PRELIMINARY DESCRIPTION OF THE LATE SILURIAN-EARLY DEVONIAN KLAKAS OROGENY IN THE SOUTHERN ALEXANDER TERRANE, SOUTHEASTERN ALASKA

George E. Gehrels and Jason B. Saleeby
Division of Geological and Planetary Sciences
California Institute of Technology
Pasadena, California 91125

and

Henry C. Berg
Branch of Alaskan Geology
U.S. Geological Survey
4200 University Drive
Anchorage, Alaska 99508

ABSTRACT

The Klakas orogeny is a Late Silurian-Early Devonian deformational, metamorphic, and mountain-building event that marks a major change in the geologic history of the southern Alexander terrane. During Ordovician-Silurian time this region was a marine volcano-plutonic province in which volcaniclastic strata and shallow-water limestones were deposited adjacent to andesitic and dacitic volcanic centers. After the Klakas orogeny, shallow-marine sedimentation prevailed with only local volcanism. Manifestations of this orogenic event included: 1) shallow-level brecciation of Ordovician-Silurian rocks on southern Prince of Wales Island, 2) deformation along with greenschist- and perhaps amphibolite-facies metamorphism of Ordovician-Silurian rocks on Annette and Gravina Islands, 3) structural uplift of at least several kilometers during or shortly after the deformation, 4) uplift of mountainous areas with kilometer-scale topographic relief, and 5) deposition of a subaerial to shallow-marine clastic wedge that was shed from these uplifted areas.

Reconstructions of the paleogeography and tectonic history of the Alexander terrane during Ordovician through Devonian time reveal that: 1) the eastern (Annette) and western (Craig) subterranes of the Alexander terrane are part of the same tectonic fragment, 2) the deformational fabrics in Paleozoic rocks in the southern part of the terrane are primarily Late Silurian-Early Devonian in age, and not a product of the Late Cretaceous accretion of the terrane, and 3) northeastern Chichagof Island may have been adjacent to southern Prince of Wales Island during Silurian-Devonian time, which suggests that the Chatham Strait fault and related fault systems may have approximately 350 km of post-Devonian right-slip displacement.

INTRODUCTION

The Alexander terrane consists of a distinct package of Lower Ordovician (and possibly older) through Upper Triassic rocks that underlies much of southeastern Alaska and part of southwestern Yukon (Fig. 1; Berg, Jones, and Richter, 1972). Wilson (1968) initially proposed that these rocks were part of an allochthonous tectonic fragment because they occurred outboard (to the west) of both the late Precambrian to Jurassic shelf of western North America and other fragments that had significantly different geologic histories. This proposal was supported by the recognition of late Paleozoic faunal assemblages in central British Columbia that were quite different from coeval assemblages to the east and west (Monger and Ross, 1971). Jones and others (1972) subsequently proposed that the Alexander terrane was adjacent to northern California during much of Paleozoic time because of the similarities in Paleozoic strata and late Paleozoic faunal assemblages in these two regions. Paleomagnetic signatures in the Alexander terrane were interpreted to be consistent with this proposal: Ordovician through Carboniferous rocks rendered paleopositions of northeastern California-western Nevada (Van der Voo and others, 1980), whereas Upper Triassic rocks yielded a paleoposition consistent with the present location of the terrane (Hillhouse and Gromme, 1980).

The displacement of the terrane may have been more complex than a single late Paleozoic-early Mesozoic movement from northern California to southeastern Alaska, however, because 1) the Alexander terrane was probably juxtaposed against Wrangellia during Late Jurassic time (Berg, Jones and Richter, 1972; Coney and others, 1980) which is when Wrangellia is thought to have been in the southern hemisphere (Stone and others, 1982), and 2) the available geologic evidence suggests that the Alexander terrane was not accreted until Late Cretaceous time (Berg, Jones and Coney, 1978).

Purpose of This Report

This report is a preliminary description of a Late Silurian-Early Devonian orogenic event that occurred long before the Alexander terrane was accreted to its present position in southeastern Alaska. This event is herein referred to as the Klakas orogeny because the geologic relations that record the orogenic activity are best-developed in the Klakas Inlet area of southern Prince of Wales Island (Fig. 3). Following a brief introduction to the geology of the southern Alexander terrane, the various manifestations of the Klakas orogeny on southern Prince of Wales Island are described in detail, and then the evidence for this orogenic event on Annette and central Prince of Wales Islands is briefly reviewed. These descriptive sections are followed by a synthesis of the nature and age of the Klakas orogeny and a discussion of several implications of this event for the tectonic evolution of the Alexander terrane.

It should be noted that the interpretations made in this report are preliminary, as investigations into the Paleozoic geologic history of the southern part of the terrane are still in progress. Because both paleontologic and radiometric age information have been used in reconstructing this orogenic event, the calibration of the geologic and geochronometric time scales is critical: approximate (± 7 m.y.) ages of 408 m.y. for the Silurian-Devonian boundary and 438 m.y. for the Ordovician-Silurian boundary (Harland and others, 1982) are used in this report.

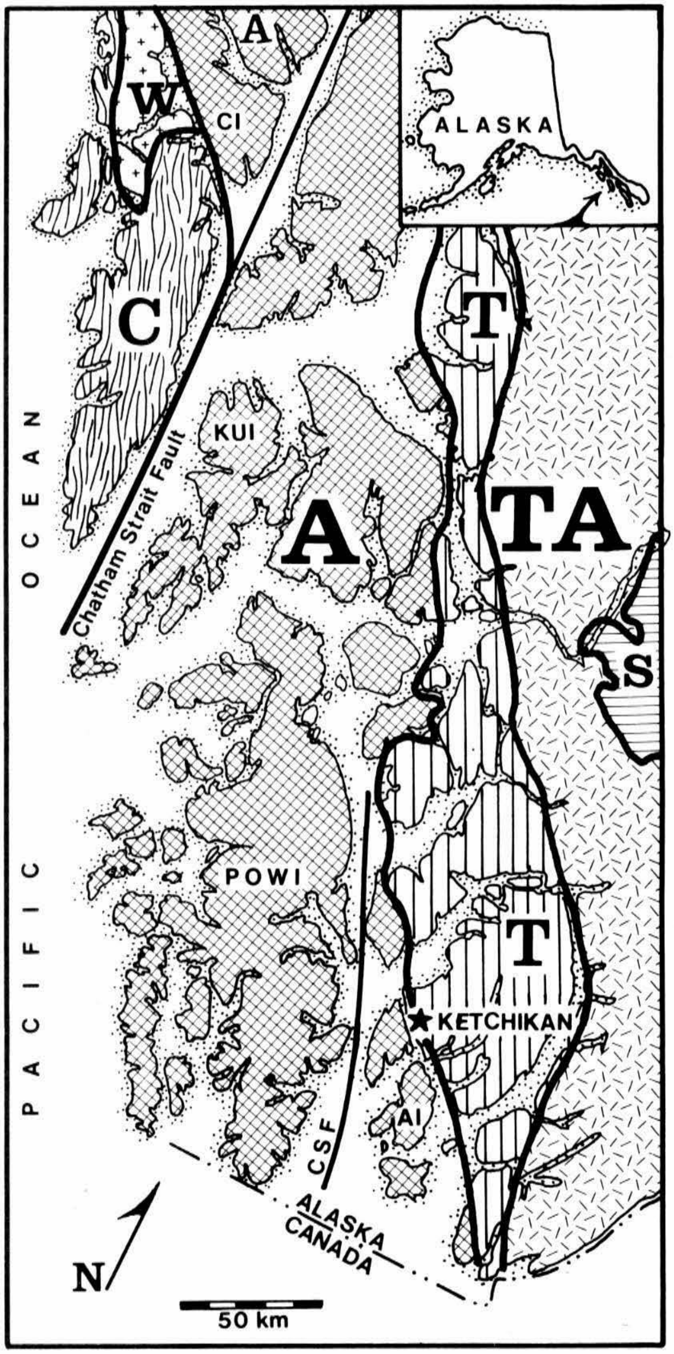

Figure 1. Terranes and terrane boundaries of southeastern Alaska (from Berg, Jones and Coney, 1978). TERRANES: A = Alexander (with Gravina-Nutzotin belt), C = Chugach, S = Stikine, T = Taku, TA = Tracy Arm, W = Wrangellia.
OTHER FEATURES: POWI = Prince of Wales Island, AI = Annette Island, KUI = Kuiu Island, CI = Chichagof Island, CSF = Clarence Strait fault.

INTRODUCTION TO THE GEOLOGY OF THE SOUTHERN ALEXANDER TERRANE

The Alexander terrane in southern southeastern Alaska consists of Ordovician-Silurian sedimentary, volcanic and plutonic rocks, superjacent Devonian through Upper Triassic sedimentary and volcanic rocks, and pre-Middle Ordovician metamorphic rocks of the Wales group. The Ordovician-Silurian rocks occur throughout the southern part of the terrane and include: 1) Lower Ordovician to Lower Silurian marine clastic strata and intermediate to silicic volcanic rocks that comprise or are equivalent to the Descon Formation (Eberlein and Churkin, 1970), 2) upper Lower to Upper Silurian limestones and clastic strata of the Heceta Limestone and correlative units (Ovenshine and Webster, 1970), and 3) diorites and more silicic (generally trondhjemitic) plutonic rocks. K/Ar (Lanphere and others, 1964; Turner and others, 1977) and U/Pb (Saleeby and others, 1983; Gehrels and others, 1983) ages range from 460 to 430 m.y. for the diorites, and 430 to 405 m.y. for the trondhjemites.

The Ordovician-Silurian rocks are not regionally metamorphosed or deformed on northern and central Prince of Wales Island, but to the south and east they become brecciated and foliated, and to the east the metamorphic grade increases to greenschist and perhaps amphibolite facies. This deformation and metamorphism is interpreted to be due in large part to the Klakas orogeny.

Lower Devonian strata of the Karheen Formation and correlative units were deposited in the southern part of the terrane after the Ordovician-Silurian rocks had been deformed and metamorphosed. These strata generally vary both laterally and vertically over short distances, and record deposition in a variety of subaerial, intertidal and marine environments (Eberlein and Churkin, 1970; Ovenshine and Churkin, 1969; and Savage and others, 1977). The contact at the base of the Devonian sequence is a major unconformity in the southern part of the terrane but it generally becomes more conformable toward the north (Eberlein and Churkin, 1970; Churkin and Eberlein, 1977). As described in detail in the following sections, this unconformity and the thickness and facies variations in the Devonian strata reveal significant information about the patterns of uplift during Late Silurian-Early Devonian time.

On central Prince of Wales Island the Lower Devonian strata are overlain by Middle Devonian through Pennsylvanian shallow-marine limestone, fine-grained clastic strata and volcanic rocks (Eberlein and Churkin, 1970). The lack of equivalent strata on Annette, Gravina and southern Prince of Wales Islands may be due either to non-deposition or to post-depositional erosion. On Annette and Gravina Islands the Ordovician through Devonian rocks are locally overlain by Upper Triassic sedimentary and volcanic rocks, and by Jura-Cretaceous rocks of the Gravina-Nutzotin belt (Berg, Jones and Richter, 1972). Correlative Mesozoic rocks have not been recognized on Prince of Wales Island.

Several suites of Cretaceous and Tertiary plutons have intruded the various terranes in southeastern Alaska (Brew and Morrell, 1980). Some of these suites are found in more than one terrane, and are in part younger than the juxtaposition of the various tectonic fragments.

Pre-Middle Ordovician metasedimentary and metavolcanic rocks of the Wales group occur primarily on south-central Prince of Wales Island (Fig. 2). In most areas the contact between the Wales group and the Ordovician through Devonian rocks is a thrust fault which dips away from the Wales group. Eberlein and others (1983) report that in several areas the Ordovician-Silurian rocks are in depositional or intrusive contact with the Wales group. Mid-Cretaceous granitic plutons intrude both of these packages of rocks, and also cross-cut the thrust fault that separates them (Turner and others, 1977; Redman, 1981). The available age constraints therefore suggest that this thrust fault moved after the deposition of the Devonian rocks and prior to mid-Cretaceous time, although an earlier phase of movement cannot be ruled out.

DESCRIPTION OF THE KLAKAS OROGENY

Southern Prince of Wales Island

Southern Prince of Wales Island is underlain by two distinct packages of rocks, which are separated by a regional thrust fault (Fig. 3). Beneath and west of the thrust fault are metasedimentary and metavolcanic rocks of the Wales group. Ordovician through Devonian rocks occur above and to the east of the fault.

Ordovician-Silurian rocks

Ordovician-Silurian rocks on southern Prince of Wales Island consist primarily of dioritic and more silicic plutons on the east side of the island, and interlayered volcanic and marine sedimentary rocks to the west (Fig. 3). Sedimentary rocks include mudstone, siliceous black shale, conglomeratic graywacke and minor limestone which are similar to Lower Ordovician-Lower Silurian strata in the Descon Formation on northwestern Prince of Wales Island (Eberlein and Churkin, 1970; Herreid and others, 1978). Early Middle Ordovician conodonts (A.G. Harris, 1979, written communication) and latest Early Ordovician graptolites (Eberlein and others, 1983, p. 32) have been recovered from these strata on the east shore of Klakas Inlet (Fig. 3). Interlayered volcanic rocks consist predominantly of intermediate-composition pillow flows, pillow breccia, and tuff breccia, with subordinate silicic flow breccia and tuff.

Deformational Fabrics

On most of southern Prince of Wales Island the volcanic and sedimentary rocks are moderately folded, and are either unmetamorphosed or are metamorphosed to low grades. Likewise, the plutonic rocks generally are massive, with only local brecciation, foliation, or primary compositional banding. In the Klakas Inlet area, however, these rocks are highly brecciated and fractured. The intensity of this deformation appears to increase toward the thrust fault which separates the Ordovician-Silurian rocks from the Wales group (Fig. 3). In contrast, the rocks in the Wales group beneath and west of the fault do not have similar deformational fabrics. Brecciation above the thrust is particularly well-developed in the silicic plutonic rocks, which have kilometer-size zones in which the original rock has been milled down to cobble-size angular fragments in a finer-grained, carbonate-rich matrix (Figures 4A and B). Deformational fabrics in the other rock-types include brecciation similar to that in the plutonic rocks (Fig. 4C), zones in which thin fractures are randomly oriented and distributed throughout the rock, and, locally in the finer-grained rocks, a penetrative but very irregular cataclastic(?) foliation. Planar fabrics in the brecciated and fractured rocks are not well developed, but where present they are generally NNW- or NNE-striking and steeply dipping, or are nearly horizontal. Although these rocks were not significantly metamorphosed

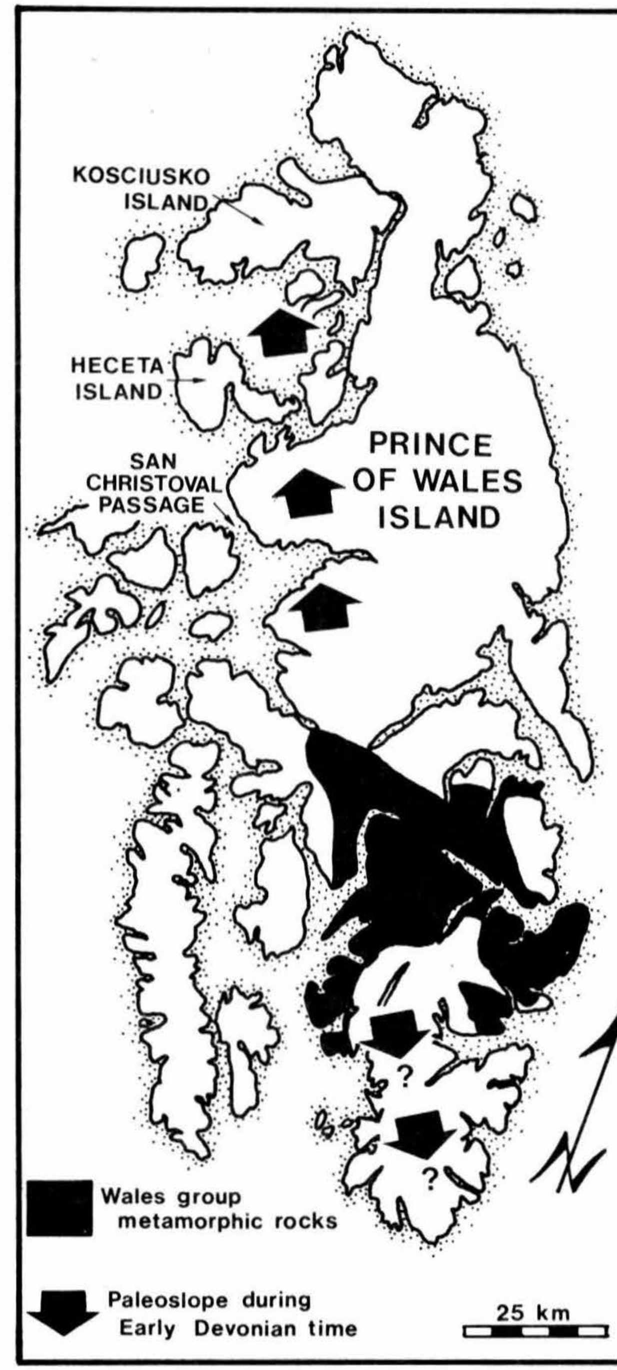

Figure 2. Map of Prince of Wales Island showing the paleoslope directions during Early Devonian time, and the present-day location of rocks of the Wales group. [Paleoslope directions from relations described in this report and inferred from Ovenshine and Churkin (1969). Location of the Wales group rocks from Eberlein and others (1983), Redman (1981) and Figure 3 of this report.]

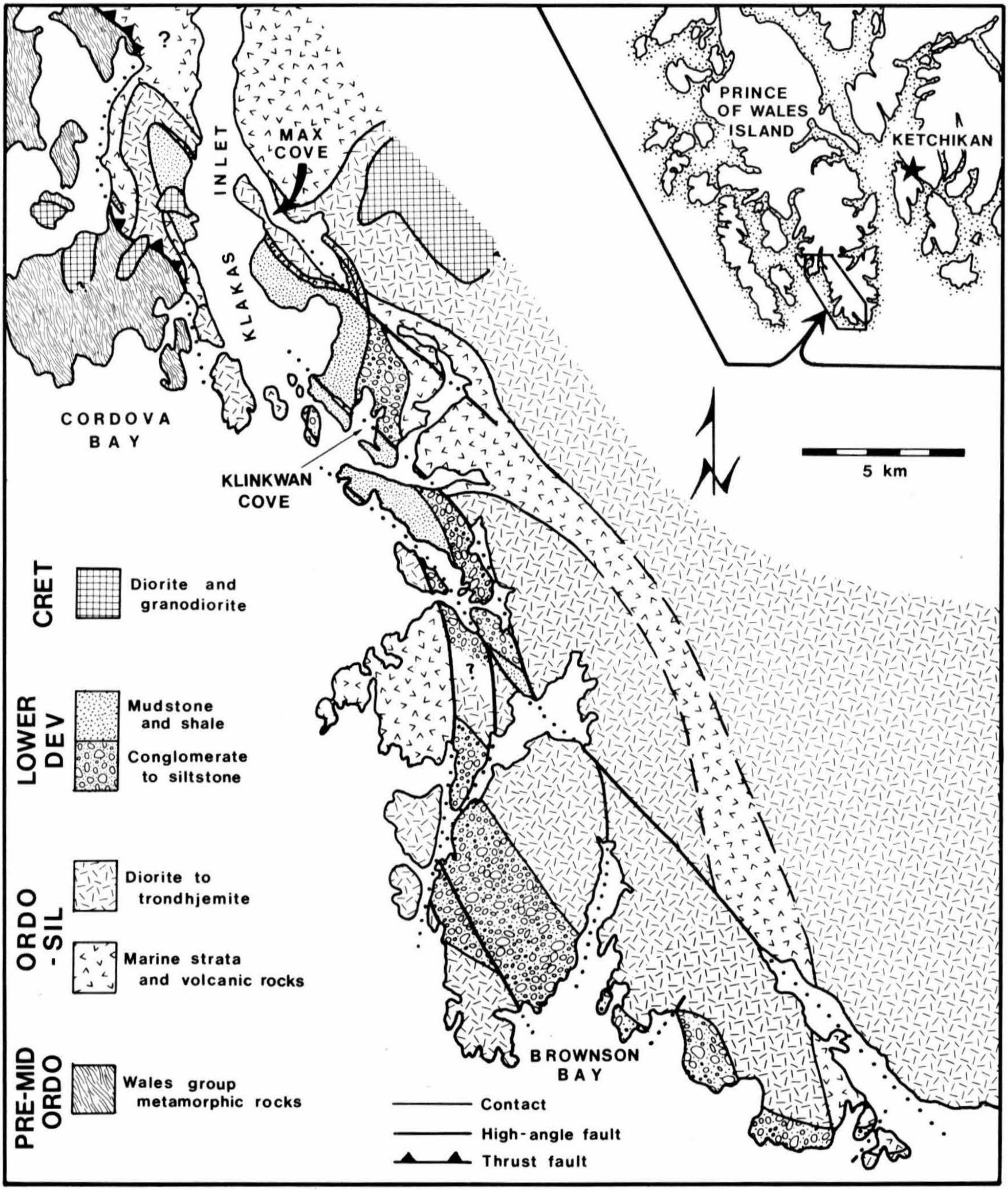

Figure 3. Geologic sketch-map of the west side of southernmost Prince of Wales Island.

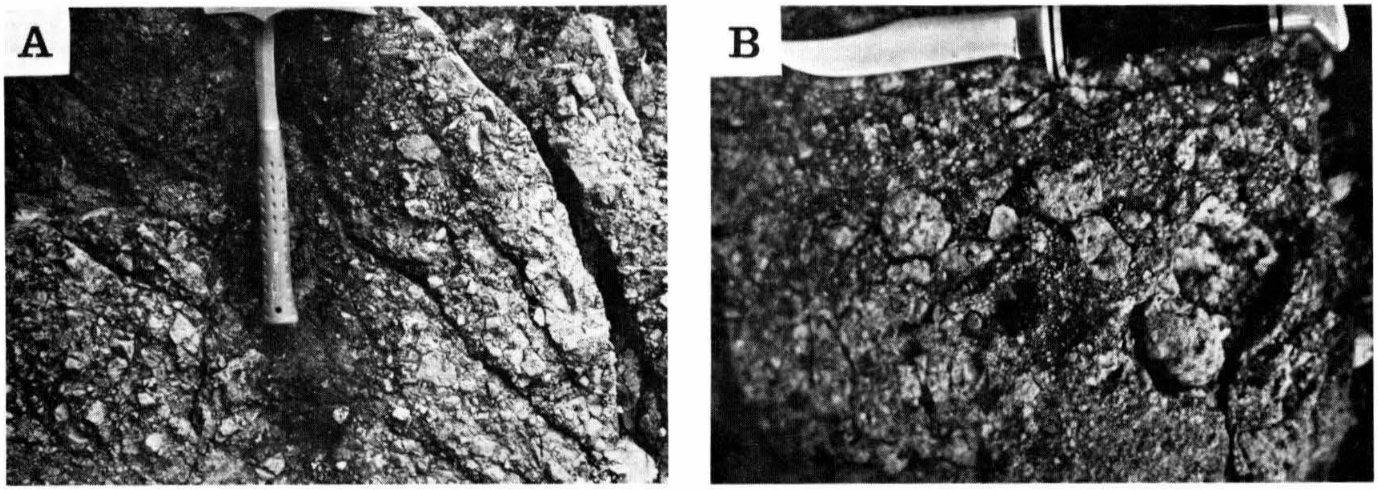

Figure 4. Photographs of the brecciation in the Ordovician-Silurian rocks. (A) and (B): Brecciation in the silicic plutonic rocks, (C): Brecciated intermediate-composition volcanic rock.

during the deformational event, they were overprinted by an orange-weathering dolomitic alteration.

The youngest dated rock in the area which has been deformed is a silicic pluton in Max Cove (Fig. 3) that has a minimum K/Ar (hornblende) age of 421 ± 13 m.y. (Turner and others, 1977). U/Pb ages of silicic plutons elsewhere in the southern part of the terrane range from 430 m.y. to as young as 405 m.y. (Saleeby and others, 1983; Gehrels and others, 1983), which, according to the time scale of Harland and others (1982), is mainly during Middle and Late Silurian time.

Devonian strata

The Ordovician-Silurian rocks on southern Prince of Wales Island are unconformably overlain by a generally transgressive sequence of Lower and lower Middle Devonian strata (Figures 3 and 5). In the Klinkwan Cove area (Fig. 3), the basal unit in the sequence is a massive polymictic conglomerate that contains rounded, meter-size boulders of diorite, more silicic plutonic rocks, and volcanic rocks (Fig. 6). This coarse conglomerate fines up-section into sandy conglomerate, sandstone, siltstone, and mudstone that have well-developed crossbedding and local channelling. These units are generally reddish in color and probably were deposited in subaerial environments by fluvial or alluvial processes. Overlying these redbeds are red and green shale, chert pebble conglomerate, and a several-meter-thick fossiliferous gray limestone which formed in intertidal to shallow-marine environments. Grain size continues to fine upsection into dark gray-brown layered and laminated mudstone and finally into graptolitic black shale. Thin layers and lenses of polymictic conglomerate in these fine-grained clastic strata may have been deposited in channels in a slope or submarine fan environment. The total thickness of the stratigraphic section in this area is approximately 2 km, with the uncertainty due to the lack of bedding in the thick basal conglomerate and to disruption of the section by younger strike-slip faults. The graptolitic shale is apparently the youngest unit in the section.

On southernmost Prince of Wales Island, the basal conglomerate, which is more than a kilometer in thickness, is overlain by a thick section of sandstone mudstone, and minor limestone (Fig. 5). Higher parts of the section are not seen in this area. Toward the north, in the Klakas Inlet-Max Cove area (Fig. 3), the lower units in the sequence are much thinner (Fig. 5). Locally in this area the conglomerate at the base of the section is a monomictic breccia which is interpreted to have been deposited adjacent to fault-bounded basement highs. At one locality this breccia

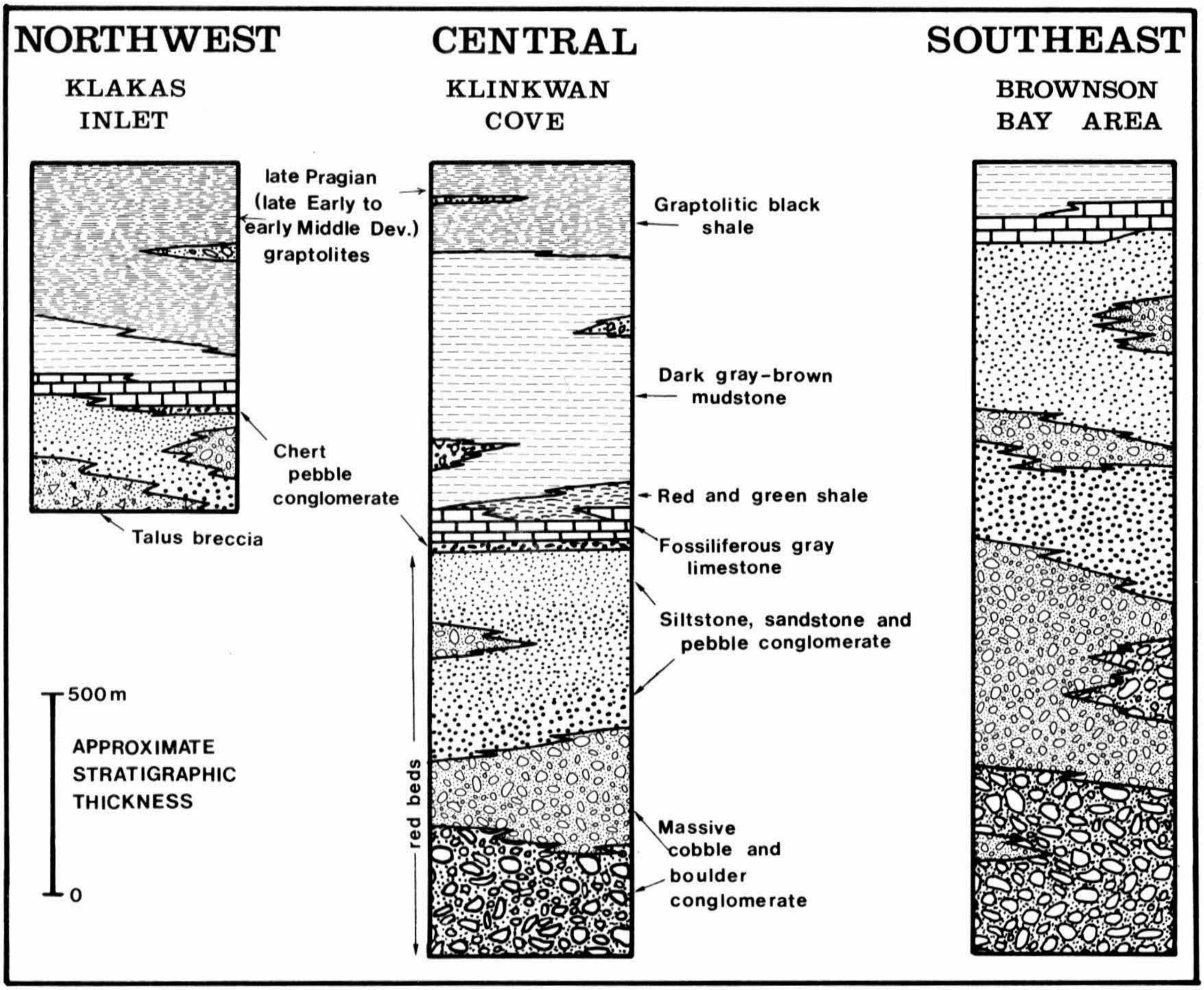

Figure 5. Schematic stratigraphic columns of Lower to lower Middle Devonian strata on southern Prince of Wales Island. Localities are shown on Figure 3. Graptolite ages from Churkin and others (1970).

Figure 6. Photograph of a large clast in the basal conglomerate of the Devonian sequence.

is flattened and foliated, whereas the overlying shale is not. The bounding faults are therefore interpreted to have been active during the deposition of the breccia, but not during the deposition of the shale.

Although the transport direction of the detritus in the Devonian strata has not yet been determined in the field, the southward thickening of the coarse clastic part of the sedimentary section, an apparent northward increase in deformation in the subjacent rocks, and the presence of talus breccia overlain by marine shale in the northern part of the study area, all suggest that the source area may have been toward the north or northwest (Fig. 2).

The age of these strata is established primarily by late Early (late Pragian) to early Middle Devonian graptolites in the black shale (Churkin and others, 1970). Limestones lower in the section have Middle and perhaps Early Devonian megafossils (Buddington and Chapin, 1929) and Late Silurian-Early Devonian conodonts (A.G. Harris, 1979, written communication). The Devonian strata have been folded into open, gently northwest-plunging folds, but they have not experienced the deformational event recorded in the Ordovician-Silurian rocks. Thus, the Ordovician-Silurian rocks in the Klakas Inlet area must have been deformed and uplifted after the emplacement of the Middle-Late Silurian silicic plutons, and prior to the deposition of the Lower to lower Middle Devonian coarse clastic strata.

ANNETTE ISLAND

Ordovician through Devonian rocks on Annette and Gravina Islands (Fig. 7) are generally correlative with those on southern Prince of Wales Island (Berg, 1972 and 1973; Gehrels and others, 1983), but they are inferred to record a somewhat different manifestation of the Klakas orogeny. Because most of our detailed work has been done on southern Annette Island, the following discussion will focus primarily on the record of Late Silurian-Early Devonian orogenic activity in this area.

Ordovician-Silurian rocks on Annette Island consist predominantly of dioritic and large trondhjemitic plutons, with only minor marine strata and volcanic rocks (Fig. 7). In contrast to southern Prince of Wales Island, the dioritic, volcanic and sedimentary rocks on Annette Island have all been metamorphosed to greenschist and perhaps amphibolite facies, and generally have a north-northwest striking foliation. The trondhjemitic plutons that underlie much of Annette Island (Fig. 7) have this foliation along their margins but they are generally brecciated in their interiors. Although the presence of similar foliations in both the trondhjemites and the metamorphic rocks suggests that the metamorphism occurred after the trondhjemites were emplaced, we have not yet been able to document a metamorphic overprint in these silicic plutonic rocks. Thus, the main deformational event and perhaps the metamorphism occurred after the emplacement of the Middle-Late Silurian trondhjemites, although the metamorphism may have occurred earlier in the Silurian.

Devonian marine strata unconformably overlie the deformed and metamorphosed Ordovician-Silurian rocks on southern Annette Island, and also occur to the south on Hotspur Island (Fig. 7). On southern Annette Island, the base of the section is a thin pebble conglomerate that overlies a highly deformed metadiorite. Overlying strata consist of black shale, mudstone, calcareous mudstone, siltstone and conglomerate. Although the base of the section has been seen at only this one locality, conglomerates higher in the section contain clasts of trondhjemitic, dioritic, and various metamorphic rocks.

On Hotspur Island the stratigraphic section includes interbedded siltstone and argillite overlain by a sequence of olistostromes (with meter-scale intraformational olistoliths), gray and black shale, and intermediate-composition pillow flows and aquagene tuff. The base of the section is not seen on this Island.

Megafossils in the lower part of the section on Annette and Hotspur Islands are probably Middle Devonian in age (Buddington and Chapin, 1929), although the faunal assemblage is permissive of an Early Devonian or possibly latest Silurian age assignment (Berg, 1972). The volcanic rocks at the top of the section may be correlative with the Middle Devonian Coronados or St. Joseph Island Volcanics, or the Upper Devonian Port Refugio volcanics on Prince of Wales Island (Eberlein and Churkin, 1970).

The Devonian strata on Annette and Hotspur Islands are moderately deformed and recrystallized, but they do not have the metamorphic mineral assemblages or foliation of the subjacent Ordovician-Silurian rocks. Because the style of deformation and the low-grade metamorphism in the Devonian strata are generally similar to those in the Triassic and Jura-Cretaceous rocks on the east side of Annette Island (Fig. 7), they are assumed to be post-Jura-Cretaceous in age and perhaps related to the Late Cretaceous accretion of the Alexander terrane (Berg, Jones and Coney, 1978).

CENTRAL PRINCE OF WALES ISLAND

The geologic record on central Prince of Wales Island contains significant information about the paleogeography and tectonics of the southern Alexander terrane during the Klakas orogeny. The geology of this area has been mapped and described primarily by Michael Churkin Jr., G.D. Eberlein, A.T. Ovenshine, and N.M. Savage, and is only briefly outlined below.

Ordovician-Silurian rocks on central Prince of Wales Island include marine clastic strata, basaltic volcanic rocks and dioritic plutonic rocks that are similar to those described on southern Prince of Wales Island. On central Prince of Wales Island, however, these rocks are overlain by upper Lower to Upper Silurian sedimentary rocks of the Heceta Limestone and correlative units (Eberlein and Churkin, 1970; Ovenshine and Webster, 1970; Eberlein and others, 1983). On the Islands west of central Prince of Wales Island (Fig. 2), the Descon Formation is overlain by as much as 3 kilometers of limestone and subordinate clastic strata of the Heceta Limestone (Eberlein and others, 1983). Toward the east this limestone thins and interfingers with clastic strata that generally overlie Ordovician-Lower Silurian volcanic rocks (Eberlein and others, 1983). Conglomerates in the Ordovician-Silurian strata throughout this region locally contain clasts of volcanic and plutonic rocks (Eberlein and others, 1983) which may have been shed from volcano-plutonic centers to the east.

The Ordovician-Silurian rocks are locally overlain by Lower Devonian conglomerate, sandstone, fine-grained clastic strata and limestone of the Karheen Formation (Eberlein and Churkin, 1970, Ovenshine and Churkin, 1969). On Kosciusko Island, near northern Prince of Wales Island (Fig. 2), Ovenshine and Churkin (1969) and Ovenshine (1975) report that intertidal calcareous mudstone of the Karheen Formation conformably overlies Upper Silurian Heceta Limestone. Toward the south, near Heceta Island (Fig. 2), these workers describe the Karheen Formation as a 3500-ft-thick (1067 m) sequence of sandstone and conglomerate that conformably overlies the Heceta Limestone. Eberlein and others (1983) report that Late Silurian (Ludlovian) shelly fossils and conodonts have been recovered from this limestone on Heceta Island, and Savage (1977) reports that the overlying Karheen Formation on eastern Heceta Island has yielded early Pragian (middle Early Devonian) conodonts. South of Heceta Island, in the San Cristoval Passage area (Fig.

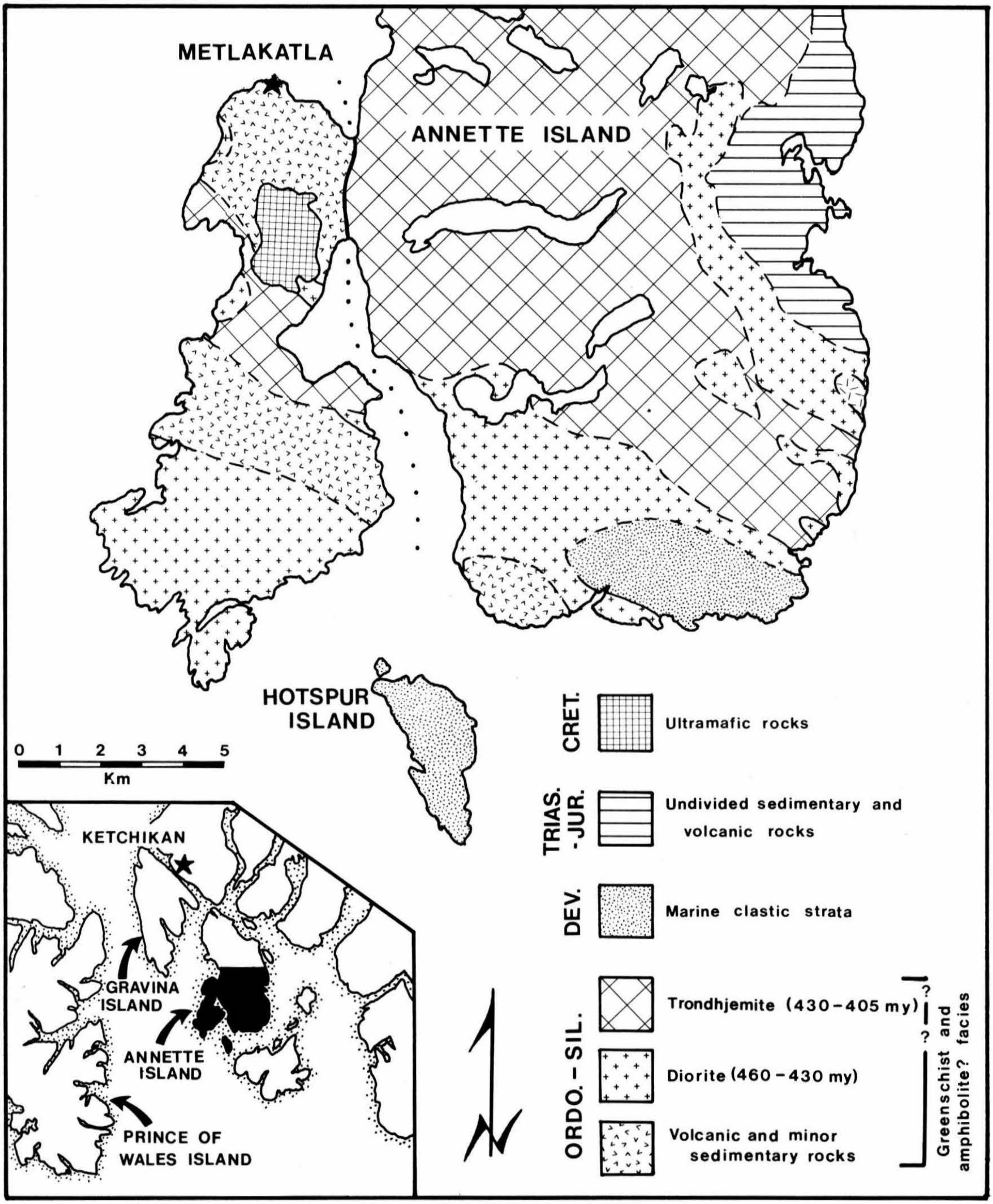

Figure 7. Geologic sketch-map of southern Annette Island (from Berg, 1972; Gehrels and others, 1983; and Gehrels, 1982, unpublished mapping).

2), the Karheen is a 6000-ft-thick (1830 m) conglomerate that unconformably overlies the Descon Formation (Ovenshine and Churkin, 1969), with no Heceta Limestone in between. Eberlein and Churkin (1970) report that the southward thinning and disappearance of the Heceta Limestone in this area may be due to pre-Karheen erosion.

Sedimentary cycles and facies relations suggest that the Karheen Formation was deposited in intertidal to shallow-marine environments toward the northwest, and locally subaerial environments to the southeast (Ovenshine, 1975). Northwest-directed paleocurrent indicators combined with the southward thickening and coarsening of these strata led Ovenshine and Churkin (1969) to interpret the Karheen Formation as a clastic wedge that was shed from a source area to the southeast. These workers concluded that "the clastic wedge of the Karheen Formation records an interval of shallow marine to possibly nonmarine sedimentation that is the basinward manifestation of Late Silurian to pre-Middle Devonian diastrophism in southern southeastern Alaska".

SYNTHESIS OF THE KLAKAS OROGENY

A major unconformity between Devonian strata and the older rocks in southern southeastern Alaska was initially described by Buddington and Chapin (1929, p. 289). Boucout and others (1974) suggested that this unconformity separated Middle Devonian strata from older rocks, and was the result of a regional Middle Devonian orogeny. Ovenshine and Churkin (1969) and Churkin and Eberlein (1977, p. 779) proposed that the main unconformity occurred beneath the Lower Devonian strata (Karheen Formation and correlative units) and resulted from a major tectonic event during Late Silurian-pre-Middle Devonian time. The relations described in this report strongly suggest that the main tectonic event in the area occurred during Late Silurian-Early Devonian time and that this event was most intense in the southernmost part of the terrane in southeastern Alaska. This tectonic event produced all of the main attributes of an orogeny, including deformation and metamorphism, structural uplift of at least several kilometers, and the formation of kilometer-scale topographic relief and probably mountain ranges. These manifestations of the Klakas orogeny are summarized below.

Deformation and Metamorphism

The earliest manifestation of the Klakas orogeny is the deformation and metamorphism of Ordovician-Silurian volcanic, plutonic and sedimentary rocks. On southern Prince of Wales Island the cataclastic style of deformation, a pervasive carbonate alteration, and the lack of attendant metamorphism all suggest that the rocks were deformed at fairly shallow depths. In contrast, the Ordovician-Silurian rocks on Annette and Gravina Islands were metamorphosed to greenschist and perhaps amphibolite facies, which suggests that they were at significant depths during at least the early stages of the orogenic activity. In both areas the youngest rocks that have experienced this deformation are the silicic plutons, which were emplaced primarily during Middle and Late Silurian time. We have not yet been able to determine whether these silicic plutons have been metamorphosed to the same degree as the slightly older rocks. The Ordovician-Silurian rocks on central and northern Prince of Wales Island have not experienced the same deformation and metamorphism as the rocks to the south and east.

Structural Uplift

Uplift of the Ordovician-Silurian rocks began during or shortly after the main phase of deformation and metamorphism. On southern Prince of Wales Island the silicic plutonic rocks were uplifted by an amount greater than their emplacement depth, and exposed at the surface prior to the deposition of the Lower Devonian strata. The amount of structural uplift was probably greater on Annette Island, as Ordovician-Silurian rocks of greenschist- and perhaps amphibolite-facies were brought to the surface prior to Middle Devonian or perhaps earlier time. On central Prince of Wales Island this structural uplift may be recorded by the southward thinning and disappearance of the Heceta Limestone (Eberlein and Churkin, 1970). The amount of uplift decreased to the north on Prince of Wales Island, as indicated by the conformable contact between the Karheen Formation and the Heceta Limestone on Heceta and Kosciusko Islands.

Mountain-building

Evidence for a major mountain-building event on southern Prince of Wales Island is recorded in the facies and thickness relations in the superjacent Devonian strata. Deposition in a high-energy fluvial environment is recorded by cross-bedding, channelling, and the presence of rounded, meter-size boulders (Fig. 7) in the lower part of the Devonian section. The thickness of these units, the large size of the clasts, and the similarity in composition of the clasts and the subjacent rocks, all suggest that the strata were deposited near the source area, and that the region had considerable topographic relief. Variations in the thickness and facies of these strata suggests that the source area may have been to the north or northwest, but this has not yet been documented by paleocurrent or detailed provenance studies. Ovenshine and Churkin (1969) and Ovenshine (1975, p. 128) concluded that the conglomerate in the Karheen Formation on central Prince of Wales Island also may have been deposited in a subaerial environment, and that these clastic strata were shed from a source area to the southeast. The available evidence therefore suggests that the coarse clastic detritus on Prince of Wales Island may have been shed from a source area near south-central Prince of Wales Island (Fig. 2). The influx of clastic detritus between Ludlovian (Late Silurian) and early Pragian (middle Early Devonian) time on Heceta Island and between Middle-Late Silurian and late Pragian (late Early-early Middle Devonian) time on southern Prince of Wales Island presumably records the initiation of this mountain-building event.

The patterns of deformation and uplift suggest that mountainous areas also existed on Annette and Gravina Islands, although the presence of these uplifted areas has not been preserved in the Devonian sedimentary record. However, because the base of the section has been seen at only one locality, and because overlying strata are probably Middle Devonian in age (Berg, 1972), the Late Silurian-Early Devonian paleogeography is difficult to reconstruct.

Cause of the Klakas orogeny

An appreciation for the cause of the Klakas orogeny must await more detailed studies of the deformational fabrics on Annette, Gravina, and southern Prince of Wales Islands; the metamorphic history on Annette and Gravina Islands; and the age and facies relations of Devonian strata throughout the southern Alexander terrane. This preliminary analysis suggests, however, that there is a spatial coincidence on Prince of Wales Island between the area that is thought to have been uplifted during the Klakas orogeny and the present distribution of rocks in the Wales group (Fig. 2). Although the thrust fault which separates the Wales group from the Ordovician through Devonian rocks is known to have moved after the Devonian strata were deposited, it is an interesting possibility that the deformation and uplift during the Klakas orogeny could have been genetically related to a Late Silurian-Early Devonian phase of movement on this and other thrust faults.

REGIONAL IMPLICATIONS

This reconstruction of Late Silurian-Early Devonian orogenesis in southern southeastern Alaska provides several interesting implications for the tectonic history of the Alexander terrane:

1) Differences in the geologic records of Prince of Wales and Annette-Gravina Islands led Berg, Jones and Coney (1978) to suggest that these two regions were different subterranes of the Alexander terrane. The main differences between these two regions were that the pre-Devonian rocks on Annette and Gravina Islands (Annette subterrane) are not directly correlative with coeval rocks on Prince of Wales Island (Craig subterrane), and that the Upper Devonian through Pennsylvanian rocks on central Prince of Wales Island are not present to the east. The Clarence Strait fault (Fig. 1) was recognized as the boundary between the two subterranes.

However, similarities in both the Ordovician through Devonian rocks and the inferred Late Silurian-Early Devonian orogenic activity in these two regions strongly suggests that the two subterranes have been adjacent to one another since Ordovician time. Neither can the lack of upper Paleozoic strata on Annette and Gravina Islands be used to distinguish the two subterranes because these strata also are lacking on southern Prince of Wales Island. Thus, although the two subterranes have somewhat different geologic records, they are fundamentally part of the same tectonic fragment, and the Clarence Strait fault is apparently not a suture, terrane boundary, or a major strike slip fault.

2) Although the Alexander terrane is hypothesized to have been accreted during Late Cretaceous time (Berg, Jones and Coney, 1978), the predominant deformational fabrics in Paleozoic rocks in the southern part of the terrane are inferred to be a product of the Klakas orogeny. The terrane may therefore have been transported and accreted during late Paleozoic and Mesozoic time by tectonic processes that did not produce major deformation, metamorphism or uplift in the interior of the terrane.

3) This reconstruction of the Klakas orogeny suggests that the main area of deformation and uplift during Late Silurian-Early Devonian time was in the southernmost part of southeastern Alaska, and that the amount of uplift decreased toward the north. On the northwest side of the Chatham Strait fault (Fig. 2), however, there is considerable evidence for a major uplift and erosional event during Late Silurian to perhaps Middle Devonian time. On northeastern Chichagof Island Loney and others (1975) report that clasts in a thick Middle Devonian conglomerate were derived from a suite of syenite, trondhjemite and other plutonic rocks which outcrops nearby. Although correlation of various features across the Chatham Strait fault suggests that northeastern Chichagof Island was offset between 150 km (Hudson and others, 1981) and 205 km (Ovenshine and Brew, 1972) from an original position west of Kuiu Island (Fig. 2), similarities in the Silurian plutonic rocks (Brew and Morrell, 1980) and the nature and age of this uplift and erosional event suggest that northeastern Chichagof Island may originally have been adjacent to the southernmost part of the terrane.

Displacement of northeastern Chichagof Island from an original position directly west of southern Prince of Wales Island would require approximately 350 km of right-lateral displacement on the Chatham Strait fault and its northern and southern extensions. Although this amount of displacement is inconsistent with tie-points recognized by previous workers, it is interesting that the Denali fault, which is thought to be the northern extension of the Chatham Strait fault, has also been interpreted to have approximately 350 km or right-slip displacement (Lanphere, 1978).

ACKNOWLEDGEMENTS

Our studies in southeastern Alaska have been funded by the U.S. Geological Survey, with additional financial assistance awarded to Gehrels from the California Institute of Technology, the Geological Society of America, and Sigma Xi. We would like to thank these organizations for their support. The assistance of Ryan Turner, Bill McClelland and Karl Mueller in the field is also much appreciated. David A. Brew provided a thorough and very helpful review of an early version of this manuscript. This is California Institute of Technology contribution number 3888.

REFERENCES

Berg, H.C., 1972, Geologic map of Annette Island, Alaska: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-684.

Berg, H.C., 1973, Geology of Gravina Island, Alaska: U.S. Geological Survey Bulletin 1373, 41 p.

Berg, H.C., Jones, D.L., and Richter, D.H., 1972, Gravina-Nutzotin belt - tectonic significance of an upper Mesozoic sedimentary and volcanic sequence in southern and southeastern Alaska, in Geological Survey Research 1972: U.S. Geological Survey Professional Paper 800-D, p. D1-D24.

Berg, H.C., Jones, D.L., and Coney, P.J., 1978, Map showing pre-Cenozoic tectonostratigraphic terranes of southeastern Alaska and adjacent areas: U.S. Geological Survey Open-File Report 78-1085, scale 1:1,000,000, 2 sheets.

Boucot, A.J., Dunkle, D.H., Potter, A., Savage, N.M., and Rohr, R., 1974, Middle Devonian orogeny in western North America?: a fish and other fossils: Journal of Geology, v. 82, p. 691-708.

Brew, D.A., and Morrell, R.P., 1980, Intrusive rocks and plutonic belts of southeastern Alaska, U.S.A.: U.S. Geological Survey Open-File Report 80-78, 34 p.

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

Churkin, Michael, Jr., Jaeger, Herman, and Eberlein, G.D., 1970, Lower Devonian graptolites from southeastern Alaska: Lethaia, v. 3, no. 2, p. 183-202.

Churkin, Michael, Jr., and Eberlein, G.D., 1977, Ancient borderland terranes of the North American Cordillera: correlation and microplate tectonics: Geological Society of America Bulletin, v. 88, p. 769-786.

Coney, P.J., Jones, D.L., and Monger, J.W.H., 1980, Cordilleran suspect terranes: Nature, v. 228, p. 329-333.

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

Eberlein, G.D., Churkin, Michael Jr., Carter, Claire, Berg, H.C., and Ovenshine, A.T., 1983, Geology of the Craig quadrangle, Alaska; U.S. Geological Survey Open-File Report 83-91.

Gehrels, G.E., Saleeby, J.B., and Berg, H.C., 1983, Geologic framework of Paleozoic rocks on Annette and Hotspur Islands, southeastern Alaska, in Coonrad, W.L. and Elliot, R.L., eds., The U.S. Geological Survey in Alaska: Accomplishments during 1981: U.S. Geological Survey Circular, in press.

Harland, W.B., Cox, A.V., Llewellyn, P.G., Pickton, C.A.G., Smith, A.G., and Walters, R., 1982, A geologic time scale: Cambridge, Cambridge University Press, 128 p.

Herreid, Gordon, Bundtzen, T.K., and Turner, D.L., 1978, Geology and geochemistry of the Craig A-2 quadrangle and vicinity, Prince of Wales Island, southeastern Alaska: Alaska Division of Geological and Geophysical Surveys Geologic Report 48, 49 p.

Hillhouse, J.W., and Gromme, C.S., 1980, Paleomagnetism of the Triassic Hound Island Volcanics, Alexander terrane, southeastern Alaska: Journal of Geophysical Research v. 85, no. B5, p. 2594-2602.

Hudson, Travis, Plafker, George, and Dixon, Kirk, 1981, Horizontal offset history of the Chatham Strait fault; in Coonrad, W.L., ed., The U.S. Geological Survey in Alaska: Accomplishments during 1980: U.S. Geological Survey Circular 844, p. 128-132.

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

Lanphere, M.A., 1978, Displacement history of the Denali fault system, Alaska and Canada: Canadian Journal of Earth Sciences, v. 15, p. 817-822.

Lanphere, M.A., MacKevett, E.M. Jr., Stern, T.W., 1964, Potassium-argon and lead-alpha ages of plutonic rocks, Bokan Mountain area, Alaska: Science, v. 145, p. 705-707.

Loney, R.A., Brew, D.A., Muffler, L.J.P., and Pomeroy, J.S., 1975, Reconnaissance geology of Chichagof, Baranof, and Kruzof Islands, southeastern Alaska: U.S. Geological Survey Professional Paper 792, 105 p.

Monger, J.W.H. and Ross, C.A., 1971, Distribution of fusulinaceans in the western Canadian Cordillera: Canadian Journal of Earth Sciences, v. 8, p. 259-278.

Ovenshine, A.T., 1975, Tidal origin of parts of the Karheen Formation (Lower Devonian), southeastern Alaska, in Ginsburg, R.N. ed., Tidal Deposits: A case book of recent examples and fossil counterparts: Berlin, Springer-Verlag, p. 127-133.

Ovenshine, A.T., and Churkin, Michael, Jr., 1969, Paleotectonic significance of a Silurian-Devonian clastic wedge, southeastern Alaska: Geological Society of America Abstracts with Programs, v. 1, no. 3, p. 50.

Ovenshine, A.T., and Brew, D.A., 1972, Separation and history of the Chatham Strait fault, southeast Alaska, North America: Montreal, 24th International Geological Congress, section 3, Proceedings, p. 245-254.

Ovenshine, A.T., and Webster, G.D., 1970, Age and stratigraphy of the Heceta Limestone in Sea Otter Sound, southeastern Alaska, in Geological Survey Research 1970: U.S. Geological Survey Professional Paper 700-C, p. 170-174.

Redman, Earl, 1981, The Keete Inlet thrust fault, Prince of Wales Island: Alaska Division of Geological and Geophysical Surveys Geologic Report 73, p. 17-18.

Saleeby, J.B., Gehrels, G.E., Eberlein, G.D., and Berg, H.C., 1983, Progress in Pb/U zircon studies of lower Paleozoic rocks of the southern Alexander terrane, in Coonrad, W.L., and Elliot, R.L., eds., The U.S. Geological Survey in Alaska: Accomplishments during 1981: U.S. Geological Survey Circular, in press.

Savage, N.M., 1977, Lower Devonian conodonts from the Karheen Formation, southeastern Alaska: Canadian Journal of Earth Sciences, v. 14, no. 2, p. 278-284.

Savage, N.M., Churkin, Michael, Jr., and Eberlein, G.D., 1977, Devonian faunas from the southern Alexander Archipellago, in Murphy, M.A., Berry, W.B.N., and Sandberg, C.A., eds., Paleontological Society Symposium on Western North American Devonian: Seattle, p. 226-231.

Stone, D.B. Panuska, B.C., and Packer, D.R., 1982, Paleolatitudes versus time for southern Alaska: Journal of Geophysical Research, v. 87, no. B5, p. 3697-3707.

Turner, D.L., Herreid, Gordon, and Bundtzen, T.K., 1977, Geochronology of southern Prince of Wales Island, Alaska: Alaska Division of Geological and Geophysical Surveys Geologic Report 55, p. 11-16.

Van der Voo, R., Jones, M., Gromme, C.S., Eberlein G.D., and Churkin, Michael, Jr., 1980, Paleozoic paleomagnetism and northward drift of the Alexander terrane, southeastern Alaska: Journal of Geophysical Research, v. 85, no. B10, p. 5281-5296.

Wilson, J.T., 1968, Static or mobile earth: the current scientific revolution: American Philosophical Society Proceedings, v. 112, no. 5, p. 309-320.