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Blueschists of the Kodiak Islands, Alaska: An extension of the Seldovia schist terrane

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ABSTRACT

The Kodiak Islands are composed of a series of northeast-trending belts of schists and deep-sea rock types that are interpreted as having been accreted to the continental margin during several discrete phases of subduction since early Mesozoic time. The Kodiak Islands schist terrane is the oldest of these accretionary belts and crops out discontinuously along the northwest side of the islands. Metamorphic rocks in this belt include quartz-mica schist, marble, metachert, greenschist, blueschist, and epidote amphibolite; the rocks yield Early Jurassic K-Ar mineral ages. These ages apparently provide a measure for the age of emplacement of the Kodiak Islands schists and are consistent with independently determined age estimates based on (1) biostratigraphy of the associated forearc basin deposits and (2) K-Ar ages from the associated plutonic arc on the Alaska Peninsula. Similarities in rock types, mineral ages, and tectonic setting indicate that the Kodiak Islands schist terrane is the southwestern extension of the Seldovia blueschists of the Kenai Peninsula.

GEOLOGIC SETTING

The Kodiak Islands are composed of northeast-trending belts of accreted deep-sea deposits that become systematically younger to the southeast toward the present continental margin (Moore, 1974). The Kodiak Islands schist terrane of early Mesozoic age is the oldest of these accretionary belts and is discontinuously exposed along the northwest side of the islands (Connelly and others, 1976). This schist belt marks the southeastern extent of the early Mesozoic Alaskan craton and apparently is in fault contact on the southeast against the Cretaceous Uyak Complex (Connelly, 1976).

The Uyak Complex is a tectonic melange composed of various-sized blocks of gabbroic and ultramafic rocks, greenstone, radiolarian chert, wacke, and limestone, all suspended in a matrix of gray chert and tuffaceous argillite. The complex has undergone prehnite-pumpellyite–facies metamorphism and contains sparse fossils ranging in age from middle Permian to mid-Early Cretaceous (Valanginian to possibly Aptian). To the northwest, the Kodiak Islands schists structurally underlie a little-deformed sequence of pillowed greenstone and volcaniclastic turbidites which are interpreted as the seaward margin of a forearc basin that existed during emplacement of the Kodiak Islands schist terrane (Moore and Connelly, 1976).

In the Seldovia area of the Kenai Peninsula, the Seldovia schist terrane occupies a structural position equivalent to that of the Kodiak Islands schists. It is underthrust on the southeast by deformed deep-sea deposits of the McHugh Complex (Clark, 1973), which are similar to those in the Uyak Complex although somewhat more intact, and is in fault contact on the northwest with Upper Triassic to Lower Jurassic volcaniclastic rocks (Carden, unpub. data). Moore and Connelly (1976) proposed that the Uyak and McHugh Complexes are correlative and that the combined Uyak-McHugh belt represents a subduction complex that was emplaced along the southern Alaska margin during a period of underthrusting in Mesozoic time.

METAMORPHIC TERRANES

Field Relationships. The existence of metamorphic rocks on the southwestern part of the Kenai Peninsula has been known since Martin (1915) described the "crystalline schists" of Seldovia Bay and Port Graham. In his description of these rocks, Martin mentioned an epidote-glaucophane schist that he collected near Seldovia Point. Forbes and Lanphere (1973) confirmed the presence of blueschists in the Seldovia area and obtained Early Jurassic K-Ar ages from white mica, actinolite, chlorite, and crossite (Table 1; App. Table 1).[1] Further work (Carden, unpub. data) indicates that the schist terrane is a wedge-shaped tectonic sliver at least 16 km in length which narrows to the southwest and pinches out in a zone of gouge on the southwest shore of Port Graham. This metamorphic block includes quartz-mica schist, marble, metachert, greenschist, and blueschist. The blueschist at Seldovia is intimately intercalated with greenschist. Recognized blueschist assemblages include: (1) crossite + chlorite + albite + sphene, (2) crossite + chlorite + white mica + epidote + sphene, and (3) crossite + chlorite + epidote + albite + sphene.

The contact between the wedge of metamorphic rocks and the dismembered metaophiolite sequence to the southeast is not exposed at Seldovia Bay or Port Graham, but we think that it is a fault because of the sudden change in the degree of metamorphism and structural style. Along the northeast shore of Port Graham, the contact between the schists and Upper Triassic volcaniclastic turbidites to the northwest is clearly a fault zone, here named the Port Graham fault, with a well-developed megashear zone nearly 0.5 km in width. This zone is characterized by a loss of bedding continuity and an increase in shear foliation in the bedded rocks toward the contact. Adjacent to the contact, bedding is completely obliterated, with broken remnants of more resistant beds rotated into the plane of foliation. We interpret the Port Graham fault as being a segment of the early Mesozoic plate boundary along southwestern Alaska.

Based on the earlier observations of Martin (1912), Maddren (1917), and Capps (1937), who described schists along the northwest shore of the Kodiak Islands, Forbes and Lanphere (1973) predicted that the southwestern extension of the blueschist-bearing Seldovia schist terrane would be found on the northwest coast of Kodiak Island. In the summer of 1975, J. Carden discovered blueschist assemblages in the metamorphic terrane at the mouth of Uyak Bay (Carden and Forbes, 1976), and W. Connelly and M. Hill mapped this blueschist belt to the northeast on Afognak Island (Fig. 1).

The schist terrane at Uyak Bay appears to be a large tectonic block on the northwest side of the Uyak Complex. On Afognak Island, the schists occur in a 2- to 3-km-wide belt that extends for at least 40 km along the northwest side of the Uyak Complex. This belt is tectonically juxtaposed against the younger Uyak melange.

The Kodiak Islands schist terrane is bounded on the northwest by diorite and quartz diorite of the Lower Jurassic Afognak pluton, which appears to have intruded along the fault that juxtaposes the Kodiak Islands schists against the structurally overlying Upper Triassic volcanic and volcaniclastic rocks. The relationship between the blueschist-bearing Kodiak Islands schist terrane and the apparently coeval Afognak pluton (Hill and Morris, 1977) is somewhat uncertain, as discussed below.

The most complete sections of metamorphic rocks occur on Afognak Island at Malina and Paramanof Bays. Our limited sampling of this terrane seems to indicate that the grade of metamorphism increases toward the northwest from blueschist facies in

TABLE 1. K-Ar AGES

No. on Fig. 1	Rock type	Mineral dated	Age ± 1σ (m.y.)
		Seldovia	
1	Blueschist	Crossite	162.9 ± 4.9
2	Quartz-mica schist	Muscovite	190.4 ± 5.7
3	Amphibole-mica schist	Amphibole	184.4 ± 5.5
3	Amphibole-mica schist	Amphibole	184.2 ± 5.5*
3	Amphibole-mica schist	Muscovite	192.2 ± 5.8
4	Greenschist	Actinolite	191.0 ± 11.0†
4	Greenschist	White mica	188.0 ± 10.0†
4	Greenschist	Chlorite	181.0 ± 8.3†
5	Blueschist	White mica	189.0 ± 5.7†
5	Blueschist	Crossite	154.0 ± 4.8†
		Port Graham	
6	Quartz-mica schist	Muscovite	192.2 ± 5.8
		Kodiak Islands	
7	Blueschist	Crossite	161.4 ± 19.4
8	White mica-crossite schist	White mica	187.6 ± 5.6
8	White mica-crossite schist	Crossite	170.6 ± 5.1
9	Dioritic migmatite	Hornblende	184.9 ± 5.5
9	Dioritic migmatite	Hornblende	183.7 ± 5.5*
10	Hornblende diorite	Hornblende	188.4 ± 5.7
11	Hornblende diorite		192.7 ± 5.8
12	Quartz-mica schist	Muscovite	192.1 ± 5.8

Note: Ar extractions and K analyses by Diane Duvall. K-Ar dating was done at the Geophysical Institute, University of Alaska. Constants used in age calculations: $\lambda_\epsilon = 0.585 \times 10^{-10}/yr$, $\lambda_\beta = 4.72 \times 10^{-10}/yr$, $^{40}K/K_{total} = 1.19 \times 10^{-4}$ mol/mol.

*Average of replicate analyses.

†From Forbes and Lanphere (1973).

the southeast to epidote amphibolite (blue-green amphibole + epidote + plagioclase) near the pluton. Migmatitic diorite gneiss constitutes the marginal phase of the Afognak pluton. Adjacent to the pluton, pillowed greenstones commonly are upgraded to amphibolites (hornblende + plagioclase ± epidote), and interpillow limestone has been metamorphosed to calc-silicate assemblages (calcite + garnet ± diopside ± talc). Field relations and metamorphic facies assemblages seem to indicate that the migmatitic gneiss is genetically related to the emplacement of the pluton into the metamorphic terrane and that the amphibolite facies assemblages in the migmatites and adjacent rocks are related to late synkinematic upgrading near the margin of the pluton.

The proximity of the Afognak pluton to the blueschist terrane is an apparent paradox since blueschists are generally thought to form at low temperatures and are not associated with plutonism. The relationship on Afognak Island may possibly be due to an unrecognized fault juxtaposing the pluton and associated migmatitic belt against the high-pressure–low-temperature schist terrane. An alternative explanation is that the plutonism could represent the near-trench type described by Marshak and Karig (1977).

Petrology. The contact between the schist terrane and the Uyak Complex is apparently tectonic. The schist terrane is characterized by complex isoclinal folds whose fold axes commonly trend to the northeast. Some chlorite–white mica schists display a well-developed axial-plane cleavage, although compositional layering is commonly preserved.

[1]Copies of Appendix Table 1, which includes the analytical data for the K-Ar determinations (GSA supplementary material 77-13), may be ordered from Documents Secretary, Geological Society of America, 3300 Penrose Place, Boulder, Colorado 80301.

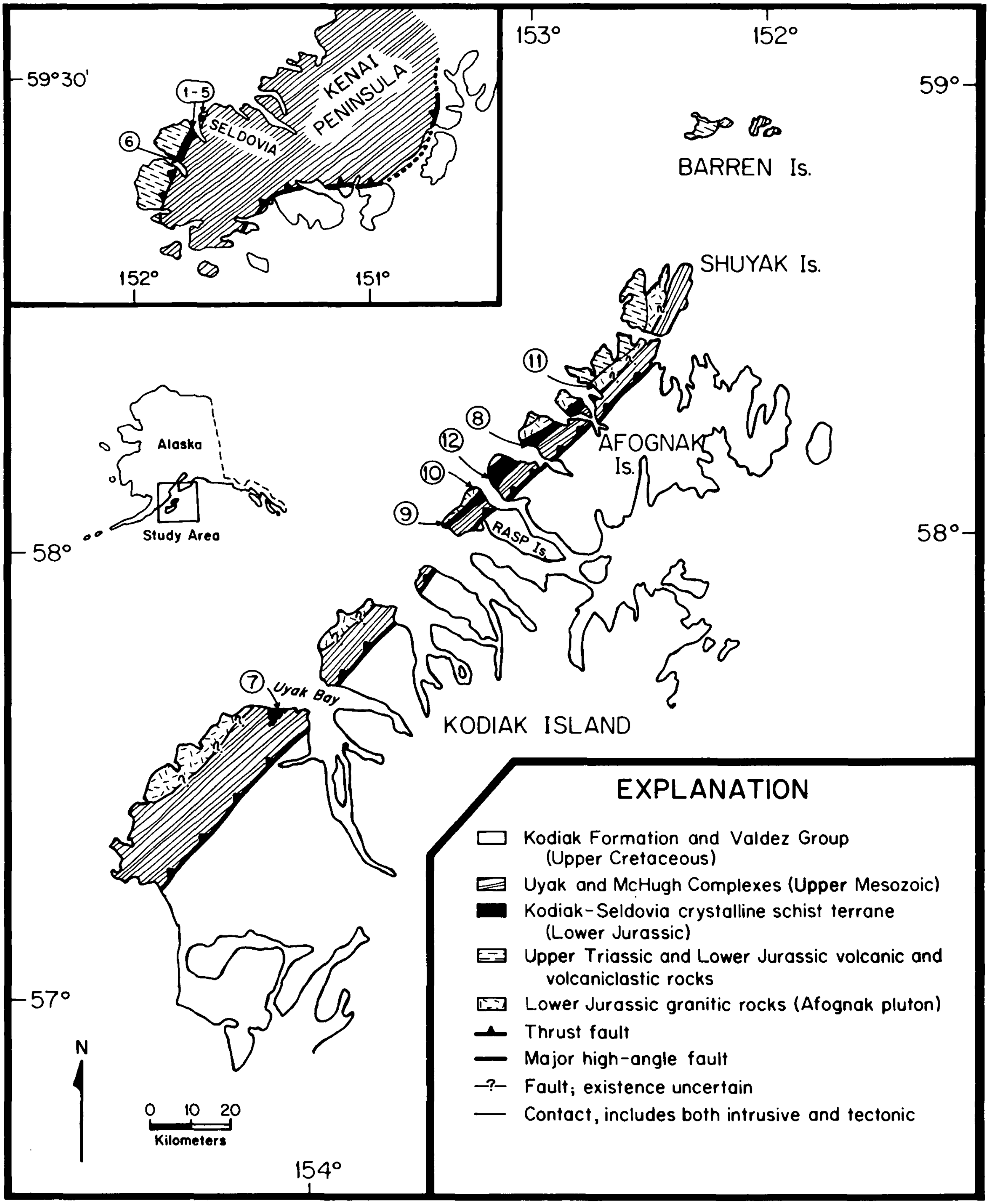

Figure 1. Generalized geologic map of the northwestern side of the Kodiak Islands and the southwestern Kenai Peninsula after Martin (1915), Moore (1967), Connelly and Moore (1977), and Cowan and Boss (1977). Numbers give locations of dated samples in Table 1.

Like the Seldovia schist terrane, the blueschists near Seven Mile Beach (near Uyak Bay) and on Afognak Island are intimately intercalated with greenschists (chlorite + epidote + albite + sphene ± actinolite) on a scale ranging from centimetres to metres, and there is no evidence that the greenschists were produced by thermal upgrading of former blueschist assemblages. The difference in mineral content of the layers may be due to original compositional control, metamorphic differentiation, or other factors that are discussed by Brown (1974). The blueschists are divided into four groups on the basis of mineral assemblages. Each of the assemblages also represents a major textural variation.

Group 1 is characterized by crossite + epidote + stilpnomelane assemblages. In outcrop, these have a blue hue and display a coarse schistosity. In thin section, the fabric is dominated by as much as 80% fine-grained radiating bundles of flamboyant crossite. Pistacitic epidote occurs as subhedral laths as much as 1.0 mm long; stilpnomelane is present as an accessory phase.

Group 2 includes rocks with well-preserved relict textures with superimposed blueschist-facies mineral assemblages. These rocks have a blastoporphyritic texture and an incipient schistosity. Relict clinopyroxene occurs as subhedral to anhedral grains as much as 0.3 mm in diameter, with randomly oriented relict plagioclase laths. Relict minerals and textures indicate that the protolith for this blueschist was a fine-grained basalt. The matrix of this rock is composed of fine-grained crossite, chlorite, epidote, albite, and sphene.

Group 3 is characterized by the assemblage lawsonite + crossite + chlorite + sphene, with a well-developed nematoblastic texture. Crossite occurs as subhedral prisms as much as 1.0 mm in length which tend to define the schistosity. The discovery of lawsonite in these rocks marks the first occurrence reported in Alaska. The lawsonite occurs as subhedral and euhedral porphyroblasts approximately 0.2 mm in diameter in a matrix of crossite, chlorite, and sphene. The presence of lawsonite was confirmed by x-ray diffraction.

We think that the schists of Group 4 were derived from a pelitic sedimentary protolith because of the abundant quartz and muscovite; these minerals are conspicuously absent in blueschist derived from basalts. This group is characterized by the assemblage quartz + epidote + crossite + muscovite. The rock is very coarse grained with a well-developed nematoblastic texture.

Taylor and Coleman (1968) divided the blueschist facies into a high-temperature assemblage (T = 400 to 550 °C) containing epidote and a low-temperature assemblage (T = 200 to 325 °C) containing lawsonite. Both lawsonite and epidote have been recognized in the Kodiak blueschists, which suggests that the temperature of recrystallization was between 325 and 400 °C. Since most of the blueschists contain epidote rather than lawsonite, we infer that temperatures were probably closer to 400 °C. Experimental studies by Nitsch (1968) suggest that the minimum pressure necessary for the formation of lawsonite at 400 °C is approximately 5.5 kb, which implies that the Kodiak Islands blueschists were formed at a depth of at least 20 km. Physical conditions of metamorphism are now under investigation and will be reported in a future paper.

Radiometric Ages. Analytical data for 13 previously unreported K-Ar mineral ages from Seldovia, Port Graham, and the Kodiak Islands are given in Appendix Table 1 (see footnote 1), along with five ages reported previously from the Seldovia area by Forbes and Lanphere (1973). A striking feature of these data is the excellent agreement of the ages from the Seldovia schist terrane with ages from the proposed extension of this belt on the Kodiak Islands.

Five white-mica ages from Seldovia and Port Graham agree within analytical uncertainty and have an average age of 190 m.y. Two actinolites yield an average of 187 m.y., and two crossites average 158 m.y. (Table 1). The systematic difference between the apparent ages of crossite versus actinolite and white mica is greater than the analytical error of individual measurements. Coleman and Lanphere (1971) first reported this phenomenon in blueschists from the Franciscan Complex and ascribed it to inferior Ar retentivity in blue amphiboles as compared to white micas during retrograde metamorphism (also see Suppe and Armstrong, 1972).

On the Kodiak Islands, crossite dated from a blueschist at Seven Mile Beach gives an age of 161 ± 19 m.y., and coexisting crossite and white mica extracted from a crossite–white mica schist collected at east Malina Bay give ages of 170 ± 5 m.y. and 187 ± 5 m.y., respectively. The white-mica age agrees within analytical uncertainty with the 192-m.y. age determined from a quartz-mica schist collected at Raspberry Strait. These ages agree with the ages determined on the schists at Seldovia and Port Graham, even to the discordance between the crossite and white mica.

In addition to the metamorphic-rock ages discussed above, we have dated two hornblende separates from samples of both massive and migmatitic hornblende diorite along the northwest coast of Raspberry Island and one hornblende separate from Afognak Island. These ages agree within analytical uncertainty and average 188 ± 5 m.y. (Table 1), an age which is essentially identical to ages obtained from white micas and actinolites from the schist belt discussed above. D. S. Cowan and R. F. Boss (1977, personal commun.) have obtained a K-Ar hornblende age of 187 ± 14 m.y. from quartz diorite on Ushagat Island in the Barren Islands (Fig. 1). This quartz diorite is on the same structural trend as the Afognak pluton and apparently is correlative with it, as supported by agreement with our radiometric ages. Recent work by Turner (1977) has shown that three small diorite plutons near Pt. Bede, on the western tip of the Kenai Peninsula (Magoon and others, 1976) are coeval with the Afognak and Barren Islands plutons and may represent a northeastern extension of the same plutonic trend. All of these plutonic ages are about 10 m.y. older than the oldest episode of plutonic activity dated by Reed and Lanphere (1973) in the Alaskan–Aleutian Range batholith.

The mineral ages of the Kodiak Islands schist belt are coeval with those determined from the adjacent Afognak pluton. This may be interpreted according to one of two hypotheses: (1) The schists are actually older than 190 m.y., but their K-Ar ages have been reset to this value by the intrusion of the Afognak pluton; or (2) the schist ages date the time of cooling to Ar-retention temperatures following metamorphic recrystallization in a subduction zone, and the Afognak and related plutons represent a late synkinematic plutonic event. The Afognak pluton with its adjacent migmatite zone may or may not be juxtaposed against the schist belt by an unrecognized fault.

We prefer the second hypothesis for the following reasons: (1) No plutons occur adjacent to the schist belt at Seldovia–Port Graham, yet K-Ar ages there are essentially identical to those from the extension of this belt on the Kodiak Islands—even to the crossite–white mica age discordance. (2) Although Lower Jurassic plutons do occur at the western tip of the Kenai Peninsula (Turner, 1977), they are more than 11 km from the nearest schist belt outcrop. The thick, intervening section of Triassic sedimentary rocks shows no effects of thermal metamorphism other than local contact effects adjacent to the plutons. (3) Petrologic relationships between the quartz diorite and migmatitic diorite gneiss of the

Afognak Pluton and the blueschists appear to indicate that these units have experienced a similar crystallization and cooling history; these relationships therefore support the proposed late synkinematic history of the migmatitic phase of this pluton.

REGIONAL SIGNIFICANCE

We interpret the Seldovia–Kodiak Islands schist terrane as a remnant of a deeply subducted portion of a subduction complex which was emplaced by Early Jurassic time. The Early Jurassic K-Ar ages from schists are consistent with a Late Triassic through Middle Jurassic time of emplacement inferred from the biostratigraphy of the associated forearc basin deposits (Burk, 1965; Detterman and Hartsock, 1966) and from K-Ar ages of the Jurassic granitic rocks forming the associated Alaska–Aleutian Range plutonic arc (Reed and Lanphere, 1973).

Other blueschist-bearing terranes recognized along the southern Alaska margin include (1) the Valdez C-2 locality (lat 61°30′N, long 144°30′W; Metz, 1975, 1976), (2) the Hubbard Glacier locality (lat 60°04′N, long 139°38′W; Plafker, 1975, personal commun.), and (3) the Chichagof Island blueschist terrane (lat 56°46′N, long 136°13′W; Reed and Coats, 1941; Carden, Connelly, and Forbes, 1976, unpub. field notes). We are attempting to date these blueschists to determine whether or not they have the same Early Jurassic ages as the Seldovia–Kodiak Islands blueschists of southwestern Alaska. If they do, they would support a common early Mesozoic evolution for much of the southern Alaska margin (Forbes and others, 1976; Moore and Connelly, 1977).

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