitic rocks locally are abundant. These poorly known rocks have been called the Yukon Complex in Canada. Greenschist-facies metamorphism prevails in south-central Alaska and adjoining Yukon Territory, and in Alaska the rocks may grade northward into the higher grade rocks formerly called the Birch Creek Schist (now abandoned).

Paleontological evidence for the age of much of the Yukon terrane is scant. Tabulate and rugose corals (*Cladopora*, *Favosites*, *Thamnopora*, *Acanthophyllum*) collected from rocks in the eastern Alaska Range indicate that some are of Devonian age (Richter, unpub. data), and Muller (1967, p. 24) suggests that some may be pre-Ordovician. The time of regional metamorphism is also poorly known, although several episodes seem likely (Muller, 1967, p. 25). Mesozoic potassium-argon ages cited by Muller probably record only the latest period of intense deformation.

Upper Mesozoic rocks of the Gravina-Nutzotin belt are nowhere in depositional contact with rocks of the Yukon terrane, although the presence of Yukon terrane detritus in Gravina-Nutzotin conglomerate (p. D9, this report) indicates that the belt may originally have overlapped the terrane. In the eastern Alaska Range and in the Kluane Ranges, they are in fault contact along the Denali fault.

SUPERJACENT TERRANES

The Gravina-Nutzotin belt is distinct from two other belts of upper Mesozoic bedded rocks in southern and southeastern Alaska, which are herein informally called the Matanuska-Wrangell terrane and the Chugach terrane. After describing the Gravina-Nutzotin rocks, we compare the lithology and geologic histories of these three coeval sequences.

Gravina-Nutzotin Belt

The Gravina-Nutzotin belt comprises a distinctive suite of rocks distributed in a narrow, linear, nearly continuous inland belt that parallels the Pacific coast in southeastern Alaska, but which diverges from the arcuate coast near long 140° W. The southern part of the belt is less than 100 miles from the edge of the continental shelf, whereas the northern part is over 200 miles distant from it. The western boundary of the belt is an erosional edge complicated in places by faults that separate it from Alexander and Taku-Skolai terrane basement rocks. The eastern boundary in south-central Alaska, Yukon, and British Columbia is the Denali and related faults. In southeastern Alaska, we arbitrarily place the eastern boundary between phyllite and greenstone lithically akin to the less metamorphosed Gravina-Nutzotin belt rocks, and mica schist, amphibolite, and marble, some of which are known to be of late Paleozoic and early Mesozoic age. These older rocks appear to overlie structurally the younger Gravina-Nutzotin rocks, and we presume that major imbricate thrust faulting has produced the inverted sequence. Other geologists, however, have postulated that this relation is due to a large overturned synclinorium (Chapin, 1918, p. 87; Buddington and Chapin, 1929, p. 240), but the strikingly different nature of the eastern (Taku-Skolai terrane) and western (Alexander terrane) "limbs" does not support this hypothesis.

DESCRIPTIONS OF SELECTED AREAS

Ketchikan area

The Gravina-Nutzotin belt has been recognized in Alaska as far south as the United States–Canada boundary (fig. 1). Metamorphosed Jurassic(?) sedimentary and volcanic rocks near Prince Rupert (Hutchison, 1967) may represent a southward continuation of the belt.

Gravina-Nutzotin belt rocks near Ketchikan (figs. 1 and 2; Berg, 1972a, c) consist mainly of two structurally juxtaposed sequences of roughly coeval bedded rocks—the Gravina Island Formation and an unnamed unit—that differ in lithology, depositional environment, metamorphism, and structure.

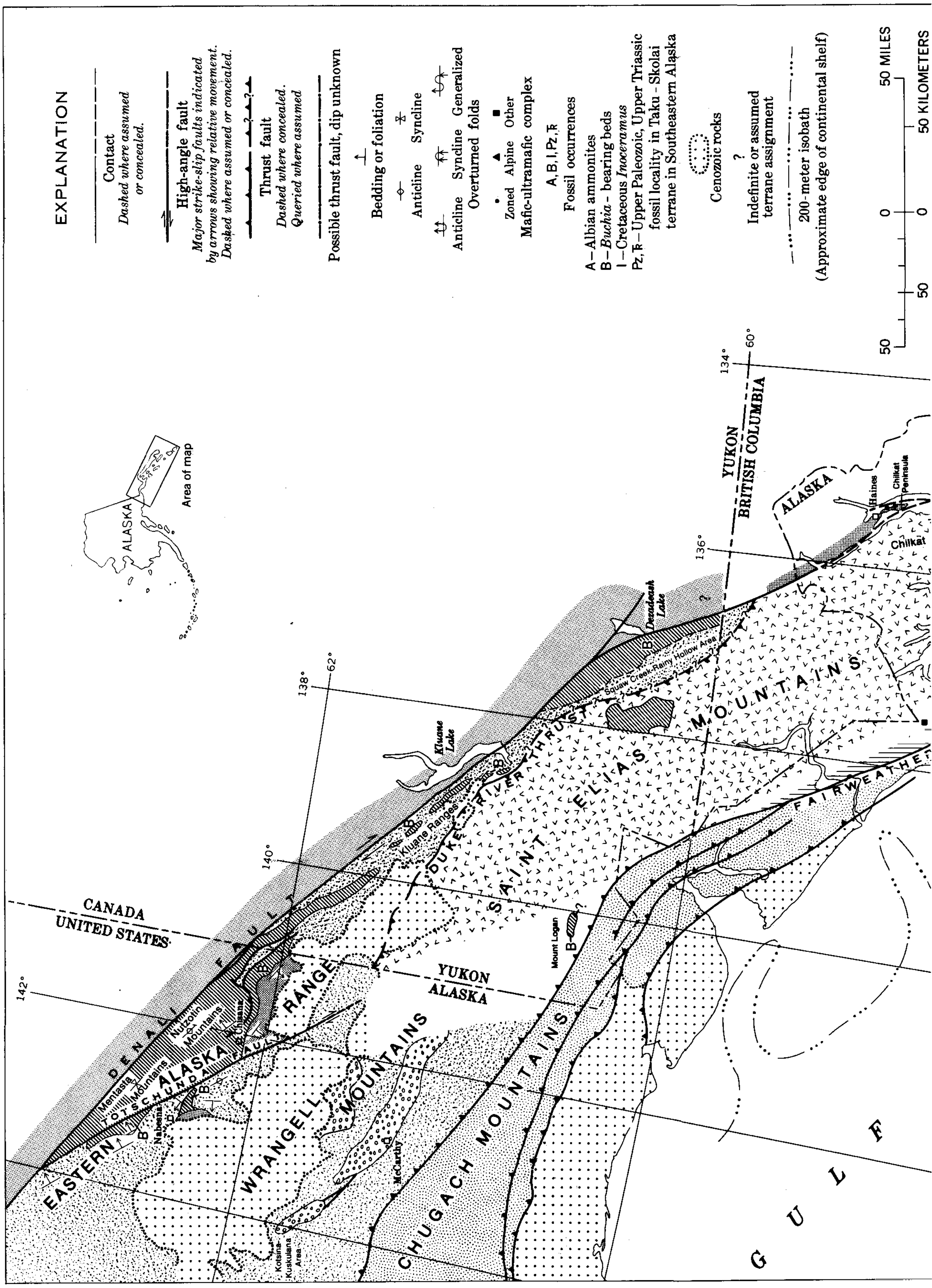
Gravina Island Formation.—This widespread bedded unit consists of andesitic metavolcanic rocks and flyschlike metasedimentary rocks. They are highly deformed, commonly phyllitic, and metamorphosed to greenschist facies. Complex folds with gently eastward-dipping axial surfaces are prevalent. Neither the base nor top of this formation has been observed.

On eastern Gravina and northeastern Annette Islands, at least 2,000 feet of fragmental metaandesite overlies and locally intertongues with dark-gray argillite and phyllitic siltstone, graywacke, and conglomerate. Fossils (*Cylindroteuthis* sp. and *Entolium* sp.) are locally abundant in siltstone beds; *Buchia* is conspicuously absent. A late Middle or early Late Jurassic age seems possible for this assemblage.

The metavolcanic rocks range from thinly laminated phyllite to thick competent beds with crude, indistinct schistosity. Most consist of green and gray porphyritic metatuff and agglomerate containing euhedral phenocrysts of light-gray plagioclase and dark-greenish-black clinopyroxene. The groundmass is fine grained and contains clinopyroxene, amphibole, epidote-clinozoisite, chlorite, albite, quartz, muscovite, prehnite, and calcite. The clinopyroxene commonly is altered to hornblende and pale-green amphibole, and the plagioclase to fine-grained albite and clinozoisite. The abundance and relative proportions of phenocrysts vary markedly; typically, they make up 10 to 15 percent of the rock.

Unnamed unit.—An unnamed bedded unit, known in the Ketchikan area only on western Gravina Island, consists of *Buchia*-bearing siltstone, argillite, and conglomerate of Late Jurassic age. In contrast to the Gravina Island Formation, this unit is characterized by relatively simple folds, slaty cleavage, and only slight metamorphism. It unconformably overlies older Mesozoic and Paleozoic rocks of the Alexander terrane; its top has not been observed.

The lower part of the unit is an elongate lens of conglomerate as much as 350 feet thick; the upper part comprises at least 500 feet of thinly interbedded, locally fossiliferous siltstone and argillite, and subordinate limestone, grit, and pebbly to cobbly mudstone. Clasts in the conglomerate were derived mainly from underlying Mesozoic and Paleozoic rocks on western Gravina Island. The strong contrast of this unit with the nearby Gravina Island Formation indicates large-scale



EXPLANATION
Contact
Dashed where assumed or concealed.
High-angle fault
Major strike-slip faults indicated by arrows showing relative movement. Dashed where assumed or concealed.
Thrust fault
Dashed where concealed. Queried where assumed
Possible thrust fault, dip unknown
Bedding or foliation
Anticline Syncline
Anticline Syncline Generalized Overturned folds
Zoned Alpine Other
Mafic-ultramafic complex
A, B, I, Pz, Ŧ
Fossil occurrences
A—Albian ammonites
B—Buchia-bearing beds
I—Cretaceous Inoceramus
Pz, Ŧ—Upper Paleozoic, Upper Triassic fossil locality in Taku-Skolai terrane in Southeastern Alaska
Cenozoic rocks
Indefinite or assumed terrane assignment
200-meter isobath
(Approximate edge of continental shelf)
50 MILES
50 KILOMETERS
ALASKA
Area of map
CANADA
UNITED STATES
YUKON
ALASKA
YUKON
BRITISH COLUMBIA
DENALI FAULT
EASTERN
ALASKA
RANGE
TOTSCHUNDA FAULT
Mentasta Mountains
Nutzotin Mountains
Nabesna
WRANGELL MOUNTAINS
CHUGACH MOUNTAINS
SAINT ELIAS MOUNTAINS
DUKE RIVER THRUST
FAIRWEATHER
Kluane Lake
Kluane Ranges
Dezadeash Lake
Squaw Creek-Rainy Hollow Area
Mount Logan
McCarthy
Kotsina-Kuskulana Area
Haines
Chilkat Peninsula
Chilkat
GULF
142°
140°
138°
136°
134°
62°
60°

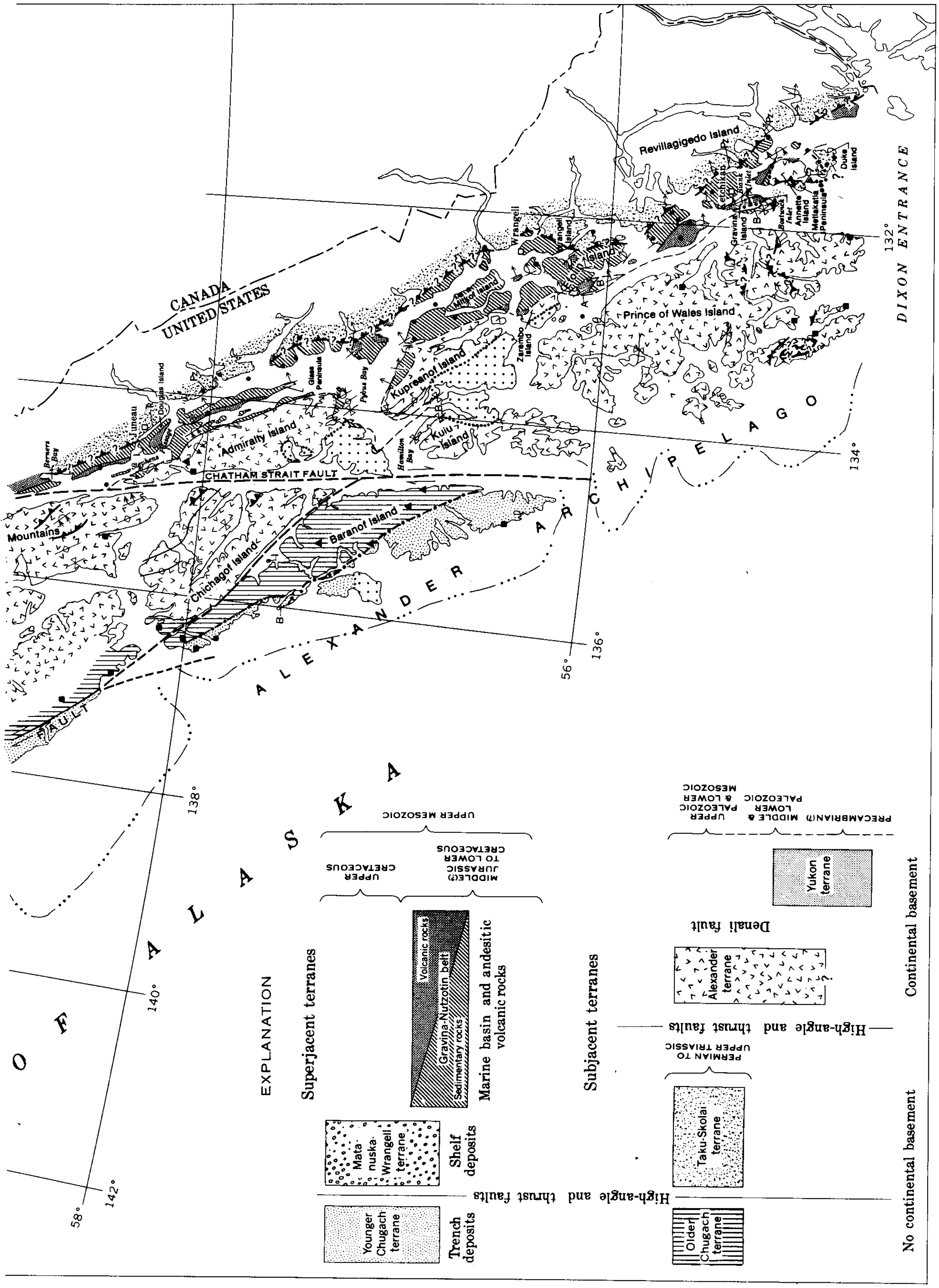


Figure 1.—Generalized geologic map of southern and southeastern Alaska, showing Gravina-Nutzotin belt and other superjacent terranes, subjacent terranes, and selected structural features and granitic intrusive rocks. Compiled in part from Buddington and Chapin (1929), Brew and others (1966), Kindle (1953), Muller (1967), and Taylor and Noble (1969).

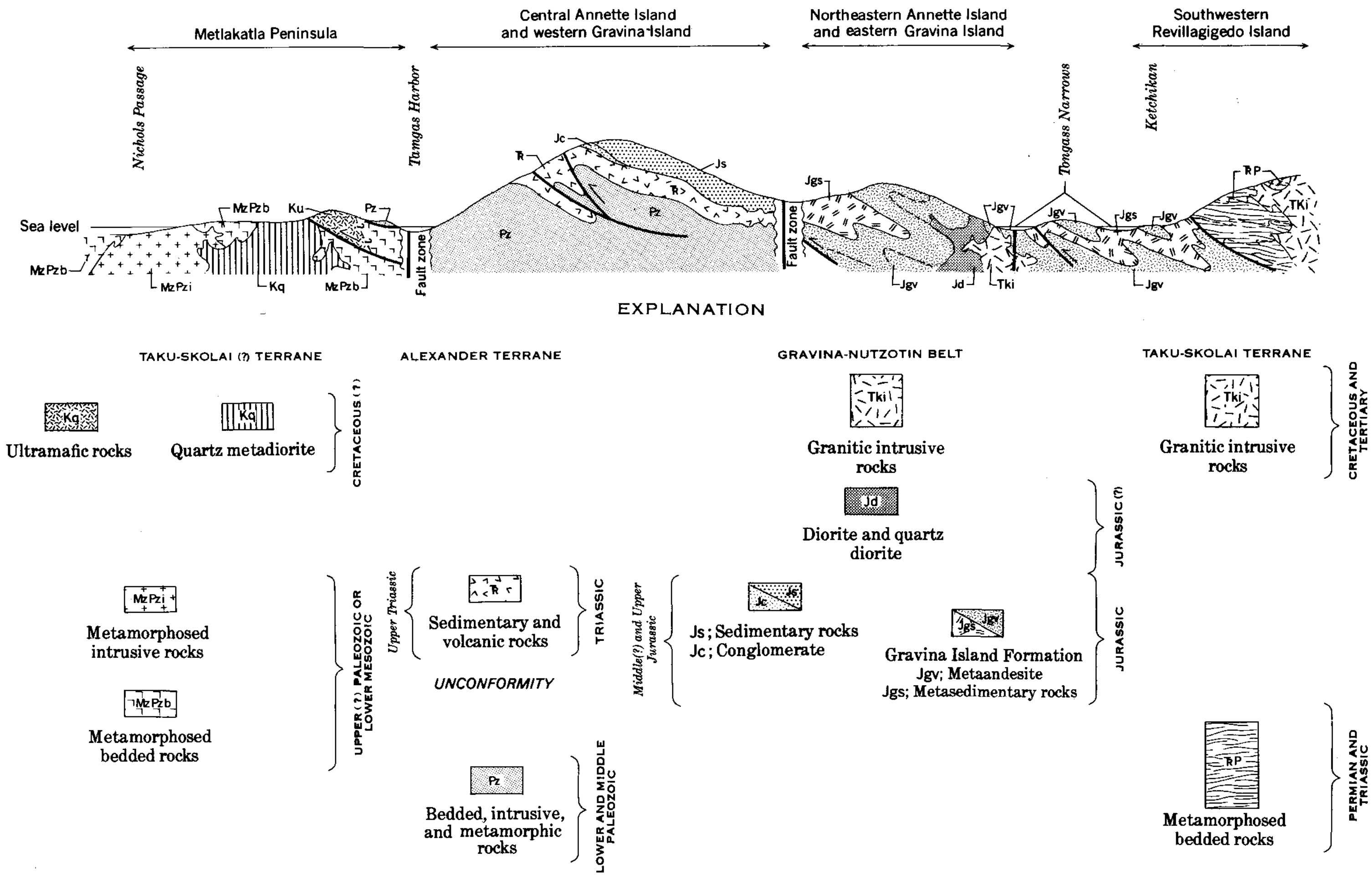


Figure 2.— Diagrammatic composite section of Ketchikan and Annette-Gravina areas, showing inferred structural and stratigraphic relations within the Gravina-Nutzotin belt and between the belt and subjacent terranes. Length of section about 25 miles; otherwise not to scale. Queried contact may be intrusive or a fault.

internal structural juxtaposition within the Gravina-Nutzotin belt.

Etolin-Kupreanof area

Upper Mesozoic bedded rocks assigned to the Gravina-Nutzotin belt crop out on Etolin and Kupreanof Islands, and on several smaller intervening islands.

On western Etolin Island, these rocks are folded and faulted, but only slightly recrystallized; primary sedimentary and volcanic textures are well preserved. The sedimentary beds commonly have pronounced slaty cleavage, whereas competent volcanic units are massive and jointed. The youngest bedded rocks known anywhere in the belt are on Marsh Island, just off the coast of westernmost Etolin Island, where about a 50-foot-thick section of thinly interbedded argillite, siltstone, volcanogenic sandstone, and andesite tuff contains scattered ammonites of early Albian age.

The tuff typically is a mottled green fragmental rock containing angular to subrounded clasts of clinopyroxene and plagioclase (An_{11-30}) porphyry and minor black argillite in a matrix of minute porphyritic fragments, individual clinopyroxene and feldspar crystals, hydrothermal alteration products, and locally a little very finely disseminated potassium feldspar. The porphyry clasts average less than 1 foot in maximum dimension; bedding ranges from less than 1 inch to 6 to 8 feet.

The Albian beds grade downward into *Buchia*-bearing siltstone, argillite, and minor conglomerate and limestone of Late Jurassic and Early Cretaceous age and upward into a very thick unit of andesitic crystallithic tuff, flows, and volcaniclastic rocks with minor argillite and graywacke lenses. Neither the base nor top of this sequence has been observed, nor is its thickness known.

Central and eastern Etolin Island, and Woronkofski, Wrangell, and eastern Zarembo, Mitkof, and Kupreanof Islands are composed mostly of granitic plutons (Buddington and Chapin, 1929, pl. 1), but also present are small tracts of unfossiliferous phyllite, graywacke semischist, greenschist, and greenstone (primarily metaandesite), which we assume from their lithology to be regionally metamorphosed equivalents of at least part of the western Etolin section. Near some plutons, these rocks are thermally metamorphosed to schist and hornfels locally containing garnet, andalusite, and staurolite. The bedded rocks are complexly deformed, most commonly into isoclinal overturned to recumbent folds with gently eastward-dipping axial surfaces.

Fossiliferous, thin-bedded lithic sandstone and mudstone of Early Cretaceous age near Hamilton Bay on northwestern Kupreanof Island (Muffler, 1967, p. C44–C45) disconformably overlie Upper Triassic strata. These rocks, about 1,000 feet thick, are simply folded, locally slaty, and, near the contact of a Tertiary gabbro pluton, converted to hornfels. They lack the flyschlike character of most of the Gravina-Nutzotin rocks, and we interpret them to be shallow-water marginal deposits.

Unfossiliferous, complexly folded, and dynamically metamorphosed graywacke, argillite, and conglomerate crop out on the coast of north-central Kupreanof Island. Although these rocks may be partly coeval with the beds near Hamilton Bay, they differ from them in lithology, structure, and metamorphism and instead resemble the Seymour Canal Formation of Admiralty Island (Muffler, 1967, p. C44; Loney, 1964, p. 55–69; Lathram and others, 1965, p. R22–R27). Contacts between these rocks and Alexander terrane rocks on northern Kupreanof Island are obscured by faults, but we infer original depositional relations from the presence of conglomerate clasts derived from middle and lower Paleozoic rocks nearby on Kupreanof and Kuiu Islands.

Admiralty Island

Upper Mesozoic strata on Admiralty Island include a lower unit of flyschlike sedimentary rocks and an upper unit of augite-bearing volcanic flow-breccia and tuff, with minor graywacke and slate. The entire assemblage (see table 1) constitutes the Stephens Passage Group (Lathram and others, 1965, p. R22), including the predominantly sedimentary Seymour Canal Formation (Loney, 1964, p. 55) and two overlying formations, the Douglas Island Volcanics (Lathram and others, 1965, p. R23; Barker, 1957) and Brothers Volcanics (Loney, 1964, p. 69).

The Seymour Canal Formation has two phases that differ in structure and metamorphism. The less-deformed phase is mainly near Pybus Bay on southeastern Admiralty Island and comprises fossiliferous (*Buchia*-bearing) argillite, graywacke, and conglomerate. It is faulted and complexly folded, but relatively unmetamorphosed.

The more deformed phase, on eastern Admiralty Island, is unfossiliferous slate, phyllite, and semi-schistose siltstone, graywacke, and conglomerate. The beds are regionally deformed into tight to isoclinal northwest-trending folds with both eastward- and westward-dipping axial surfaces.

The Seymour Canal Formation conformably underlies the Douglas Island and Brothers Volcanics. It disconformably overlies Upper Triassic strata near Pybus Bay, but its stratigraphic relations to older Mesozoic and Paleozoic formations elsewhere on the island are obscured by faulting. Loney (1964, p. 57) estimated 4,000 to 8,000 feet of Seymour Canal strata in the Pybus Bay area, and Lathram and others (1965, p. R26) report an approximately 3,500-foot-thick lens of conglomerate in the formation on northern Admiralty Island.

The Douglas Island Volcanics, mapped mainly on Glass Peninsula, consists mostly of dark-green andesitic flow breccia and tuff containing conspicuous augite and subordinate hornblende crystals as much as ½-inch in diameter. Near the base, the volcanic rocks intertongue with slate and graywacke, which also occur sporadically throughout the formation. Bedding commonly is thick and massive without conspicuous layering or foliation, but on eastern Glass Peninsula the rocks are schistose. The top of the formation has not been observed.

The Brothers Volcanics occurs only on islands near Pybus Bay and consists of at least 2,000 feet of well-bedded, dark-hued andesitic flows, breccia, and minor volcanogenic sedimentary rocks. According to Loney (1964, p. 71–72), the andesite typically is porphyritic, with phenocrysts of plagioclase (An_{25-48}), clinopyroxene, and hornblende set in a very fine grained groundmass of plagioclase, chlorite, calcite, and opaque minerals. The rocks are folded and only slightly altered, with locally well developed fracture cleavage, and thus are structurally like the less deformed phase of the Seymour Canal Formation.

Fossils have not been found in either of these volcanic units; Loney (1964, p. 71) and Lathram and others (1965, p. R28) assigned both formations a Jurassic and Cretaceous age mainly because they conformably overlie and also appear to intertongue laterally with the Seymour Canal Formation.

Juneau area

Upper Mesozoic bedded rocks similar to those on Admiralty Island are widespread on the islands and mainland west and north of Juneau. They crop out in a wedge-shaped belt along the east side of Lynn Canal from Stephens Passage to beyond Berners Bay. The belt, nearly 10 miles wide near Juneau, narrows northwestward, where it is encroached by granitic intrusive rocks.

As on Admiralty Island, the Gravina-Nutzotin belt near Juneau consists of an upper unit principally of volcanic rocks and a lower unit mainly of sedimentary rocks. The rocks are moderately to strongly deformed and variably recrystallized in the greenschist facies. Structure of the belt is still poorly known, and undoubtedly there is tectonic repetition of some units. This deformation, coupled with regional metamorphism, has obscured original stratigraphic relations, not only internally but also between the belt and the adjoining mostly higher rank and probably older metamorphic rocks to the east. Metamorphic grade increases eastward through a typically Barrovian metamorphic zonal sequence from biotite through sillimanite isograds (Forbes, 1959) between Juneau and the western margin of the Coast Range batholithic complex. The biotite isograd generally is about 1 to 2 miles east of Douglas Island (D. A. Brew and A. B. Ford, unpub. data), and the belt near Juneau thus is entirely within the chlorite zone.

Permian and Triassic rocks structurally overlie the Gravina-Nutzotin rocks, but the actual contact, which may be a thrust fault, has not been observed. Fossils of Permian and late Triassic age (Buddington and Chapin, 1929, p. 119; Martin, 1926, p. 94) occur locally in the rocks adjoining the batholithic complex, but the extent of these older rocks is largely unknown. Because both the younger and older rocks are poorly fossiliferous and are grossly similar in lithology, they cannot be readily discriminated, particularly in the more metamorphosed areas. Hence, the boundary between the Gravina-Nutzotin belt and the Taku-Skolai terrane is arbitrarily placed at the easternmost known occurrences of Jurassic or Cretaceous rocks.

A number of formal rock-stratigraphic names have been applied to Gravina-Nutzotin belt rocks of the Juneau area, some of which are conflicting or duplicative (see table 1). The metasedimentary rocks underlying and locally intertonguing with the Douglas Island Volcanics (Martin, 1926; Lathram and others, 1965) are probably correlative with parts or all of the Berners Formation of Knopf (1911), the Treadwell Slate of Martin (1926), the Symonds and Shelter Formations of Barker (1957), and the Seymour Canal Formation as used by Lathram and others (1965).

The Douglas Island Volcanics near Juneau comprises a thick pile of greenstone, mostly of fragmental volcanic origin, interlayered in places with varied volcaniclastic metasedimentary rocks. The greenstone, called augite melaphyre by Knopf (1912), is characterized by an abundance of dark-green clinopyroxene crystals, commonly 3 to 5 mm and rarely 10 mm across, set in a dense, recrystallized matrix of chlorite, pale- to dark-green amphiboles, epidote, and generally minor sodic plagioclase, quartz, and calcite.

The greenstones structurally and probably stratigraphically overlie a thick metasedimentary section that includes mainly argillite, slate, and graywacke. Original thicknesses are indeterminable, but the sedimentary and volcanic rock sequences must each have been at least several thousand feet thick. The only fossils known are Jurassic or Early Cretaceous plants found in argillite east of Berners Bay (Knopf, 1911, p. 17) and deformed specimens of *Inoceramus* in slaty argillite interlayered with metagraywacke a few miles northwest of the town of Douglas (J. G. Smith and A. B. Ford, unpub. data). Mafic and felsic dikes and small dioritic masses intruded the sedimentary rocks prior to or contemporaneously with Late Cretaceous(?) deformation and regional metamorphism. This deformation predates emplacement of the nearby Coast Range batholithic complex, at least part of which is of Eocene age (Forbes and Engels, 1970).

Haines area

Greenstone, slate, and graywacke similar to the rocks of the Gravina-Nutzotin belt in the Juneau area crop out southeast of Haines near the tip of the Chilkat Peninsula (Buddington and Chapin, 1929, pl. 1; Brew and others, 1966, p. 164 and fig. 2a). Fossils have not been found in these beds, and we assign them to the Gravina-Nutzotin belt solely on the basis of lithology.

Northwest of Haines, bedded rocks metamorphosed to amphibolite and schist are provisionally assigned to the Gravina-Nutzotin belt. The premetamorphic age of these rocks is uncertain, but according to E. M. MacKevett, Jr. (oral commun., 1972), they may be late Mesozoic and hence part of the belt.

Yukon Territory

A thick sequence of upper Mesozoic sedimentary rocks, known as the Dezadeash Group (Kindle, 1953; Muller, 1967), is exposed intermittently between Dezadeash Lake and the Alaska-Yukon border. Near Dezadeash Lake, where the rocks are extensively exposed, Kindle reports more than 12,000 feet of slate, graywacke, argillite, quartzite, chert, impure limestone, grit, conglomerate, tuffaceous sandstone, and bedded volcanic tuff. Locally, 200 to 500 feet of conglomerate occurs at the base and rests on "reddish-hued andesite". A few thin beds of coal occur in this conglomerate and also in carbonaceous slate and argillite. In places, these rocks are strongly deformed and metamorphosed to quartz-mica and cordierite schists.

To the northwest, in the Kluane Lake area, Dezadeash rocks occur in small patches within the Kluane Ranges, where they disconformably overlie Triassic rocks of the Mush Lake Group, in places with a basal conglomerate (Muller, 1967, p. 56). These rocks comprise a sequence of dull, dark-gray to black argillite, graywacke, and sparse tuffaceous beds. Graded bedding is common where bedding features are preserved. The thickness of Dezadeash rocks observed by Muller barely exceeds 1,000 feet.

Eastern Alaska Range

The eastern Alaska Range affords the most widespread and thickest sequences of Gravina-Nutzotin rocks within the presently known extent of the belt. Folded Upper Jurassic and Lower Cretaceous marine strata form the entire Mentasta and Nutzotin Mountains, the two principal mountain masses in the eastern Alaska Range. Although most of the Gravina-Nutzotin belt is structurally terminated at the junction of the Denali and Totschunda fault systems (fig. 1), isolated remnants of it just southwest of the Totschunda and flyschlike sedimentary rocks of late Mesozoic age in the less-known central Alaska Range suggest that the original terrane may have been considerably more extensive.

Two thick and very distinct lithologic sequences constitute most of the Gravina-Nutzotin belt in the eastern Alaska Range. A variety of shallow- and deep-water deposits, informally and collectively referred to as the Nutzotin Mountains sequence, are the stratigraphically lowest rocks in the belt. Lying above these, but probably in part coeval, is the Chisana Formation (Richter and Jones, 1972b), a thick sequence of andesitic fragmental rocks, flows, and volcaniclastics. A third sequence of nonmarine sedimentary rocks, very restricted in extent, occurs between the Chisana Formation and the Nutzotin Mountains sequence. The minimum cumulative thickness of the entire assemblage is about 20,000 feet. In contrast to the Gravina-Nutzotin rocks in southeastern Alaska, those in the eastern Alaska Range are relatively unmetamorphosed and only moderately deformed. However, original lithology and depositional characteristics of rocks at the two extremes of the belt are similar.

The age span of the Gravina-Nutzotin belt in the eastern Alaska Range is fairly well established. On the basis of fossils, the oldest rocks are Late Jurassic (Oxfordian) in age, and the youngest are Early Cretaceous (Barremian); all rocks are cut by middle Cretaceous (110 m.y.) granitic plutons (M. A. Lanphere and D. H. Richter, unpub. data).

Nutzotin Mountains sequence.—The Nutzotin Mountains sequence comprises both shallow and deep marine sedimentary rocks that apparently intertongue. They were deposited in a linear marine basin that developed largely on Taku-Skolai terrane but, as suggested by provenance studies, may have overlapped onto Yukon terrane. Shallow-marine facies rocks marking the southern margin of the basin are exposed locally throughout the eastern Alaska Range; none occur along the north side of the belt where the Denali fault juxtaposes deeper marine sedimentary rocks of the basin with rocks of the Yukon terrane. The inferred stratigraphic and structural relations of some of the units of the Nutzotin Mountains sequence are shown diagrammatically in figure 3.

Homoclinal structures with broad gentle folds characterize both the marine sedimentary rocks and the subjacent terrane along the southern margin of the basin. Deformation increases in intensity toward the center of the basin, where folds commonly are isoclinal and locally overturned, and thrust and high-angle reverse faults are present. Axial surfaces and fault planes trend northwestward, parallel to the long axis of the basin, and generally dip steeply to the northeast.

Shallow-marine sedimentary rocks occur at the base of the Nutzotin Mountains sequence. North of Nabesna they consist chiefly of 3,000 feet of dark-gray argillite and minor siltstone, mudstone, graywacke, and impure limestone (unit Ja, fig. 3). Conspicuous clasts of light-gray Triassic(?) limestone, ranging in size from cobbles to house-size boulders, occur sporadically through the lower part of the argillite. Sparse remains of the pelecypod *Buchia concentrica* indicate a Late Jurassic (Oxfordian) age.

Southeast of Nabesna, massive beds of shallow-water pebble to cobble conglomerate as much as 100 feet thick are interbedded with dark-gray siltstone and argillite (unit Jcs, fig. 3) that locally contain fragments of coalified wood and other carbonaceous debris, as well as the pelecypod *Buchia rugosa* of Late Jurassic (Kimmeridgian) age. Clasts in the conglomerate are well-rounded volcanic and volcaniclastic rocks, limestone, chert, and crystalline igneous rocks derived from the underlying Taku-Skolai terrane. Very conspicuous clasts of white quartz and subordinate metamorphic rocks that strongly suggest derivation from the Yukon terrane are also locally abundant. This unit, as much as 5,000 feet thick, is conformably overlain by, and is possibly gradational with, an unnamed sequence of nonmarine sedimentary rocks.

Turbidite deposits (unit KJgb, figs. 3 and 4A) constitute a major part of the Nutzotin Mountains sequence. They consist

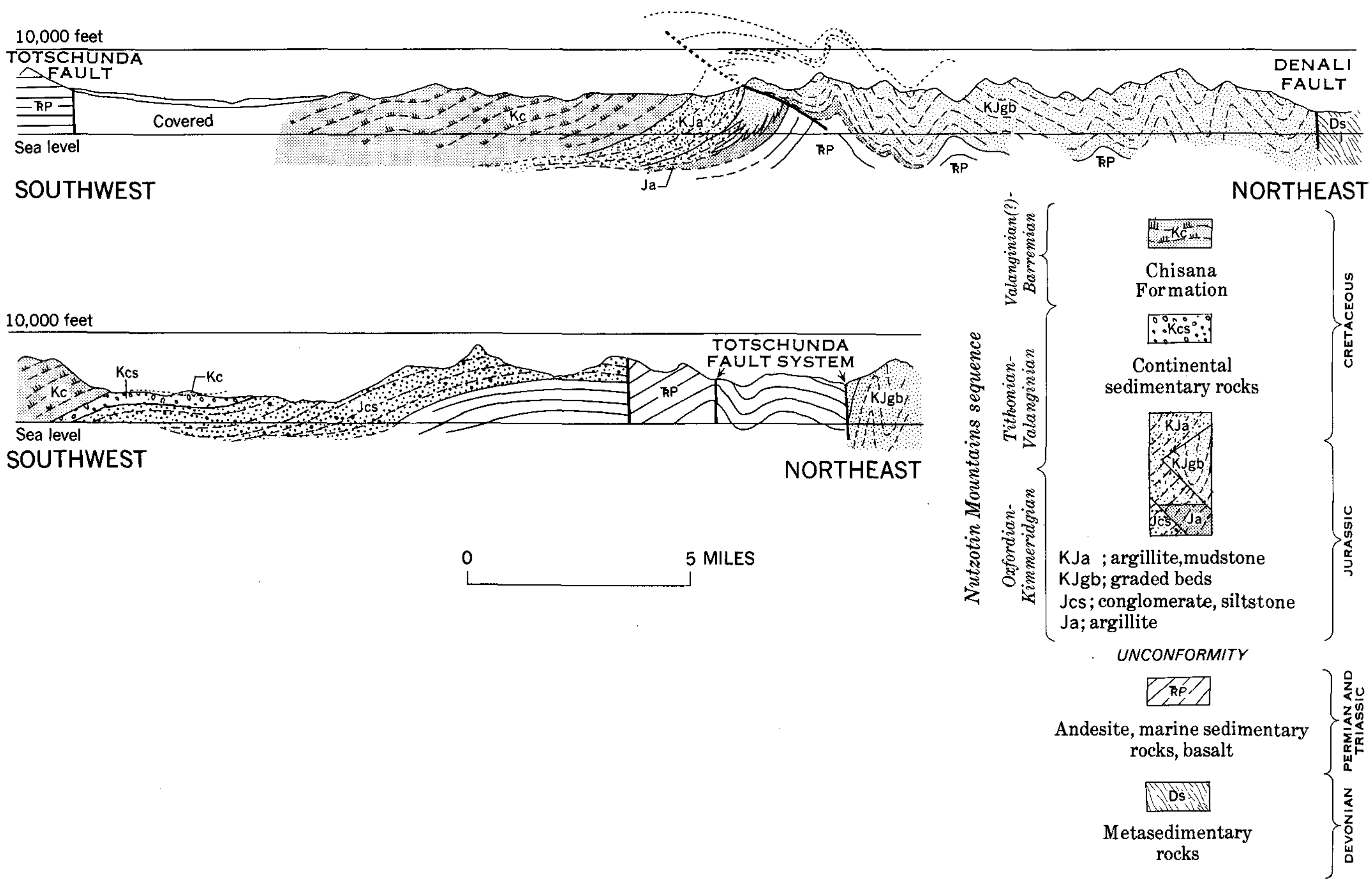


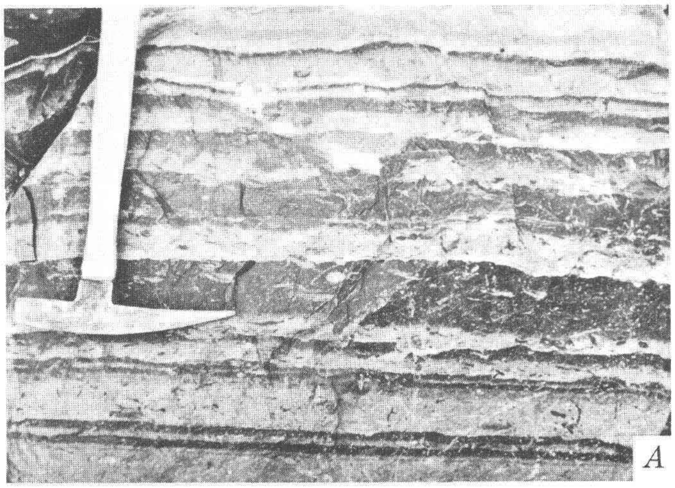
Figure 3.—Generalized sections through parts of the eastern Alaska Range near Chisana (above) and Nabesna (below), showing some inferred structural and stratigraphic relations within the Gravina-Nutzotin belt and between the belt and subjacent terranes.

chiefly of rhythmically alternating graded beds of gray to dark-gray argillite, siltstone, and graywacke in thick sections that locally alternate with massive beds of pebble to cobble conglomerate, pebbly graywacke, graywacke, and argillite. Zones of graded beds, with rhythmic sequences ranging from less than 1 inch to more than 15 inches in thickness occur throughout thousands of feet of uninterrupted section. The massive units may be as much as 500 feet thick and generally lack discernible bedding. The conglomerates are polymictic, similar to those in the shallow-water conglomerate-siltstone unit, with rounded clasts probably derived from both the Taku-Skolai and Yukon terranes. Fossils are extremely rare in these beds; a few specimens of *Buchia* collected at one locality northwest of Chisana indicate a Late Jurassic (Oxfordian to Kimmeridgian) age.

The upper part (KJa, figs. 3 and 4*B*) of the Nutzotin Mountains sequence is exposed between Chisana and the international boundary and consists of about 3,000 feet of graded argillite and graywacke overlain by 600 to 1,500 feet of mudstone. Tuffaceous beds near the top are conformably overlain by massive andesite breccias of the Chisana Formation. Several species of *Buchia* are abundant throughout the unit and indicate an age span from Late Jurassic (Tithonian) to Early Cretaceous (Valanginian).

Nonmarine sedimentary rocks.—Nonmarine clastic sedimentary rocks about 1,000 feet thick (unit Kcs, fig. 3) are exposed in the isolated Gravina-Nutzotin belt remnant southeast of Nabesna (fig. 1). There, carbonaceous thin-bedded to massive, drab brown and gray sandstone, siltstone and shale with minor grit and conglomerate conformably overlie, and probably grade into, the conglomerate and siltstone in the basal part of the Nutzotin Mountains sequence. Fragmental volcanic rocks of the Chisana Formation conformably overlie these deposits. Wood and other plant debris are abundant, but no age-diagnostic fossils have been found.

Chisana Formation.—Interlayered submarine and subaerial andesitic fragmental volcanic rocks, volcanic flows, and volcaniclastic rocks exposed near Nabesna and throughout the Chisana area (fig. 1) have been named the Chisana Formation (Richter and Jones, 1972b). In the type locality near Chisana, at least 10,000 feet of these rocks is estimated to overlie conformably shallow marine sedimentary rocks of the Nutzotin Mountains sequence (fig. 3). Coarse clastic terrigenous deposits of Late(?) Cretaceous age locally overlie the



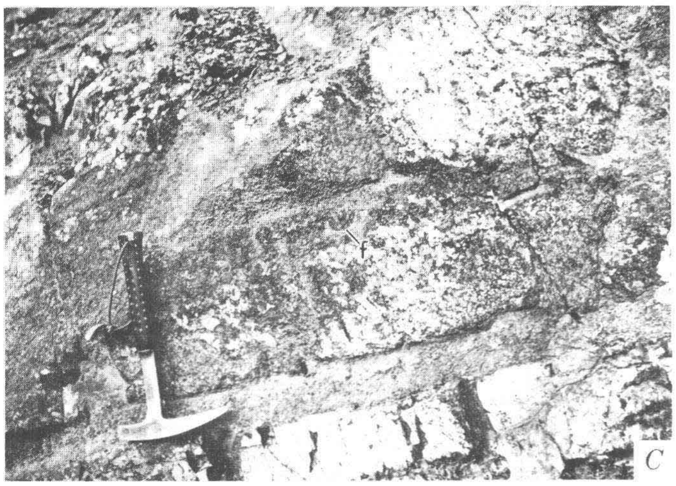


Figure 4.—Upper Mesozoic bedded rocks of the eastern Alaska Range.
A. Graded beds of very fine grained graywacke (light beds) and limy argillite (unit KJgb, fig. 3), lower part of Nutzotin Mountains sequence.
B. Argillite and mudstone (unit KJa, fig. 3), Nutzotin Mountains sequence near Chisana.
C. Bedded andesite crystal tuff, Chisana Formation (unit Kc, fig. 3). Note fossil fragment (f) in center of photograph.

volcanic rocks with slight angular unconformity; elsewhere, Cenozoic rocks overlie them with marked angular unconformity.

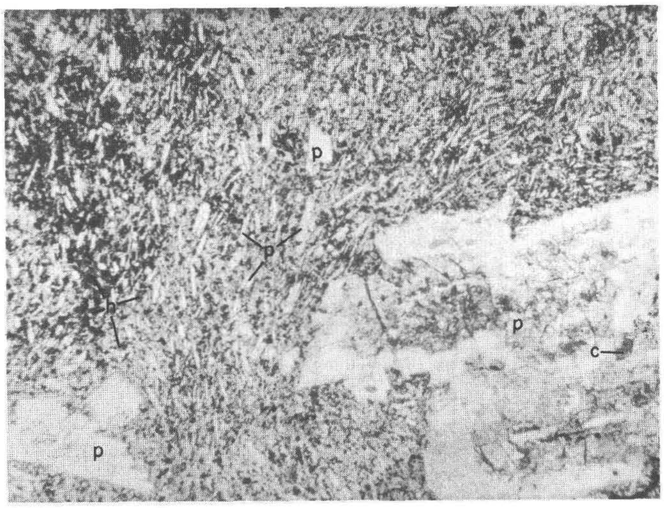
The Chisana Formation consists mostly of massive lahar and submarine avalanche deposits—dark gray to gray-green fragmental volcanic units as much as 300 feet thick. The rocks consist of angular to subrounded clasts of effusive volcanic rock and of crystal fragments of plagioclase and clinopyroxene set in a dense, dark fine-grained volcanic mud matrix. Clasts of intraformational sedimentary rock and lignitized wood are locally abundant near the exposed top of the formation. Interlayered with the fragmental volcanics are dense, dark-green porphyritic flows, maroon to dark-green amygdaloidal flows, thin-bedded terrigenous green and maroon volcaniclastics ranging from conglomerate to mudstone, and minor buff to dark-gray vitric and crystal tuffs (fig. 4*C*). Thin-bedded shaly argillite, graywacke, and mudstone of shallow-marine origin occur sparsely in the lower part of the formation.

The volcanic flows and volcanic clasts in the fragmental units consist of a variety of andesitic porphyritic rocks, the most prevalent of which (fig. 5) contain conspicuous phenocrysts of zoned plagioclase (An_{30-45}) or both plagioclase and diopsidic augite in a fine-grained groundmass of plagioclase microlites, minute stubby prisms of clinopyroxene, and scattered opaque minerals. All the rocks show the effects of low-grade chemical alteration. The feldspar is commonly saussuritized and the clinopyroxene replaced in various degrees by amphibole and chlorite. Similar alteration products are locally abundant in the groundmass. Quartz forms veinlets and amygdules where it generally is associated with calcite and chalcedony.

Fragments of *Inoceramus* are locally abundant in the sparse mudstone and argillite in lower parts of the Chisana Formation that overlie the *Buchia*-bearing beds of the Nutzotin Mountains sequence. Higher in the formation, a few scattered remains of the ammonite *Shasticrioceras* indicate an Early Cretaceous (Barremian) age.

FOSSILS AND AGE

Fossils are rare throughout most of the Gravina-Nutzotin belt, but they have been found in abundance in a few places (table 1). Depth of water throughout much of the marine basin was probably too great to allow growth of abundant shelly faunas, and subsequent deformation and metamorphism, especially in southeastern Alaska, have obliterated some fossil remains. The most abundant fossils are several species of *Buchia*, ranging in age from late Oxfordian to Valanginian, from scattered localities throughout the belt. In southeastern Alaska, these localities are in the western part of



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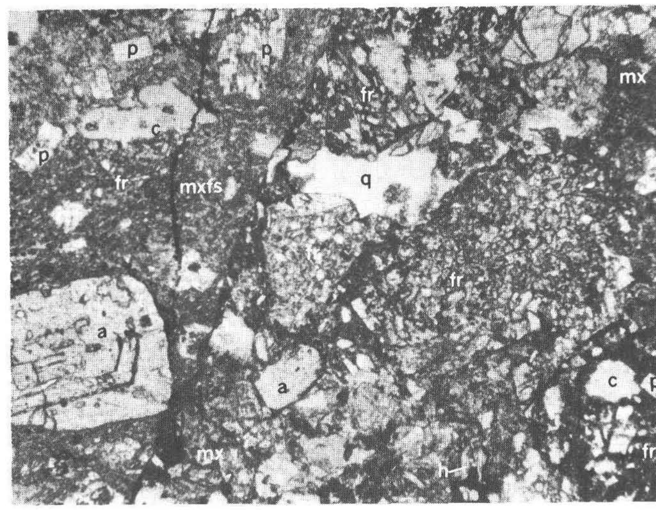

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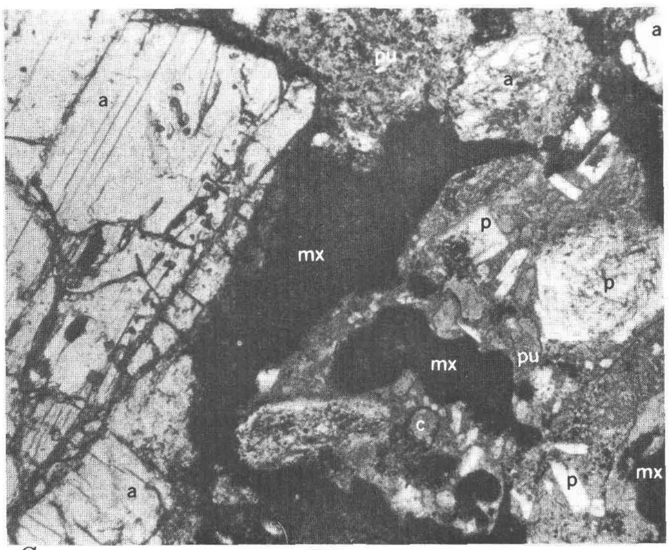

C 0.5mm

Figure 5.–Photomicrographs of volcanic rocks of the Chisana Formation.

A. Maroon amygdaloidal andesite. Plagioclase (p) phenocrysts are zoned from An_{45} (core) to An_{35} (rim); microlites in trachytic groundmass are An_{35}. Sparse grains of green pleochroic chlorite(?) (c), and of augite with magnetite rims (out of field). Abundant opaque material, including fine-grained hematite (h). Sample No. 68AMn266A. Crossed nicols.

B. Fragmental andesite. Densely packed fragments (fr) of porphyritic andesite in a comminuted crystal matrix (mx). Fragments all consist of plagioclase (An_{30}) (p) and diopsidic augite (a) in a matrix of feldspar microlites (mxfs). Minor chlorite (c), quartz (q), and brown hornblende (h). Sample No. 68ARh94. Plane polarized light.

C. Waterlain crystal-vitric tuff. Abundant crystals of diopsidic augite (a) and fragments of pumice (pu) with plagioclase (An_{35}) (p) in a dense, dark, very fine grained volcanilutite matrix (mx). Minor chlorite (c). Sample No. 69ARh301. Plane polarized light.

the belt, which presumably represents a marginal, shallow depositional environment, in contrast to the deeper marine environment of the central and eastern parts. Places where Buchias are fairly abundant are designated on figure 1. The most complete and richly fossiliferous sequence of *Buchia*-bearing beds studied by the writers is in the Nutzotin Mountains (Richter and Jones, 1972b). There, sparse specimens of *Buchia concentrica* and *B. rugosa* near the base of the sequence document the presence of upper Oxfordian and Kimmeridgian strata. The overlying Tithonian, Berriasian, and Valanginian rocks locally are abundantly fossiliferous and are characterized by the following species:

Early Cretaceous	Valanginian	*Buchia "sublaevis"* (Imlay)
		B. crassicollis solida
	-----?-----?-----	*B. n. sp. cf. B. tolmatschowi*
	Berriasian	*B. okensis*
Jurassic	Tithonian	*B. fischeriana*

From the Kluane Ranges of Yukon Territory, Jeletzky (*in* Muller, 1967, p. 57, 58) identified several species of *Buchia* from the Dezadeash Group, including *B. okensis*, *B. fischeri* (= *B. fischeriana*), and other forms indicating a latest Jurassic or earliest Cretaceous age. In similar strata farther south near Dezadeash Lake, Jeletzky (*in* Kindle, 1953, p. 36) records several *Buchia* species of Early Cretaceous (Neocomian) age.

Strata that locally contain abundant *Buchia* are widespread in southeastern Alaska. On southern Admiralty Island, *Buchia rugosa* is abundant in Pybus Bay (Loney, 1964, p. 96), and *B.* n. sp. cf. *B. tolmatschowi* is found at several nearby localities. Poorly preserved specimens of *Buchia* that may be *B.*

Table 1.—*Summary of fossil occurrences and stratigraphic nomenclature, Gravina-Nutzotin belt*

(10) Thickness in thousands of feet. — Conformable contact. ~~~ Unconformity or disconformity. - - - - Fault, intrusive or indeterminate contact

System	Series	Stage	East Alaska Range (Nutzotin Mountains)	Yukon Territory: Kluane Lake	Yukon Territory: Dezadeash Lake	Juneau area (Douglas Island)	Admiralty Island (Pybus Bay)	North Kupreanof Island (Hamilton Bay)	West Etolin Island (Johnson Cove)	West Etolin Island (Rocky Bay)	West Gravina Island (Bostwick Inlet)	East Gravina Island (Blank Inlet)
CRETACEOUS	Upper	Cenomanian-Maestrichtian										
CRETACEOUS	Lower	Albian				*Inoceramus* sp. (age uncertain); Seymour Canal Formation (Berners Formation, Shelter Formation, Symonds Formation, Treadwell Slate) (4-8); Douglas Island Volcanics; Brothers Volcanics (3+); Stephens Passage Group (10+)		Seymour Canal Formation	*Arcthoplites belli* (McLearn) *Grantziceras* sp.	Unnamed volcanic rocks		
CRETACEOUS	Lower	Aptian				3				Unnamed sedimentary rocks		
CRETACEOUS	Lower	Barremian	*Shasticrioceras* sp. *Pseudolimea* sp. *Anchura* sp.; Chisana Formation (10+)		Dezadeash Group (12+)	2						
CRETACEOUS	Lower	Hauterivian	*Inoceramus* sp.									
CRETACEOUS	Lower	Valanginian	? *B. sublaevis* *B. crassicollis solida*; Nutzotin Mountains sequence (10+)		*Buchia* spp.	1				*B. pacifica* (?)		
CRETACEOUS	Lower	Berriasian	*B.* n. sp. cf. *B. tolmatschowi* *B. okensis*	*B. okensis*			*B.* n. sp. cf. *B. tolmatschowi*	*B. keyserlingi* (?) *B. subokensis* (?); 4	*B. okensis* (?)			
JURASSIC	Upper	Tithonian	*B. fischeriana*	*B. fischeriana*								
JURASSIC	Upper	Oxfordian-Kimmeridgian	*B. rugosa* *B. concentrica*				*B. rugosa*				*Buchia* cf. *B. rugosa*; 5	Gravina Island Formation (2+)
JURASSIC	Upper	Callovian										
JURASSIC	Middle	Bajocian-Bathonian										*Cylindroteuthis* sp. *Entolium* sp.

[1] Of Knopf (1911). [2] Of Barker (1957). [3] Of Martin (1926). [4] Unnamed sedimentary rocks (1). [5] Unnamed sedimentary rocks (.85+).

subokensis or *B. keyserlingi* occur near Hamilton Bay on northern Kupreanof Island (Muffler, 1967, p. C45). Buchias have been collected on and near Etolin Island, but most specimens are too poorly preserved for positive identification. Small, coarsely ribbed specimens from the Johnson Cove area on the western part of the island may be *B. okensis*, and a single specimen from Rocky Bay at the southern end may be *B. pacifica* of Valanginian Age. The southernmost occurrence of Buchias in the Gravina-Nutzotin belt is at Bostwick Inlet on western Gravina Island, where poorly preserved specimens of *Buchia* cf. *B. rugosa* are locally abundant.

Fossils from Blank Inlet on southern Gravina Island may be the oldest known from the Gravina-Nutzotin belt (Berg, 1972c), but unfortunately, an unequivocal age determination cannot be established. The fossils consist of abundant belemnites of the genus *Cylindroteuthis* (J. A. Jeletzky and V. N. Saks, oral commun., 1971) and large pelecypods of the genus *Entolium*. In North America *Cylindroteuthis* is abundant in Jurassic strata, commencing in middle Bajocian time and extending into the Tithonian (Stevens, 1965). Although it has not been found in North American Cretaceous strata, Saks (1960) recorded it from the Lower Cretaceous (Neocomian) of northern Siberia. According to Stevens (1965, p. 175) this is the only known Cretaceous occurrence of this genus.

Belemnites are abundant in Hauterivian and Berremian beds in southern Alaska and elsewhere along the Pacific coast of North America (Jones and Detterman, 1966), but these belong mainly to the genus *Acroteuthis*, a form notably absent from Gravina Island. Likewise, the very large specimens of *Entolium*, some measuring 6 to 8 inches in diameter, are unknown from Cretaceous deposits along the Pacific coast of North America.

The evidence thus afforded by both the belemnites and pelecypods supports a late Middle to Late Jurassic age for the enclosing strata, but neither form has a sufficiently short range nor is well enough preserved to permit a more precise age determination.

A negative, but extremely important, factor bearing on the age of the Gravina Island Formation is the striking absence of Buchias. We know of no place along the west coast of North America where fossiliferous strata of late Oxfordian to Tithonian Age do not contain a fauna dominated by, or at least containing, *Buchia*. Such an absence from the Gravina Island suggests to us that these beds may be of pre-*Buchia* age, perhaps somewhere in the range of middle Bajocian to middle Oxfordian.

The youngest fossils from the Gravina-Nutzotin belt are ammonites of early Albian Age collected from argillite interbedded with andesite breccia and tuff on westernmost Etolin Island (locality A on fig. 1). These ammonites are *Arcthoplites belli* (McLearn) (fig. 6) and a crushed specimen that probably is *Grantziceras* sp.; both types are well known from lower Albian strata of the Wrangell Mountains (Imlay, 1960; Jones, 1967) and also occur on the Queen Charlotte Islands to the south.

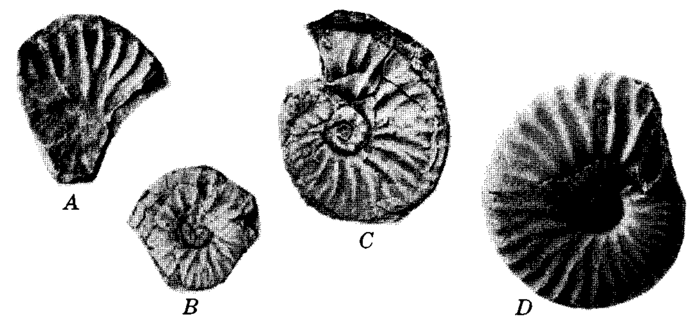

Figure 6.—*Arcthoplites belli* (McLearn). Natural size.
A, *B*, and *C* are rubber casts of crushed specimens from USGS Mesozoic loc. M5835, northern end of Marsh Island, off the northwest coast of Etolin Island. Casts are made from exterior molds in black argillite interbedded with andesite breccia and crystal tuff. USNM No. 183770a, 183770b, 183770c, respectively.
D is specimen from USGS Mesozoic loc. M1339, Kennicott Formation, lower Albian (zone of *Brewericeras hulenense*), McCarthy A-4 quadrangle, Wrangell Mountains. Lat 61°12.3′ N., long 142°19.8′ W. USNM 183771. Well-preserved specimen is illustrated to document the occurrence of the same early Albian fossils in both the Gravina-Nutzotin belt and the Matanuska-Wrangell terrane.

Large specimens of *Inoceramus* collected from argillite on Douglas Island near Juneau (J. G. Smith and A. B. Ford, unpub. data) may be middle Cretaceous in age. Although numerous, these fossils are strongly deformed and cannot be specifically identified. Also, near Chisana in the southern Nutzotin Mountains, large but indeterminable fragments of *Inoceramus* have been found in shaly argillite interbedded with Chisana Formation andesite that overlies upper Valanginian beds (fig. 4*C*). Much higher in the Chisana volcanic sequence, rare fossils, including among others, *Shasticrioceras* sp., *Pseudolimea* sp., and *Anchura* sp. indicate a probable Early Cretaceous (Barremian) age.

In summary, the fossil evidence establishes that sedimentation in the Gravina-Nutzotin belt may have commenced in Middle Jurassic (Bajocian) time in the southernmost part of the belt and somewhat later in the Late Jurassic (Oxfordian) elsewhere in the belt. Except for presumably local interruptions, deposition was evidently continuous until near the end of Early Cretaceous (Albian) time. Volcanism was episodic, as volcanic rocks occur with the presumed oldest beds in southeastern Alaska and lie above the youngest marine beds in the eastern Alaska Range and on Etolin Island. Significantly, no volcanic rocks have been found intercalated with the *Buchia*-bearing beds (upper Oxfordian through Valanginian). Hence, it appears that the bulk of volcanic activity occurred during post-Valanginian time.

CHEMISTRY AND CLASSIFICATION OF THE VOLCANIC ROCKS

Table 2 summarizes the major-oxide chemistry of 27 specimens of volcanic materials from the Gravina-Nutzotin belt. Of these, 26 (table 2, cols. 1a–1c) are metavolcanic rocks from the Gravina Island Formation, near Ketchikan, where the belt has been strongly deformed and its rocks regionally metamorphosed in the greenschist facies. The remaining specimen (table 2, col. 2c) is relatively unaltered flow rock from the Chisana Formation in the Nutzotin Mountains.

The Gravina Island rocks vary considerably in composition; individual analyses range in SiO_2 content and normative An ratio between those of basalt (Nockolds, 1954, p. 1021) and dacite (Chayes, 1969, p. 2; and 1970, p. 179), with most

Table 2.—*Analyses, in weight percent, of volcanic rocks in the Gravina-Nutzotin belt, Alaska*

[All analyses performed in U.S. Geological Survey rapid rock analysis laboratory under Leonard Shapiro. Analysts: P. L. D. Elmore, G. W. Chloe, James Kelsy, H. Smith, Lowell Artis, and J. L. Glen]

	1 Gravina Island Formation (Berg, 1972c)			[1]2 Chisana Formation (Richter and Jones, 1972b)		3 Andesite (Nockolds, 1954, p. 1019)	4 Cenozoic andesite (Chayes, 1969, p. 2)
	a	b	c				
			Chemical analyses				
SiO_2	44.0 –59.8	51.36	53.19	61.90	(51.7)	54.20	58.17
Al_2O_3	16.2 –19.5	18.12	18.79	17.00	(17.1)	17.17	17.26
Fe_2O_3	1.60– 4.90	3.66	3.75	3.10	(2.2)	3.48	3.07
FeO	2.30– 9.80	5.47	5.61	2.70	(6.2)	5.49	4.17
MgO	1.70– 7.20	4.52	4.74	1.40	(5.0)	4.36	3.23
CaO	5.10–11.50	8.76	9.17	4.50	(7.9)	7.92	6.93
Na_2O	.81– 5.80	2.70	2.77	4.10	(2.8)	3.67	3.21
K_2O	.34– 2.20	.89	.93	1.70	(.91)	1.11	1.61
H_2O+	1.30– 4.20	2.71	.....	1.60	(3.3)	.86	1.24
TiO_2	.44– 1.20	.73	.75	.77	(.83)	1.31	.80
P_2O_5	.04– 0.54	.17	.17	.42	(.31)	.28	.20
MnO	.08– 0.35	.16	.17	.12	(.13)	.15	.....
CO_2	.00– 3.20	[2].39	.....	.39	(.23)	.....	.....
Total		99.64	100.04	99.70		100.00	99.89
			CIPW norms				
Q	0–20.42 (22)	6.65	6.21	21.52		5.7	13.63
C	0– 6.27 (4)	.....	.....	2.15		.....	.....
or	2.0 –12.85	5.28	5.49	10.08		6.7	9.52
ab	6.91–49.11	22.93	23.43	34.80		30.9	27.19
an	9.51–46.25	34.82	36.08	17.17		27.2	27.96
ne	0– 2.18 (1)	.....	.....	.....		.....	.....
wo	0– 9.11 (22)	2.17	3.46	.....		4.2	2.15
en	1.26–17.75	11.30	11.80	3.50		10.9	8.05
fs	0–15.41 (25)	6.14	6.28	1.35		5.3	3.80
fo	0– 8.20 (4)	.....	.....	.....		.....	.....
fa	0– 7.87 (4)	.....	.....	.....		.....	.....
mt	2.30– 7.14	5.33	5.44	4.51		5.1	4.46
il	.48– 2.30	1.39	1.42	1.47		2.4	1.52
ap	.10– 1.26	.40	.40	1.00		.7	.47
cc	0– 7.19 (14)	.89	.....	.89		.....	.....
Normative an ratio.		60.3	60.6	33.0		46.8	50.7

1. Summary of rapid rock chemical analyses of 26 samples of greenschist facies regionally metamorphosed volcanic rock from the Gravina Island Formation, Annette and Gravina Islands, Alaska.
   a. Range of values in the 26 analyses. Number in parentheses in normative analyses indicates number of samples in which constituent is reported.
   b. Average of the 26 analyses. CIPW norm is calculated from this average.
   c. Average of the 26 analyses recalculated to 100.00 percent on a volatile-free basis.
2. Amygdaloidal flow, Chisana Formation, Nutzotin Mountains, Alaska.
3. Average of 49 analyses of andesite.
4. Average of 1,775 analyses of Cenozoic andesite.

[1] The average of three additional chemical analyses of Chisana Formation volcanic rocks was added to column 2 at time of proof. We believe that this average, shown in parentheses, which closely approximates that of the Gravina Island samples, is more representative of the Chisana Formation than the single analysis reported.

[2] Reported in 14 samples.

falling in the range of basalt-andesite (Williams and others, 1954, p. 43; Coats, 1968, p. 693–717). Doubtless, variability is the combined result of compositional variation in the original lavas and of alteration and metamorphic transfer (Smith, 1968). The distance and magnitude of transfer is unknown, but we assume that element redistribution was largely confined to the volcanic pile. Therefore, although any individual analysis is not representative of original lava composition, we believe that the average of many analyses (table 2, col. 1b) approximates the bulk composition of the parent rocks.

A precise classification of Gravina Island metavolcanic rocks depends on the effects of the volatile constituents, mainly H_2O, which can only be arbitrarily assigned. Recalculated on a water-free basis, and assuming that all H_2O was introduced—an assumption not wholly justified because the original lava may have contained a hydrous phase such as hornblende—the average Gravina Island rock (table 2, col. 1c) can be classed as basaltic andesite (Williams and others, 1954; Coats, 1968). The andesitic nature of these rocks shows well on an ACF diagram (fig. 7), where they plot along the margin of the basalt field of D. S. Coombs (after Smith, 1968), distant from Nockolds' (1954, p. 1021) tholeiitic and "central" basalts, and proximate to average andesite of Chayes (1969; table 2, col. 4 of the present report) and Nockolds (1954, p. 1019; table 2, col. 3 of the present report), and to average island-arc andesite of McBirney (1969, p. 503).

The analysis of the Nutzotin Mountains specimen shows more SiO_2, higher normative quartz, and a lower An ratio than any of the Gravina Island samples, but nevertheless is well within the range commonly reported in andesitic volcanic suites (Dickinson, 1970, p. 818). (See footnote 1, table 2, for additional chemical analyses.)

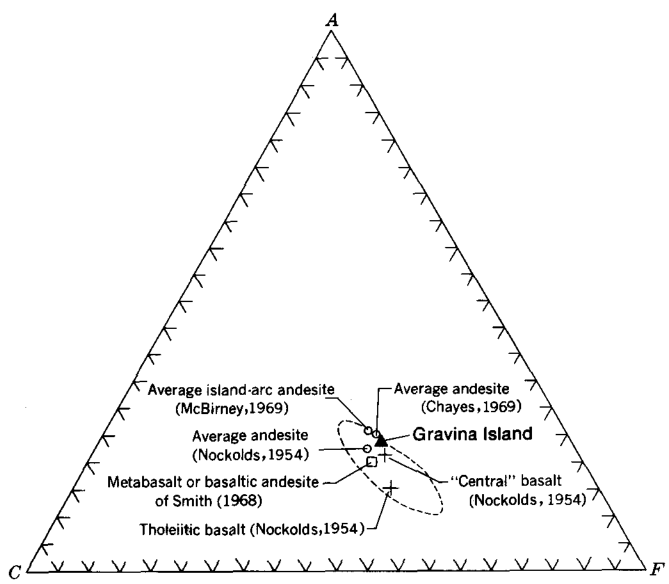

Figure 7.—ACF diagram comparing average Gravina Island metavolcanic rocks (table 2, col. 1b) with average basalt and andesite. Dashed line shows basalt field of D. S. Coombs (after Smith, 1968).

Gravina-Nutzotin volcanic rocks vary considerably in alkali content, but the regional variation in alkalis has not been established.

COGENETIC GRANITIC ROCKS

Rocks of the Gravina-Nutzotin belt and adjacent terranes are intruded by numerous granitic plutons ranging in size from dikes a few feet thick to batholiths. Only a few of the plutons, however, have been precisely dated by stratigraphic or radiometric methods. Those that are late Mesozoic and Tertiary in age postdate formation of the Gravina-Nutzotin belt and are not discussed further. Those known to have formed during Late Jurassic to middle Cretaceous time, and thus assumed to be cogenetic with the Gravina-Nutzotin volcanic rocks, are described in this section.

In the eastern Alaska Range and adjoining Kluane Ranges in Canada, more than 15 plutons ranging in size from small stocks to complex batholiths intrude rocks of the Gravina-Nutzotin belt. Reconnaissance K-Ar radiometric studies indicate an age of 110–112 m.y. for the Alaskan plutons (M. A. Lanphere, unpub. data), which is consistent with a post-Barremian–pre-Late Cretaceous age deduced from fossil and field evidence. In the Kluane Ranges, Muller (1967) has bracketed the age of the plutons between Early Cretaceous and early Tertiary on the basis of contact relations.

The Alaskan plutons are principally granodiorite but include quartz monzonite, quartz diorite, diorite, and syenodiorite as locally abundant variants. Less common are trondjhemite, pyroxene monzonite, and biotite gabbro. The rocks are nonfoliate, medium to coarse grained, and in thin section exhibit a subhedral equigranular texture.

The plutons in the eastern Alaska Range generally have sharp intrusive contacts with the country rocks and contain abundant xenoliths. A thermal metamorphic aureole, as much as 1 mile wide, surrounds many of the plutons.

In southeastern Alaska, Gravina-Nutzotin bedded rocks are intruded by numerous granitic plutons (Buddington and Chapin, 1929), but only one, on northern Annette Island, has been recognized as clearly coeval with the andesitic metavolcanic rocks.

This pluton is a crudely tabular diorite to quartz diorite stock, with contacts that strike approximately parallel to the regional northwesterly trend of the enclosing Gravina Island Formation. There is some local baking of the metasedimentary beds along the diorite contact, but thermal effects in the metavolcanic rocks have not been observed. The pluton is moderately foliated and hydrothermally altered and grades outward from an equigranular core of feldspar, amphibole, and minor quartz to a porphyritic border zone containing relict phenocrysts of feldspar and amphibole. The border zone, in turn, grades imperceptibly into feldspar-, amphibole-, and pyroxene-crystal-bearing andesitic metatuff.

The similarity in composition and texture of the diorite border phase and adjoining Gravina-Nutzotin metavolcanic rocks, together with the absence of thermal effects at the intrusive contact and close spatial association of the two rock types, strongly suggests that the pluton is a hypabyssal variant of the precursive andesitic extrusives.

Several granitic plutons that intrude rocks of the terranes adjacent to the Gravina-Nutzotin belt (fig. 1) have been dated as Early and middle Cretaceous by other workers (Loney and others, 1967; E. M. MacKevett, Jr., and J. G. Smith, oral commun., 1972). Although coeval upper Mesozoic volcanic rocks are not known to occur in these terranes, we assume that the plutons were subjacent to andesitic extrusive rocks, all traces of which have been removed by erosion.

ZONED ULTRAMAFIC COMPLEXES

Concentrically zoned ultramafic complexes that ideally grade outward from a core of dunite, through successive shells of peridotite and (clino)pyroxenite, to peripheral hornblendite and gabbro are abundant in southeastern Alaska (Taylor, in Wyllie, 1967, p. 97–121). Of the 35 such complexes that have been reported (Taylor and Noble, 1969), 24 are in the Gravina-Nutzotin belt, and 11 lie within 10 miles of the belt.

The zoned ultramafics are partly serpentinized and, along with the enclosing country rocks, are more or less deformed and dynamically metamorphosed. In addition, the country rocks near several of them are contact metamorphosed to granulite, hornfels, schist, and gneiss containing pyroxene, hornblende, biotite, and garnet (Taylor, 1967, p. 99, 104).

Several of the ultramafic complexes in and near the Gravina-Nutzotin belt have been dated radiometrically by K-Ar methods (Lanphere and Eberlein, 1966). Their ages range from 90 to 110 m.y. and average about 100 m.y., an age closely comparable with that of the faunally dated Albian andesitic volcanic rocks on western Etolin Island (p. D7).

The significance of the zoned ultramafic complexes in southeastern Alaska, a type known to be abundant elsewhere only in the Ural Mountains of Russia (Taylor and Noble, 1969), is uncertain. However, their contemporaneity with Gravina-Nutzotin belt andesite, combined with isotopic (Lanphere, 1968) and petrologic (Irvine, 1967) data suggest that they may be fractional crystallization products in floored magma chambers that fed the andesitic vents.

Matanuska-Wrangell Terrane

An extensive belt of upper Mesozoic rocks extends for nearly 1,000 miles in a sinuous arc from the Wrangell Mountains to near Port Moller on the Alaska Peninsula (see fig. 8). This belt, termed the Matanuska geosyncline by Miller, Payne, and Grye (1959), consists of thick sequences of Lower Jurassic sedimentary and volcanic rocks and Middle Jurassic through uppermost Cretaceous shallow marine deposits. Fossils are locally very abundant, and they have been the subject of numerous paleontologic and biostratigraphic studies.

Of particular significance for this report is the character of the Upper Jurassic (Oxfordian) through Lower Cretaceous (Albian) part of the sequence in the eastern part of the belt. These strata are very different from those of the nearby Gravina-Nutzotin belt and have been studied extensively by MacKevett (1970, 1971) in the McCarthy region of the Wrangell Mountains. There, Upper Jurassic (Oxfordian and Kimmeridgian) rocks, characterized by *Buchia rugosa* and *Buchia concentrica*, of the Root Glacier Formation (MacKevett, 1969, 1971) include 3,000 to 4,000 feet of mudstone and siltstone, and minor amounts of shale, sandstone, and conglomerate. Graded bedding is rare, and MacKevett suggests that deposition occurred in moderately shallow water. The Root Glacier Formation and older rocks are overlain unconformably by the shallow marine Kennicott Formation of Albian Age (Jones and MacKevett, 1969); strata of Tithonian through Aptian Age are missing. Farther to the west, in the Kotsina-Kuskulana area of the Wrangell Mountains, the Root Glacier Formation and lower Neocomian strata are absent, and fossiliferous strata of Hauterivian and Barremian Age underlie those of Albian Age (Grantz and others 1966; Jones, unpub. data).

A nearly complete Upper Cretaceous sequence overlies the Kennicott Formation near McCarthy (Jones and MacKevett, 1969), and similar rocks are widely exposed in the Talkeetna Mountains to the west (Grantz and Jones, 1960). In both places, these rocks are richly fossiliferous (Jones, 1963, 1967; Imlay, 1960) and were deposited in relatively shallow marine waters; volcanic rocks are absent. The degree of deformation of the sedimentary rocks is slight except near several large fault zones.

The rocks of the Matanuska-Wrangell belt differ markedly from those of the Gravina-Nutzotin belt. These differences, which are summarized in table 3, indicate that the two belts have very different geologic histories, even though they are now only a few tens of miles apart.

Chugach Terrane

The Chugach Mountains are underlain by a great thickness of Mesozoic and upper Paleozoic rocks consisting of graywacke, argillite, slate, conglomerate, volcanic rocks, chaotic melanges, and granitic plutons. The rocks are complexly deformed and have been subjected to low-grade regional metamorphism. Similar rocks, which may represent the southernmost exposures of the Chugach terrane, occur on Baranof and Chichagof Islands in southeastern Alaska.

We have subdivided the rocks of this terrane into two units (fig. 1) that appear to differ in age. The older unit (older Chugach terrane) consists of a regionally metamorphosed and multiply deformed assemblage of phyllite, metagraywacke, quartzite, metachert, greenstone, amphibolite, and ultramafic rocks exposed along the southern margin of the St. Elias

Table 3.—*Comparison of Upper Jurassic and Cretaceous rocks of the Gravina-Nutzotin belt and Matanuska-Wrangell terrane*

	Gravina-Nutzotin belt	Matanuska-Wrangell terrane
Time of deposition.	Probably continuous from Middle(?) Jurassic into Albian.	Oxfordian-Kimmeridgian, with local major folding and deep erosion during Tithonian to early Neocomian; deposition resuming in late Neocomian (but Aptian deposits not identified) and extending into Maestrichtian.
Conditions of deposition.	Predominantly deep marine in trough bordering volcanic arc with minor shallow marine and nonmarine facies. Flysch-type rocks predominate; fossils rare.	Shallow marine on an unstable continental shelf, with rapid facies changes and many local disconformities; flysch-type rocks rare; fossils common.
Volcanic activity.	Abundant submarine and subaerial andesitic fragmental volcanic rocks and volcaniclastic rocks; rare flows.	None.
Basement rocks.	Upper Paleozoic to Triassic rocks of Taku-Skolai terrane.	Taku-Skolai and Lower and Middle Jurassic sedimentary and volcanic rocks.
Tectonic activity.	Moderate to intense regional deformation. Local large-scale thrusting and tight-to-isoclinal folding with gently dipping axial surfaces. Contact aureoles near granitic plutons. Vertical uplift at least 10,000 feet.	Minor folding, thrusting, and normal faulting; vertical uplift at least 8,000 feet.

Range and on Baranof and Chichagof Islands. The assemblage locally is intruded by Middle Jurassic and younger granitic plutons. Studied only in reconnaissance, the rocks may be as old as Triassic and Permian (Loney and others, 1963, 1964), but definitive evidence is lacking. We have considered the possibility that these older Chugach terrane rocks may be part of the Taku-Skolai terrane, which they appear to resemble. However, because the age of the older Chugach rocks is uncertain, and because their continuity with the Taku-Skolai terrane has not been demonstrated, we believe it more appropriate to describe them here, along with the neighboring younger Chugach rocks.

Rocks of the younger Chugach terrane include the Sitka Graywacke of Baranof and Chichagof Islands (Loney and others, 1963, 1964), the Yakutat Group in the Gulf of Alaska region (Plafker, 1967), and the Valdez Group and an unnamed formation in the Prince William Sound—Cook Inlet area (S. H. B. Clark, 1972). Fossils are very rare in these rocks, but in a few places sufficiently well preserved forms have been found to establish a range in age from probable Late Jurassic to Late Cretaceous (Maestrichtian). Parts of the Sitka Graywacke and the Yakutat Group are coeval with some of the rocks of the Gravina-Nutzotin belt, as similar *Buchia* assemblages occur in both terranes. Much of the Yakutat and Valdez Groups, however, are younger (Campanian and Maestrichtian) than any rocks known in the Gravina-Nutzotin belt. An unconformity between Sitka Graywacke—Yakutat Group rocks and older Chugach terrane rocks has been mapped on northern Baranof Island (Berg and Hinckley, 1963, p. O11), and inferred on southwestern Chichagof Island (R. A. Loney, oral commun., 1971) and in the Gulf of Alaska region (George Plafker, oral commun., 1972), but in most places, the present contact appears to be a major fault (Loney and others, 1964; Plafker, 1971, p. 122–123, 130; S. H. B. Clark, 1972).

The rocks of the younger Chugach terrane were apparently deposited in a deep marine trench. Rocks in the older Chugach terrane may have accumulated on oceanic crust as indicated by the presence locally of alpine-type ultramafic rocks in association with chert, greenstone, amphibolite, and gabbro.

At least three episodes of deformation can be inferred: one in pre-Late Jurassic time presumably resulted in at least partial accretion of older Chugach terrane rocks to the continent; another, in late Mesozoic and Tertiary time, produced regional metamorphism and thrusting of the younger oceanic trench deposits against and beneath the continental margin (Jones and others, 1971). Lastly, Plafker (1972, p. 30, and oral commun.) believes that rocks of the Chugach terrane in the St. Elias Range may once have been contiguous with those on Baranof and Chichagof Islands and were moved into their present position by about 150 miles of Cenozoic right-lateral slip on the Fairweather fault.

A depositional contact between the older Chugach terrane (probably formed largely on oceanic crust) and the Paleozoic Alexander terrane (composed of older continental crust) seems unlikely. Instead, we postulate that these terranes of wholly dissimilar age and origin were juxtaposed along a major fault and that rocks of the Alexander terrane do not depositionally underlie any part of the Chugach terrane to the west.

HISTORY AND TECTONIC SIGNIFICANCE OF THE GRAVINA-NUTZOTIN BELT

The three upper Mesozoic lithologic and structural belts that rim southern and southeastern Alaska (fig. 8) satisfy many of the geologic criteria for an ancient tripartite arc-trench system (Dickinson, 1970, 1971a, b). In plate-tectonic theory, the three elements of such a system—the trench, arc-trench gap, and magmatic (volcanoplutonic) arc—are interrelated features produced at converging plate margins through the process of plate consumption in subduction zones.

The deep-marine origin of the slate and graywacke of the younger Chugach terrane has long been recognized (for example, see Burk, 1965, p. 69; and Moore, 1969, p. 30), and accumulation in an oceanic trench at the continental margin seems to be the most reasonable interpretation of its depositional environment (Jones and others, 1971; Moore, 1972). The shallow-water, fossiliferous, and only slightly deformed

Matanuska-Wrangell terrane formed on an unstable continental shelf and upper continental slope and is the near-shore correlative of the deep-water Chugach trench deposits. The Gravina-Nutzotin belt, innermost of the three partly coeval terranes, with its thick lenses of andesitic volcanic rocks and cogenetic plutons, thus apparently corresponds to at least part of the magmatic arc, analogous to modern arcs such as the Aleutians (Coats, 1962) or the older arcs of Japan (Matsuda and Uyeda, 1971). However, the presence of granitic plutons coeval with Gravina-Nutzotin rocks in the older terranes adjacent to the Gravina-Nutzotin belt suggests that the arc originally extended beyond the present borders of the belt. Furthermore, certain features of the belt, especially its great thickness of flyschlike turbidite deposits derived in part from older, external terranes, suggest that it was not a typical magmatic arc (see table 4), and might instead more appropriately be termed a "basinal" arc.

This interpretation of a late Mesozoic arc-trench system in southern and southeastern Alaska fits quite nicely the region near long 142° W., just west of the international boundary (fig. 9). There, the three belts occur in proper sequence, but both to the west and southeast the tripartite arrangement breaks down, and the genetic and spatial relations of the parts are not so evident.

To the west, and extending on to the southwest down the Alaska Peninsula, both the Matanuska-Wrangell and Chugach terranes are well developed, but the Gravina-Nutzotin belt has not been recognized beyond the central part of the Alaska Range. Neither the characteristic flyschlike rocks, the fragmental andesitic rocks, nor granitic rocks approximately 100 to 120 m.y. old have been identified.

To the southeast the arc-trench gap deposits of the Matanuska-Wrangell terrane terminate near the border of the much older Alexander terrane (figs. 1 and 8). Farther to the

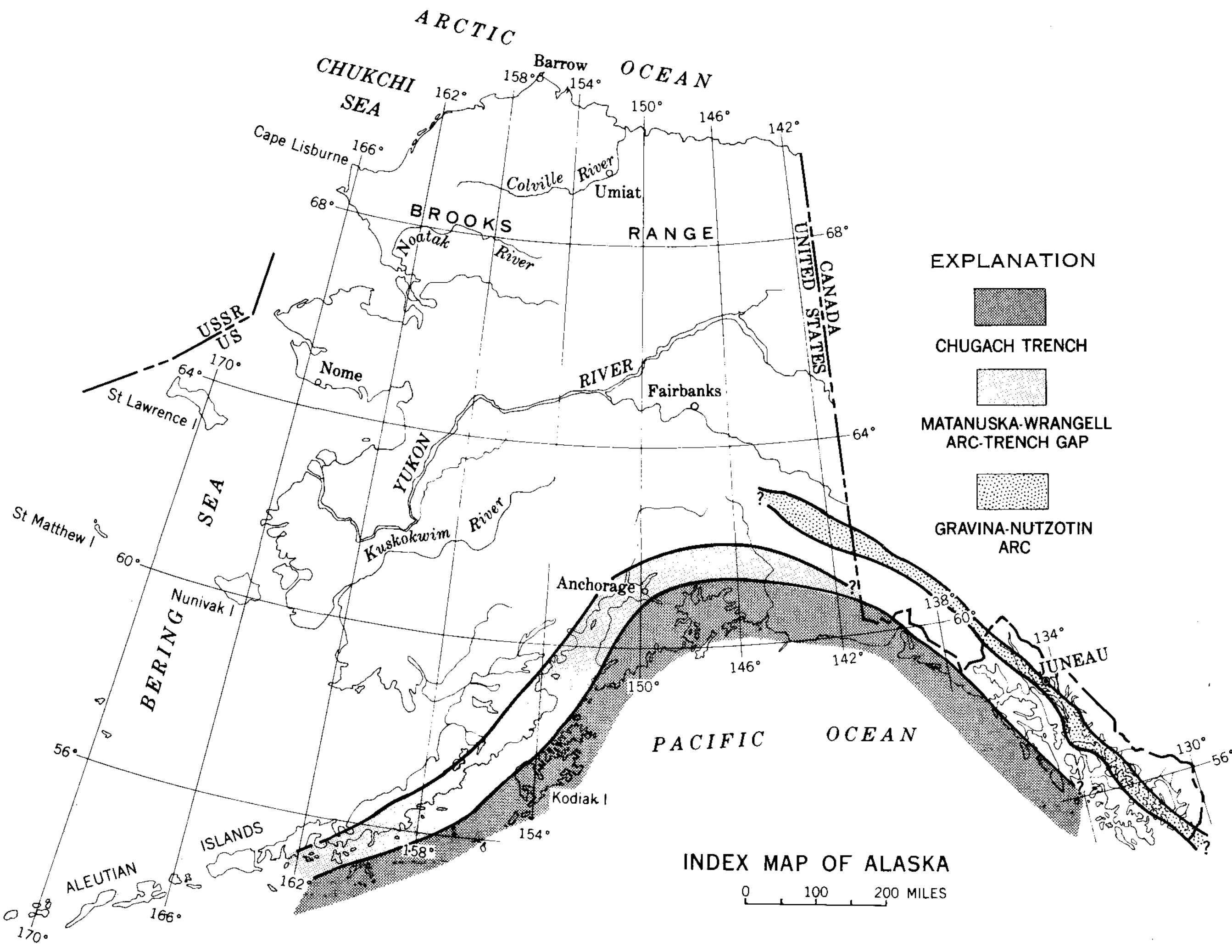

Figure 8.—Sketch map showing inferred extent of upper Mesozoic terranes in southern and southeastern Alaska.

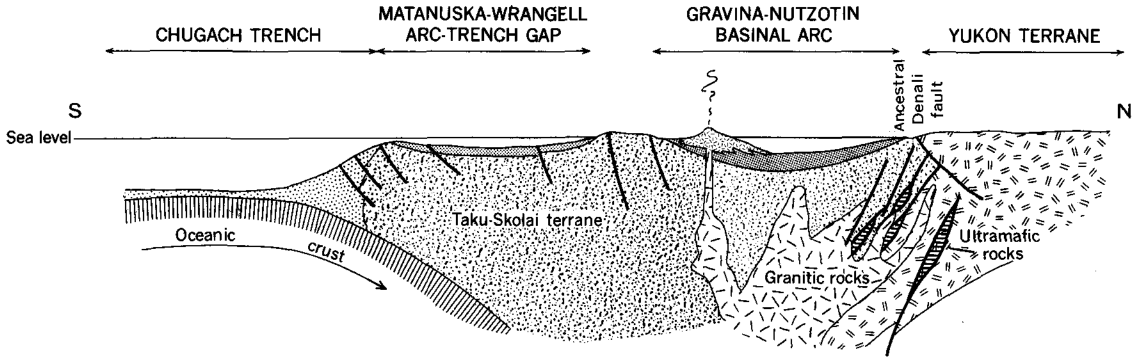

Figure 9.—Interpretation of Upper Jurassic and Lower Cretaceous tectonic elements along long 142° W., southern Alaska (adapted from Richter and Jones, 1972a).

southeast, along the present continental margin, the trench and oceanic crustal deposits of both Chugach terranes also terminate at the Alexander terrane. Such old rocks are not found elsewhere along the Pacific rim in southern Alaska or adjoining British Columbia, and the Alexander terrane may represent an allochthonous fragment of continental crust (Jones and others, 1972) emplaced prior to the development of the late Mesozoic arc-trench system. Thus, a tectonic interpretation of southeastern Alaska (fig. 10) in late Mesozoic time differs from one in southern Alaska in the absence of an arc-trench gap assemblage. Instead, the Alexander and older Chugach terranes were evidently emergent, shedding detritus eastward into the Gravina-Nutzotin basinal arc and probably westward into the Chugach trench.

Reasons for the absence of parts of the tripartite system elsewhere in southern and southeastern Alaska are obscure. In places, they may be present, but incomplete or inadequate mapping so far precludes their recognition. In addition, large-scale tectonic dislocations during late Mesozoic and early Tertiary times may have destroyed or displaced once-existing parts of the system.

Our view that the Gravina-Nutzotin belt represents an ancient volcanoplutonic arc genetically linked with subduction in the Chugach trench faces some difficulty due mainly to differences between the belt and other modern and ancient magmatic arcs (table 4). The deep-marine deposition of most of the Gravina-Nutzotin sedimentary rocks and their great thickness imply rapid depression of a long, linear belt. Moreover, the striking similarity of sedimentary structures and bedding features of the flyschlike deposits in the belt to those in the trench implies a gross similarity in depositional environment for these supposedly different petrotectonic suites. Hence, much of the belt was primarily a negative feature, not positive as expected in a volcanic arc. Anomalous also are the very large ratio of sedimentary to volcanic rock (estimated to be at least 10 to 1) and the external source of most of the sediment. Much of the identifiable debris in the Gravina-Nutzotin sedimentary rocks consists of Paleozoic and lower Mesozoic bedded and intrusive rocks, crystalline igneous and metamorphic rocks, and vein quartz, none of which could have been shed from an active volcanic arc but instead must have been derived from older terranes.

The occurrence of thick deposits of upper Mesozoic marine sedimentary rocks in many places throughout the Gravina-Nutzotin belt suggests the presence of one or more marine basins proximal to chains of andesitic volcanoes within the belt. In the eastern Alaska Range, the thousands of feet of mainly nonvolcanogenic sedimentary rocks north of thick

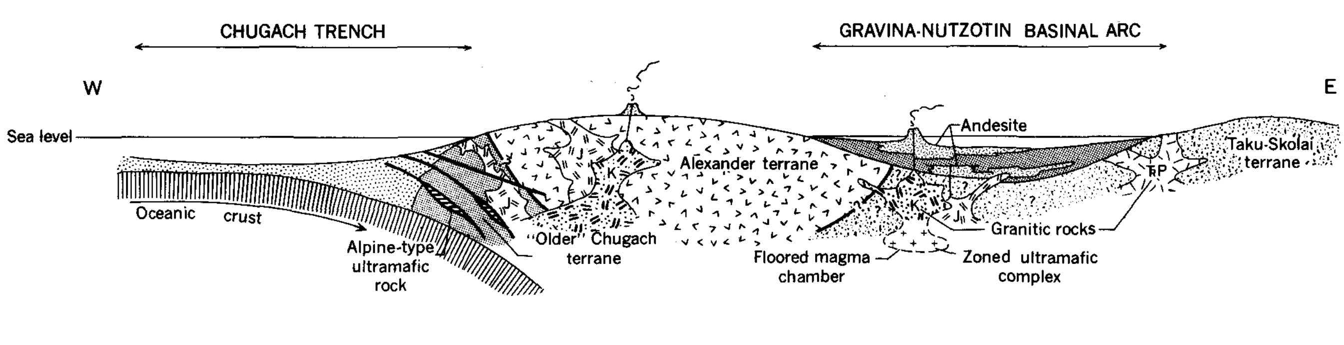

Figure 10.—Interpretation of upper Mesozoic tectonic elements along lat 58° N., southeastern Alaska. Not to scale. K, middle Cretaceous; J, Middle and (or) Upper Jurassic; ŦP, Triassic and Permian.

Table 4.—*Comparison of Gravina-Nutzotin belt and "typical" magmatic arc (Dickinson, 1970, 1971a, b)*

Gravina-Nutzotin belt	Typical magmatic arc
1. Andesitic volcanic rocks.	1. Andesitic volcanic rocks.
2. Several cogenetic granitic plutons in southern and southeastern Alaska, dated at 100–110 m.y.	2. Granitic plutons cogenetic with volcanic rocks.
3. Regional variation in alkalis not yet established.	3. Systematic increase in alkali content of volcanic and associated plutonic rocks toward hinterland.
4. Mainly deep-water (flyschlike) sedimentary rocks (= "basinal" arc).	4. Mainly shallow-water sedimentary rocks.
5. Significant amounts of sedimentary detritus derived from older, external terranes.	5. Primarily volcanogenic sedimentary detritus originating within the arc.
6. Sedimentary rocks much more abundant than volcanic rocks (>10:1).	6. Volcanic rocks more abundant than sedimentary rocks.
7. Arc-trench gap assemblage missing in southeastern Alaska.	7. Coeval arc-trench gap and trench assemblages.
8. Zoned intrusive ultramafic complexes in southeastern Alaska approximately coeval with volcanic rocks.	8. Alpine-type ultramafics may be present if arc forms on oceanic crust.
9. High T-P metamorphism in southeastern Alaska.	9. High T-P metamorphism.

deposits of partly coeval volcanic rocks probably accumulated in a marine basin between the andesitic arc and the main continent mass lying to the north. The deep and rapid subsidence of this trough may have resulted from incipient southward arc migration, similar to that suggested by Karig (1971) and Packham and Falvey (1971) for other arcs bordering marginal seas and interarc basins, but with insufficient movement to break the continental crust and permit generation of new oceanic crust in the widening gap.

Indeed, the great volume (more than 10,000 cubic miles in southern Alaska) of Middle and (or) Late Triassic tholeiitic basalt erupted prior to the development of the Gravina-Nutzotin belt may reflect a weakened and distended continental crust. Moreover, as suggested by Richter and Jones (1972a) the withdrawal of this volume of apparent mantle material may have played a dominant role in initiating trough subsidence in this region.

In our view also, the differences between present models of magmatic arcs and the Gravina-Nutzotin belt, especially that part east of long 142° W., may be due to the presence there of the Alexander terrane, an anomalous block of old continental rocks whose movement probably played a major role in the late Mesozoic tectonic history of the region. The details of this history are still very obscure, and the following paragraphs outline only the major features as presently viewed.

Deposition of Gravina-Nutzotin belt rocks began during the Middle and Late Jurassic, perhaps in Bajocian to early Oxfordian time in the southeast, and late Oxfordian time in the northwest, presumably in a relatively narrow and elongate, rapidly subsiding basin. The main source of sediment in the northwestern part was from the Yukon terrane lying to the north—a source indicated by the lithology of cobbles in conglomerates and by imbrication of cobbles that shows southward sediment transport. A source from the Alexander terrane, on the basis of conglomerate cobble lithology, seems likely for the southeastern part of the basin, at least along its western edge.

Sometime during the Kimmeridgian to Albian interval, rocks in the Wrangell Mountains were folded, uplifted, and deeply eroded. Possibly sediments were shed northward from this uplifted terrane into the Gravina-Nutzotin trough, but no clastic wedge or coarsening of the sedimentary rock sequence in the Nutzotin Mountains has been observed to document this event.

Andesitic volcanism, here interpreted as being genetically related to subduction in the Chugach trench, appears to have started very early in the southeastern end of the trough, but certainly the greatest volcanic activity was during the Early Cretaceous. The development of the Gravina-Nutzotin trough probably was roughly contemporaneous with deposition of the younger sequence of sedimentary rocks in the Chugach terrane. The history of these trench deposits, however, is still so obscure that any further speculation as to possible historic links between the two terranes seems unwarranted.

Major compressional deformation of Gravina-Nutzotin belt rocks probably began in post-early Albian time, after deposition of the youngest strata known in the belt. Significant pre-Albian deformation seems ruled out by the absence of any recognizable structural or stratigraphic breaks in the bedded sequence.

In the northern part of the belt, this deformation produced relatively simple folds and some thrusts and was accompanied or closely followed by emplacement of numerous granitic plutons. In southeastern Alaska, its effects ranged from relatively mild folding and fracturing along the western margin of the belt to intense penetrative deformation and recrystallization in the central and eastern parts, including probable underthrusting of the eastern edge beneath rocks of the Taku-Skolai terrane. This deformation was roughly contemporaneous with intrusion of zoned ultramafic complexes and with emplacement of an as yet undetermined number of granitic plutons.

Significant compressional deformation of Gravina-Nutzotin belt rocks apparently ended during the Late Cretaceous as relatively undeformed Upper Cretaceous and Tertiary continental sedimentary and volcanic rocks unconformably overlie the older rocks.

One relation that appears very significant to us is that the Gravina-Nutzotin belt is bounded on the west throughout 90 percent of its length by the old continental crustal rocks of the Alexander terrane. As pointed out by Jones, Irwin, and Ovenshine (1972), this crustal block is anomalous in that it appears to lie outboard of younger rocks formed directly on oceanic crust (see also Richter and Jones, 1971, 1972a, b; Monger and Ross, 1971). The implication of this relation is that the Alexander terrane is an allochthon that has undergone large-scale tectonic transport. It thus seems reasonable to suppose that the initiation, filling, and final collapse of the Gravina-Nutzotin trough were intimately tied to postulated movements of this terrane. This supposition is supported by the degree of deformation exhibited by Gravina-Nutzotin belt rocks, which is much greater in southeastern Alaska where they are contiguous to the Alexander terrane, than in the Nutzotin Mountains, where they lie beyond its northwestern terminous. This suggests that the Gravina-Nutzotin trough was folded and finally destroyed by lateral compression produced by the block of Alexander terrane being driven northeastward.

Another feature that deserves comment is that the Gravina-Nutzotin belt shows little offset across the Chatham Strait fault. Others (St. Amand, 1957; Twenhofel and Sainsbury, 1958; Brew and others, 1966; and Ovenshine and Brew, 1972) have speculated that this right-lateral fault is a continuation of the Denali fault. As Lathram (1964) and Ovenshine and Brew have shown, the Chatham Strait fault exhibits at least 120 miles of right-lateral separation, on the basis of reconstruction of displaced geologic features. No record of comparable displacement can be observed for the Gravina-Nutzotin belt, although some disruption of the basin could have occurred before the period of intense compression. Certainly, no evidence is seen to support significant postdeformation offset.

This relation suggests that the Chatham Strait fault is either (1) an old structure that predates the Gravina-Nutzotin belt or (2) confined for the most part to the Alexander terrane and not related to the Denali fault, except perhaps for recent minor movements along the reactivated fault trace.

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REFERENCES

Barker, Fred, 1957, Geology of the Juneau B-3 quadrangle, Alaska: U.S. Geol. Survey Geol. Quad. Map GQ-100, scale 1:63,360.

Berg, H. C., 1972a, Geologic map of Annette Island, Alaska: U.S. Geol. Survey Misc. Geol. Inv. Map I-684, scale 1:63,360.

——— 1972b, Recognition of large-scale thrust faults and locally related mineral deposits, southeastern Alaska; [abs.], *in* Faults, fractures, lineaments and related mineralization in the Canadian Cordillera: Geol. Assoc. Canada Cordilleran Sec. Programme and abstracts, Feb. 4–5, 1972, p. 8.

——— 1972c, Geology of Gravina Island, Alaska: U.S. Geol. Survey Bull. 1373. [In press]

Berg, H. C., and Hinckley, D. W., 1963, Reconnaissance geology of northern Baranof Island, Alaska: U.S. Geol. Survey Bull. 1141-O, 24 p.

Brew, D. A., Loney, R. A., and Muffler, L. J. P., 1966, Tectonic history of southeastern Alaska, *in* A symposium on tectonic history and mineral deposits of the western Cordillera in British Columbia and neighbouring parts of the United States: Canadian Inst. Mining and Metallurgy Spec. Vol. 8, p. 149–170.

Buddington, A. F., and Chapin, Theodore, 1929, Geology and mineral deposits of southeastern Alaska: U.S. Geol. Survey Bull. 800, 398 p.

Burk, C. A., 1965, Geology of the Alaska Peninsula-Island arc and continental margin (part 1): Geol. Soc. America Mem. 99 (part 1), 250 p.

Chapin, Theodore, 1918, The structure and stratigraphy of Gravina and Revillagigedo Islands, Alaska: U.S. Geol. Survey Prof. Paper 120-D, p. 83–100.

Chayes, F., 1969, The chemical composition of Cenozoic andesite, *in* McBirney, A. R., ed., Proceedings of the Andesite Conference: Oregon Dept. Geology and Mineral Industries Bull. 65, p. 1–11.

——— 1970, Experimentation on the electronic storage and manipulation of large numbers of rock analyses: Carnegie Inst. Yearbook 68, p. 174–187.

Clark, A. L., Clark, S. H. B., and Hawley, C. C., 1972, Significance of upper Paleozoic oceanic crust in the upper Chulitna district, west-central Alaska Range, *in* Geological Survey Research 1972: U.S. Geol. Survey Prof. Paper 800-C, p. C95–C101.

Clark, S. H. B., 1972, Reconnaissance bedrock geologic map of the Chugach Mountains near Anchorage, Alaska: U.S. Geol. Survey Misc. Field Inv. Map MF-350, scale 1:250,000.

Coats, R. R., 1962, Magma type and crustal structure in the Aleutian arc, *in* MacDonald, G. A., and Kuno, Hisashi, eds., The crust of the Pacific Basin: Am. Geophys. Union Mon. 6, p. 92–109.

——— 1968, Basaltic andesites, *in* Hess, H. H., and Poldervaart, Arie, eds., Basalts–The Poldervaart treatise on rocks of basaltic composition, v. 2: New York, John Wiley and Sons, p. 689–736.

Dickinson, W. R., 1970, Relations of andesites, granites, and derivative sandstones to arc-trench tectonics: Rev. Geophysics and Space Physics, v. 8, no. 4, p. 813–860.

——— 1971a, Clastic sedimentary sequences deposited in shelf, slope, and trough settings between magmatic arcs and associated trenches: Pacific Geology, no. 3 (1971), p. 15–30.

——— 1971b, Plate tectonic models of geosynclines: Earth and Planetary Sci. Letters, no. 10, p. 165–174.

Eberlein, G. D., and Churkin, Michael, 1970, Paleozoic stratigraphy in northwest coastal area of Prince of Wales Island, southeastern Alaska: U.S. Geol. Survey Bull. 1284, 67 p.

Forbes, R. B., 1959, The bedrock geology and petrology of the Juneau ice field area, southeastern Alaska: Washington Univ., Seattle, Ph. D. thesis, 265 p.

Forbes, R. B., and Engels, J. C., 1970, K^{40}/Ar^{40} age relations of the Coast Range batholith and related rocks of the Juneau ice field area, Alaska: Geol. Soc. America Bull., v. 81, no. 2, p. 579–584.

Grantz, Arthur, and Jones, D. L., 1960, Stratigraphy and age of the Matanuska Formation, south-central Alaska: Art. 159 *in* U.S. Geol. Survey Prof. Paper 400-B, p. B347–B350.

Grantz, Arthur, Jones, D. L., and Lanphere, M. A., 1966, Stratigraphy, paleontology, and isotopic ages of upper Mesozoic rocks in southwestern Wrangell Mountains, Alaska, *in* Geological Survey Research 1966: U.S. Geol. Survey Prof. Paper 550-C, p. C39–C47.

Hutchison, W. W., 1967, Prince Rupert and Skeena map-area, British Columbia: Canada Geol. Survey Paper 66-33, 27 p.

Imlay, R. W., 1960, Early Cretaceous (Albian) ammonites from the Chitina Valley and Talkeetna Mountains, Alaska: U.S. Geol. Survey Prof. Paper 354-D, p. 87–114.

Irvine, T. N., 1967, The Duke Island ultramafic complex, southeastern Alaska, *in* Wyllie, P. J., ed., Ultramafic and related rocks: New York, John Wiley and Sons, p. 84–97.

Jones, D. L., 1963, Upper Cretaceous (Campanian and Maestrichtian) ammonites from southern Alaska: U.S. Geol. Survey Prof. Paper 432, 53 p.

——1967, Cretaceous ammonites from the lower part of the Matanuska Formation, southern Alaska: U.S. Geol. Survey Prof. Paper 547, 49 p.

Jones, D. L., and Detterman, R. L., 1966, Cretaceous stratigraphy of the Kamishak Hills, Alaska Peninsula, *in* Geological Survey Research 1966: U.S. Geol. Survey Prof. Paper 550-D, p. D53–D58.

Jones, D. L., Irwin, W. P., and Ovenshine, A. T., 1972, Southeastern Alaska–A displaced continental fragment?, *in* Geological Survey Research 1972: U.S. Geol. Survey Prof. Paper 800-B, p. B211–B217.

Jones, D. L., and MacKevett, E. M., Jr., 1969, Summary of Cretaceous stratigraphy in part of the McCarthy quadrangle, Alaska: U.S. Geol. Survey Bull. 1274-K, p. K1–K19.

Jones, D. L., MacKevett, E. M., Jr., and Plafker, George, 1971, Speculations on late Mesozoic tectonic history of part of southern Alaska: Am. Assoc. Petroleum Geologists, Second Internat. Symposium on Arctic Geology, Program abstracts, p. 30.

Karig, D. C., 1971, Structural history of the Mariana Island arc system: Geol. Soc. America Bull., v. 82, p. 323–344.

Kindle, E. D., 1953, Dezadeash map area, Yukon Territory: Canada Geol. Survey Mem. 268, 68 p.

Knopf, Adolph, 1911, Geology of the Berners Bay region, Alaska: U.S. Geol. Survey Bull. 446, 58 p.

——1912, The Eagle River region, southeastern Alaska: U.S. Geol. Survey Bull. 502, 61 p.

Lanphere, M. A., 1968, Sr-Rb-K and Sr isotopic relationships in ultramafic rocks, southeastern Alaska: Earth and Planetary Sci. Letters, no. 4, p. 185–190.

Lanphere, M. A., and Eberlein, G. D., 1966, Potassium-argon ages of magnetite-bearing ultramafic complexes in southeastern Alaska: Geol. Soc. America Spec. Paper 87, p. 94.

Lanphere, M. A., Loney, R. A., and Brew, D. A., 1965, Potassium-argon ages of some plutonic rocks, Tenakee area, Chichagof Island, southeastern Alaska, *in* Geological Survey Research 1965: U.S. Geol. Survey Prof. Paper 525-B, p. B108–B111.

Lathram, E. H., 1964, Apparent right-lateral separation on Chatham Strait fault, southeastern Alaska: Geol. Soc. America Bull., v. 75, no. 3, p. 249–252.

Lathram, E. H., Loney, R. A., Condon, W. H., and Berg, H. C., 1959, Progress map of the geology of the Juneau quadrangle, Alaska: U.S. Geol. Survey Misc. Geol. Inv. Map I-303, scale 1:250,000.

Lathram, E. H., Pomeroy, J. S., Berg, H. C., and Loney, R. A., 1965, Reconnaissance geology of Admiralty Island, Alaska: U.S. Geol. Survey Bull. 1181-R, 48 p.

Loney, R. A., 1964, Stratigraphy and petrography of the Pybus-Gambier area, Admiralty Island, Alaska: U.S. Geol. Survey Bull. 1178, 103 p.

Loney, R. A., Berg, H. C., Pomeroy, J. S., and Brew, D. A., 1963, Reconnaissance geologic map of Chichagof Island and northwestern Baranof Island, Alaska: U.S. Geol. Survey Misc. Geol. Inv. Map I-388, scale 1:250,000.

Loney, R. A., Brew, D. A., and Lanphere, M. A., 1967, Post-Paleozoic radiometric ages and their relevance to fault movements, northern southeastern Alaska: Geol. Soc. America Bull., v. 78, no. 4, p. 511–526.

Loney, R. A., Pomeroy, J. S., Brew, D. A., and Muffler, L. J. P., 1964, Reconnaissance geologic map of Baranof and Kruzof Islands, Alaska: U.S. Geol. Survey Misc. Geol. Inv. Map I-411, scale 1:250,000.

McBirney, A. R., 1969, Andesitic and rhyolitic volcanism of orogenic belts, *in* Hart, P. J., ed., Earth's crust and upper mantle: Am. Geophys. Union Mon. 13, p. 501–507.

MacKevett, E. M., Jr., 1969, Three newly named Jurassic formations in the McCarthy C-5 quadrangle, *in* Changes in stratigraphic nomenclature by the U.S. Geological Survey 1967: U.S. Geol. Survey Bull. 1274-A, p. A35–A49.

——1970, Geology of the McCarthy B-4 quadrangle, Alaska: U.S. Geol. Survey Bull. 1333, 31 p.

——1971, Stratigraphy and general geology of the McCarthy C-5 quadrangle, Alaska: U.S. Geol. Survey Bull. 1323, 35 p.

Martin, G. C., 1926, The Mesozoic stratigraphy of Alaska: U.S. Geol. Survey Bull. 776, 493 p.

Matsuda, T., and Uyeda, S., 1971, On the Pacific-type orogeny and its model-extension of the paired belts concept and possible origin of marginal seas: Tectonophysics, v. 11, p. 5–27.

Miller, D. J., Payne, T. G., and Gryc, George, 1959, Geology of possible petroleum provinces in Alaska: U.S. Geol. Survey Bull. 1094, 131 p.

Monger, J. W. H., and Ross, C. A., 1971, Distribution of fusulinaceans in the western Canadian cordillera: Canadian Jour. Earth Sci., v. 8, no. 2, p. 259–278.

Monger, J. W. H., Souther, J. G., and Gabrielse, H., 1972, Evolution of the Canadian cordillera–A plate-tectonic model: Am. Jour. Sci. v. 272, no. 7, p. 577–602.

Moore, G. W., 1969, New formations on Kodiak and adjacent islands, Alaska, *in* Changes in stratigraphic nomenclature by the U.S. Geological Survey 1967: U.S. Geol. Survey Bull. 1274-A, p. A27–A35.

Moore, J. C., 1972, Southwestern Alaska–Bering Shelf edge: Science, v. 175, no. 4026, p. 1103–1105.

Muffler, L. J. P., 1967, Stratigraphy of the Keku Islets and neighboring parts of Kuiu and Kupreanof Islands, southeastern Alaska: U.S. Geol. Survey Bull. 1241-C, 52 p.

Muller, J. E., 1967, Kluane Lake map-area, Yukon Territory: Canada Geol. Survey Mem. 340, 137 p.

Nockolds, S. R., 1954, Average chemical compositions of some igneous rocks: Geol. Soc. America Bull., v. 65, p. 1007–1032.

Ovenshine, A. T., and Brew, D. A., 1972, Separation and history of the Chatham Strait fault, southeastern Alaska, North America [abs.]: Internat. Geol. Cong., 24th, Montreal, Canada, Proc. [In press]

Packham, G. H., and Falvey, D. H., 1971, An hypothesis for the formation of marginal seas in the western Pacific: Tectonophysics, v. 11, p. 79–109.

Plafker, George, 1967, Geologic map of the Gulf of Alaska Tertiary Province, Alaska: U.S. Geol. Survey Misc. Geol. Inv. Map I-484, scale 1:500,000.

——1971, Possible future petroleum resources of Pacific-margin Tertiary basin, Alaska, *in* Cram, I. H., ed., Future petroleum provinces of the United States: Am. Assoc. Petroleum Geologists Mem. 15, p. 120–135.

——1972, New data on Cenozoic displacements along the Fairweather fault system, Alaska, *in* Faults, fractures, lineaments, and related mineralization in the Canadian cordillera: Geol. Assoc. Canada, Cordilleran Section, Programme and abstracts, p. 30.

Richter, D. H., 1971a, Reconnaissance geologic map and section of the

Nabesna A-3 quadrangle, Alaska: U.S. Geol. Survey Misc. Geol. Inv. Map I-655, scale 1:63,360.

Richter, D. H., 1971b, Reconnaissance geologic map and section of the Nabesna A-4 quadrangle, Alaska: U.S. Geol. Survey Misc. Geol. Inv. Map I-656, scale 1:63,360.

Richter, D. H., and Jones, D. L., 1971, Structure and stratigraphy of eastern Alaska Range, Alaska: Am. Assoc. Petroleum Geologists, Second Internat. Symposium on Arctic Geology, Program abstracts, p. 45.

——1972a, Structure and stratigraphy of eastern Alaska Range, Alaska: Am. Assoc. Petroleum Geologists, Second Internat. Symposium on Arctic Geology Proc. [In press]

——1972b, Reconnaissance geologic map and sections of the Nabesna A-2 quadrangle, Alaska: U.S. Geol. Survey Misc. Geol. Inv. Map I-749, scale 1:63,360. [In press]

Richter, D. H., and Schmoll, H. R., 1972, Reconnaissance geologic map and sections of the Nabesna C-5 quadrangle, Alaska: U.S. Geol. Survey Geol. Quad. Map GQ-1062, scale 1:63,360. [In press]

Saks, V. N., 1960, On the problem of the distribution and stratigraphic role of Lower Cretaceous Belemnites in the north of Siberia [In Russian]: Akad. Nauk SSSR Doklady, v. 131, p. 640–642 [English translation in March, 1961, Am. Geol. Inst.].

Smith, J. G., and MacKevett, E. M., Jr., 1970, The Skolai Group in the McCarthy B-4, C-4, and C-5 quadrangles, Wrangell Mountains, Alaska: U.S. Geol. Survey Bull. 1274-Q, p. Q1–Q26.

Smith, R. E., 1968, Redistribution of major elements in the alteration of some basic lavas during burial metamorphism: Jour. Petrology, v. 9, p. 191–219.

St. Amand, Pierre, 1957, Geological and geophysical synthesis of the tectonics of portions of British Columbia, the Yukon Territory, and Alaska: Geol. Soc. America Bull., v. 68, p. 1343–1370.

Stevens, J. R., 1965, The Jurassic and Cretaceous belemnites of New Zealand and a review of the Jurassic and Cretaceous belemnites of the Indo-Pacific region: New Zealand Geol. Survey, Paleont. Bull. 36, 283 p.

Taylor, H. P., Jr., 1967, The zoned ultramafic intrusions of southeastern Alaska, *in* Wyllie, P. J., ed., Ultramafic and related rocks: New York, John Wiley and Sons, p. 97–121.

Taylor, H. P., Jr., and Noble, J. A., 1969, Origin of magnetite in the zoned ultramafic complexes of southeastern Alaska: Econ. Geology Mon. 4, p. 209–230.

Twenhofel, W. S., and Sainsbury, C. L., 1958, Fault patterns in southeastern Alaska: Geol. Soc. America Bull., v. 69, p. 1431–1442.

Watson, K. D., 1948, The Squaw Creek–Rainy Hollow area, northern British Columbia: British Columbia Dept. Mines and Petroleum Resources Bull. 25, 74 p.

Williams, Howell, Turner, F. J., and Gilbert, C. M., 1954, Petrography: San Francisco, W. H. Freeman and Co., 406 p.