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Detrital Zircon U/Pb Age Determination: Understanding the Provenance of the Upper Cretaceous Shumagin Formation, Alaska

Carly F. Roe
Lawrence University

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Faculty advisor: Prof. Marcia Bjornerud

Department of Geology

Lawrence University

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ABSTRACT

The tectonic evolution of the Chugach-Prince William Terrane (CPW), an accretionary complex along the southern Alaskan margin, has been the subject of much debate. There are two prevailing hypotheses for the location of the CPW at the time of its intrusion by the plutons of the Sanak-Baranof belt, and both require distinctly different source regions for the sediment of the CPW flysch. Therefore, a better understanding of the provenance of these sediments will help constrain the location of the CPW at the time of the deposition of its sediments. This study presents an analysis of new U/Pb detrital zircon, mineralogical and sedimentological data from the Shumagin Formation, which comprises the westernmost section of the CPW terrane. Our results indicate that the Shumagin Formation on Nagai Island has a maximum depositional age of 73-77 Ma and represents the deposition of a large volume of sediment along a basin on a deep submarine fan adjacent to an active volcanic arc. A comparison of our U/Pb age populations with those of correlative units along strike shows a striking similarity in source material along the length of the CPW. This combined mineralogical and U/Pb detrital zircon data constrain the provenance of the Shumagin Formation to a source region south of the present location of the CPW at the time of its intrusion by the Sanak-Baranof belt and are consistent with the terrane's subsequent northward, coast-parallel translation.

INTRODUCTION

The Chugach-Prince William (CPW) terrane is an Upper Cretaceous to Eocene accretionary complex exposed for ~2200 km in southern Alaska, extending from Baranof Island in the east to Sanak Island in the west. One of the thickest subduction-related accretionary complexes in the world, the CPW terrane is composed of deep-water flysch and associated volcanic rocks and is intruded by near-trench plutons of the 62-50 Ma Sanak-Baranof belt. The location of the accretion of the CPW is a matter of debate, and there are two prevailing hypotheses for the location of the CPW at the time of its intrusion by the Sanak-Baranof belt: either the CPW was formed in situ as the result of accretion related to the subduction of the now subducted Resurrection Plate (Hauessler et al., 2003); or the CPW formed further to the south and has since been translated northward, parallel to the coast (Cowan, 2003). These scenarios would result in distinctly different source regions for the sediment of the CPW flysch. Therefore, an understanding of the provenance of the different units in the CPW can help to constrain the location of the CPW at the time of its accretion.

The Upper Cretaceous Shumagin Formation is found on Sanak and Shumagin Islands in the westernmost part of the CPW terrane. This study focused on determining the maximum depositional age and provenance of the Shumagin Formation based on mineralogy, petrography, detrital zircon U/Pb ages, and U/Pb dating of an interbedded tuff.

Previous detrital zircon work of rocks in the area includes studies of the unit that lies directly inboard of the Shumagin Formation, the Kuskokwim Group—an Upper

Cretaceous turbiditite flysch sequence (Miller et al., 2007)—as well as studies of correlative units in the CPW that occur along strike of the Shumagin Formation: the Orca Group of Prince William Sound (Hilbert-Wolf, 2012) and the Kodiak and Ghost Rocks Formations of Kodiak Island (Olivas, 2012).

GEOLOGIC SETTING

The Chugach-Prince William Terrane

One of the largest accretionary complexes in the world, the Chugach-Prince William Terrane ranges from 60 to 100 km wide with a minimum total sediment volume of 270,000km^3 (Plafker et al., 1994). The CPW is mainly (up to 89%) composed of trench-derived flysch consisting of conglomerate, quartzofeldspathic sandstone, and volcanic-lithic sandstone turbidites and interbedded mudstones (Plafker et al., 1994). Belts of mélange make up about 10% and tectonic clasts of greenschist and blueschist make up about 1% of the CPW (Plafker et al., 1994). These rocks separate the flysch of the CPW from the Border Ranges fault system, which bounds the CPW to the north (Plafker et al., 1994).

The Chugach-Prince William Terrane is intruded by the Sanak Baranof belt of Paleogene near-trench plutons ranging in age from 62 Ma in the west to 50 Ma in the east (Kusky et al., 2003). These plutons are interpreted to be the result of near-trench plutonism related to the slab window of an adjacent TRT triple junction (Short, 2013) and the migration of the triple junction along the plate margin (Kusky et al., 2003).

The Shumagin Formation

Found in the westernmost part of the Chugach-Prince William Terrane, the Shumagin Formation has an estimated thickness of 3-4 km (Moore, 1975) and consists primarily of marine flysch intruded by granitic plutons. The flysch is composed of deformed, thin- to thick-bedded turbidites including quartzofeldspathic to volcanic-lithic sandstone, siltstone, and mudstone. The turbidites represent deposition on a deep-water submarine fan adjacent to an active volcanic arc. Individual turbidites are medium- to very thick-bedded with full Bouma sequences and contain sole marks, usually flutes and grooves. Paleocurrents are mainly to the southwest but flutes and grooves record transport to the SE in some beds. The presence of the age-diagnostic fossil *Inoceramus kuroensis* in several locations on Nagai Island constrains the age of the Shumagin Formation to Maastrichtian [latest Cretaceous, 66-72 Ma].

Deposition was followed by deformation, tectonic burial in the subduction wedge, and intrusion by the Sanak-Baranof Belt of plutons ~62 Ma. Detrital fission track dates from the Shumagin Formation yield cooling ages of 58-54 Ma and appear to show variable amounts of overprinting related to the intrusion of the Shumagin Batholith and slab window heating associated with passage of the TRT triple junction (DeLuca, 2013).

Thin sections of samples from the full stratigraphic thickness of the Shumagin Formation were analyzed for sedimentary textures. Most grains consist of sodic and potassic feldspar, quartz (both mono- and polycrystalline), and lithic fragments. Biotite, muscovite, chlorite and pyroxene are also present. Although most of the sheet silicates are detrital since these rocks are prehnite-pumpellyite grade, samples located close to the plutons contain metamorphic biotite. Samples range from poorly to well sorted; grain sizes typically range from about 0.025 mm to 0.675 mm, but many samples contain lithic fragments as large as 1-3 mm in diameter. Grains are angular in most samples, indicating a nearby sediment source and relatively little physical abrasion. The feldspars range from quite fresh to heavily sericitized, but the alteration transects grain boundaries and is thus clearly post-depostional.

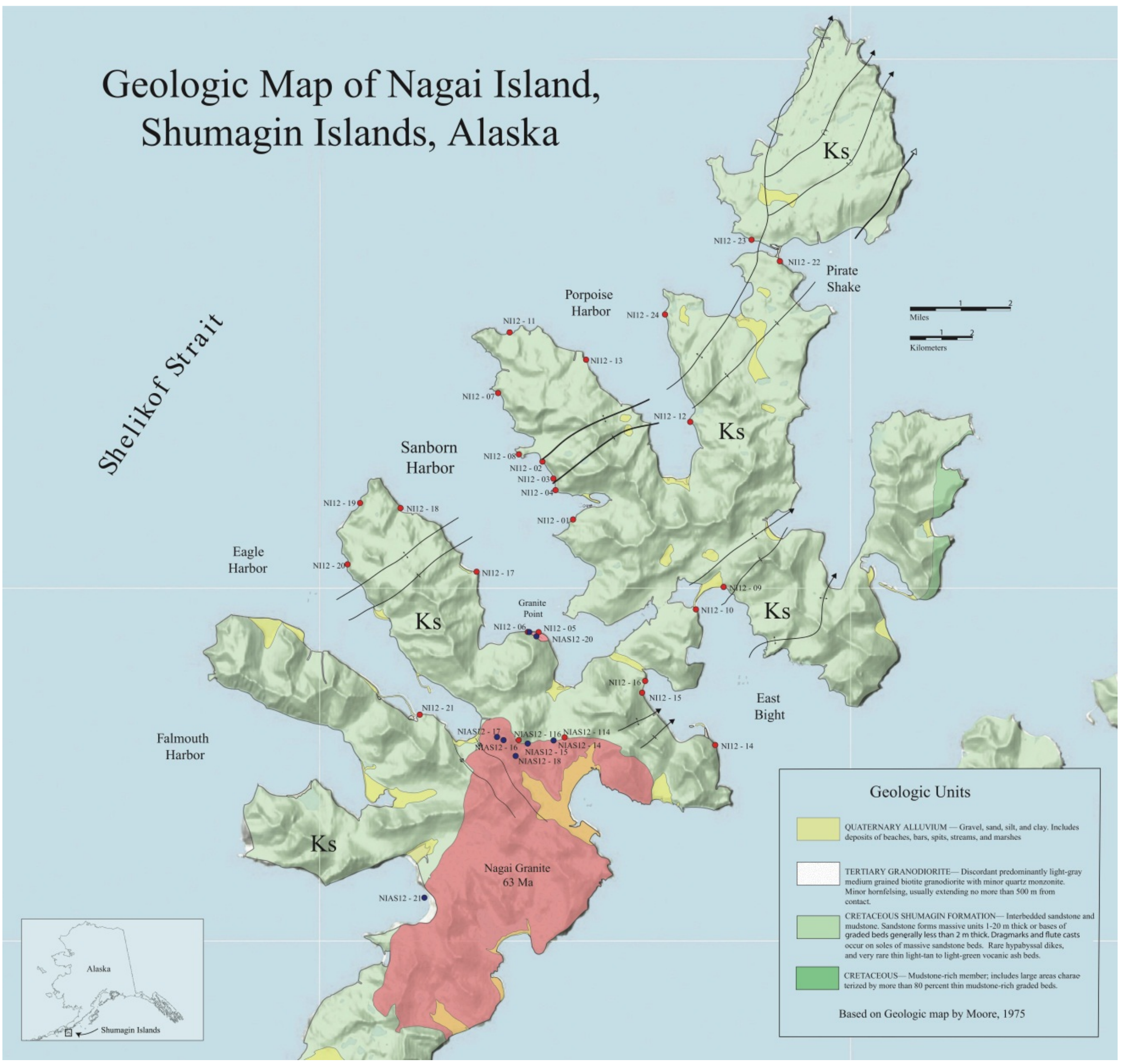

Figure 2. Geologic Map of Nagai Island showing sample location (modified from Moore, 1974).

Thin sections were analyzed for qualitative estimates of opaques and lithics (representative of volcanic input) as well as a qualitative estimate of sorting (Table 1). As shown in Table 1, samples from the lower part of the formation, exposed on the northwest side of Nagai Island, contain fewer opaque grains (likely magnetite) and lithic fragments relative to quartz and feldspar and are generally better sorted than samples higher in the stratigraphic sequence in the southeast (Table 1).

Sample	**Opaques (%)**	**Lithics (%)**	**Sorting**
NI12-11	5	10	10
NI12-19	2	5	9
NI12-07	1	7	7
NI12-18	2	7	7
NI12-13	1	10	6
NI12-20	5	5	8
NI12-24	5	5	6
NI12-23	7	3	8
NI12-08	3	10	2
NI12-22	3	7	8
NI12-17	5	10	7
NI12-12	5	13	4
NI12-21	13	10	7
NI12-06	7	5	9
NI12-15	10	25	2
NI12-14	2	25	3

Table 1. Relative content of opaques and lithic fragments and a measure of sorting of a selection of samples from the Shumagin Formation. Values for the degree of sorting are assigned on a scale from 1-10, with 1 indicating a poorly sorted sample and 10 a well-sorted sample. Samples are arranged by location from furthest northwest at the top to furthest southeast at the bottom.

Samples from the lower part of the formation, however, yielded more detrital zircon grains. Samples from the southeast (higher in the stratigraphy) contain a wider range of grain sizes, tend to be less altered, and display greater mineral diversity than samples from the northwest.

Five samples representing the range of textures in the Shumagin Formation were point-counted using standard techniques. These data (Table 2) also indicate increasing amounts of lithics and opaques relative to feldspar and quartz and higher mineral diversity towards the top of the stratigraphic section. The one possible exception to this trend is NI12-06. This sample has significant biotite overgrowth likely as a result of contact metamorphism related to the intrusion of the Shumagin Batholith since this sample is located within the contact aureole of the pluton. The more arkosic samples from the northwest likely indicate a source terrane where erosion is dissecting down into the understory of the arc, whereas the more lithic-and magnetite-rich samples represent increased volcanic input into the sediment.

The differences in zircon yield from the samples may be the result of several factors. Volcanic zircons from basalts and andesites tend to be smaller, so samples with higher amounts of volcanic zircons (like those from the southeast) would be more susceptible to zircon loss during processing (Bernet and Garver, 2005). Magmas with higher SiO_2 value also tend to have higher zircon contents, and therefore arkosic samples would typically have higher zircon content (Bernet and Garver, 2005). Finally, it is difficult to separate zircons from lithic fragments during processing, so the lower zircon yields from the southeastern samples may be related to their higher lithic content.

Sample	Feldspar	Quartz	Lithics	Other	Feldspar+Quartz	Lithics+Other
NI12-11	78	10	8	4	88	12
NI12-23	64	16	9	11	80	20
NI12-12	51	16	28	5	67	33
NI12-06	43	33	0	24	76	24
NI12-14	42	14	29	15	56	44

Table 2. Point counting data from five samples of the Shumagin Formation. These samples were selected from across the stratigraphic thickness so this data set is representative of the entire section. Samples are arranged by location from furthest northwest at the top to furthest southeast at the bottom.

U/Pb GEOCHRONOLOGY

Methods

U/Pb detrital zircon ages were obtained from ten samples collected along a transect roughly perpendicular to strike on Nagai Island (Fig. 2). Zircons were separated using standard rock pulverization and density separation techniques at Carleton College, Union College, Macalester College, and the University of Minnesota. This process consisted of rock crushing and milling, heavy mineral fractionation using a Wilfley table, and Franz barrier magnetic separation. One hundred zircons from each sample were randomly selected and mounted at the University of Arizona, imaged by SEM (BSE and CL) at Carleton College and individually analyzed for U/Pb isotopes using LA-MC-ICPMS at the Arizona Laserchron Center (Gehrels et al., 2008). Analysis of the collected

U/Pb data was conducted using the Microsoft Excel program Age Pick provided by the LaserChron Center at the University of Arizona (Gehrels et al., 2008).

Additionally, Paleozoic and Precambrian zircon grains were preferentially selected for dating, in addition to the 100 randomly selected grains, by targeting grains with characteristics of older zircon grains, specifically roundness and a pink color. Non-euhedral grains are thought to have undergone significant transport and recycling, and a pink to purple color reflects metamictization from radiation damage (Bernet and Garver, 2007). These older zircons potentially have distinctive age signatures indicative of their provenance.

RESULTS

All samples yield maximum depositional ages that are tightly clustered in the Upper Cretaceous. The youngest zircons from each sample have ages ranging from 70.2-72.8 Ma and the maximum depositional ages calculated by AgePick for each sample range from 73-77 Ma. Also, a U/Pb zircon date of 73.7 ± 1.2 Ma was determined for an interbedded tuff (NI12-02) in the middle part of the section. This further constrains the age of the Shumagin Formation to Upper Cretaceous and indicates that the maximum depositional ages are close to the depositional ages of these rocks.

Normalized age probability curves of the detrital zircon ages yield three main age populations in the Phanerozoic: 71-78 Ma, 85-100 Ma, and 146-186 Ma (Fig. 3). The main age populations were determined by identifying major peaks in the composite age probability curve from the Nagai Island samples (Fig. 4). The ten Shumagin Formation samples, from which a total 1053 zircon grains were extracted and dated, yielded only 17

Precambrian grains, ranging in age from 1445-2760 Ma, and of those 17, 13 fell within the 1750-2000 Ma range.

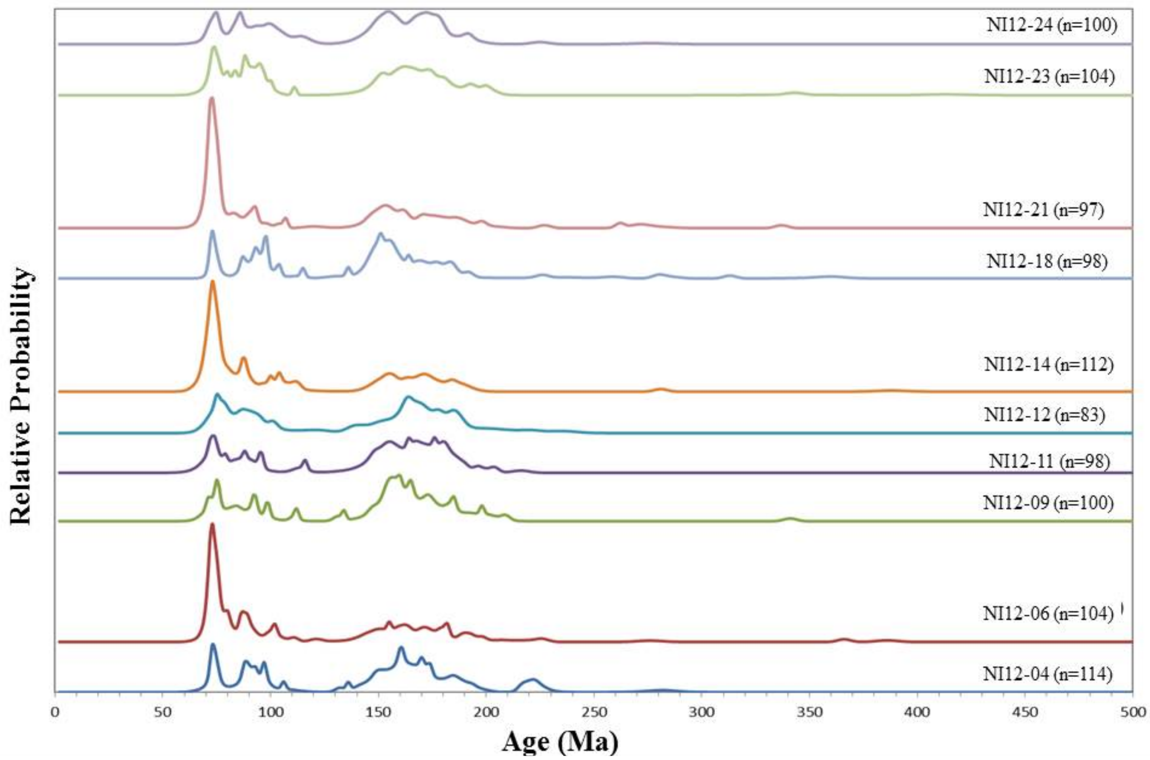

Figure 3. U/Pb detrital zircon age probability curves for ten sandstones from the Shumagin Formation, Nagai Island, Alaska. All samples exhibit main age populations at 71-78 Ma, 85-100 Ma, and 146-186 Ma.

DISCUSSION

The maximum depositional ages of all the samples from Nagai Island are tightly clustered between 73 and 77 Ma, and a 73.4 ± 1.2 Ma interbedded tuff confirms the Upper Cretaceous age of these rocks. The fact that the age of this tuff is so close to the youngest detrital zircon ages indicates that the Shumagin Formation represents the deposition of a massive volume of sediment in a volcanically active area in a relatively short period of time. This is also supported by textural evidence from thin sections of the samples. Mineral grains are very angular and any alteration transects grain boundaries and is therefore most certainly post-depositional, indicating that the sediment was immature and deposited close to its source. Based on the changing abundance of lithic fragments, magnetite and zircon, the volcanic contribution to the sediment supply appears to have increased up-section.

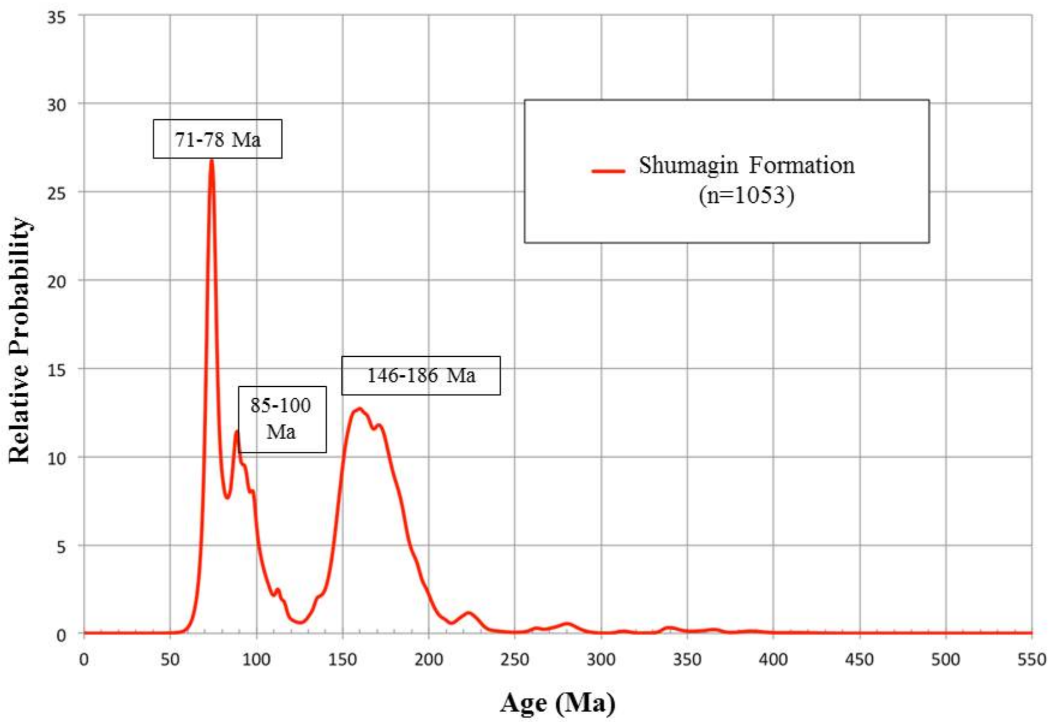

Figure 4. Composite U/Pb detrital zircon relative age probability curve for all ten of our samples from Nagai Island, calculated using the Microsoft Excel AgePick program from the Arizona LaserChron Center. The three main peaks at 71-78 Ma, 85-100 Ma, and 146-186 Ma comprise the diagnostic age populations for the Shumagin Formation on Nagai Island.

There are three main age populations in the detrital zircon U/Pb data consistent across all ten samples. The youngest population, from 71-78 Ma, is likely from an active volcanic arc. The 85-100 Ma population is from a slightly older volcanic arc and the 146-186 Ma population represents a Mesozoic arc basement terrane. There is no obvious trend in zircon age populations across the transect of Nagai Island.

The Kuskokwim Group, found directly inboard from the Shumagin Formation, has similar to slightly older depositional ages (95-77 Ma) as the Shumagin Formation (Miller et al., 2007). Therefore, as it was being deposited in a turbidite basin (Miller et al., 2007), it would likely have captured zircons from the same source area as the Shumagin Formation if the CPW was adjacent to this part of Alaska in the late Cretaceous. However, the age distribution curves of detrital zircons from Kuskokwim Group have peaks at ~93 Ma, ~185 Ma, ~350Ma, and ~525 Ma (Miller et al., 2007) and are distinctly different from those of the Shumagin Formation. It is clear, therefore, that the Kuskokwim Group and the Shumagin Formation did not share the same source. Not only are the primary modes different, but the Kuskokwim Group has a large fraction of Paleozoic grains with modes at ~350 and ~525 Ma, which are not present in the Shumagin Formation.

The detrital zircon data from the Shumagin Formation were also compared with those from correlative rock units along strike: the Kodiak and Ghost Rocks Formations from Kodiak Island (Olivas, 2012), the Orca Group from Prince William Sound (Hilbert-Wolf, 2012), and one sample from the Yakutat Group. As shown in Figure 5, the detrital zircon age populations of the Shumagin Formation closely resemble those of the other units, with the possible exception of the Yakutat Group. This implies that the four units share similar source terranes although fewer Precambrian grains (17 out of 1053) were recovered from the Shumagin Formation than from those correlative units (Roberts, 2013). The 17 Precambrian ages are consistent, however, with the Paleoproterozoic and Archean modes found in all of the correlative units farther east. The paucity of Precambrian grains in the Shumagin Formation may reflect along-strike variations in the meta-plutonic basement of the late Cretaceous arc source region. The difference in the age populations of the Yakutat Group may reflect its separate depositional history from the rest of the Chugach-Prince William Terrane. While it has been assumed to be a displaced portion of the CPW (Cowan, 2003), these data, combined with new Hf isotope data may point to a distinct source material for the Yakutat Group (Roberts, 2013).

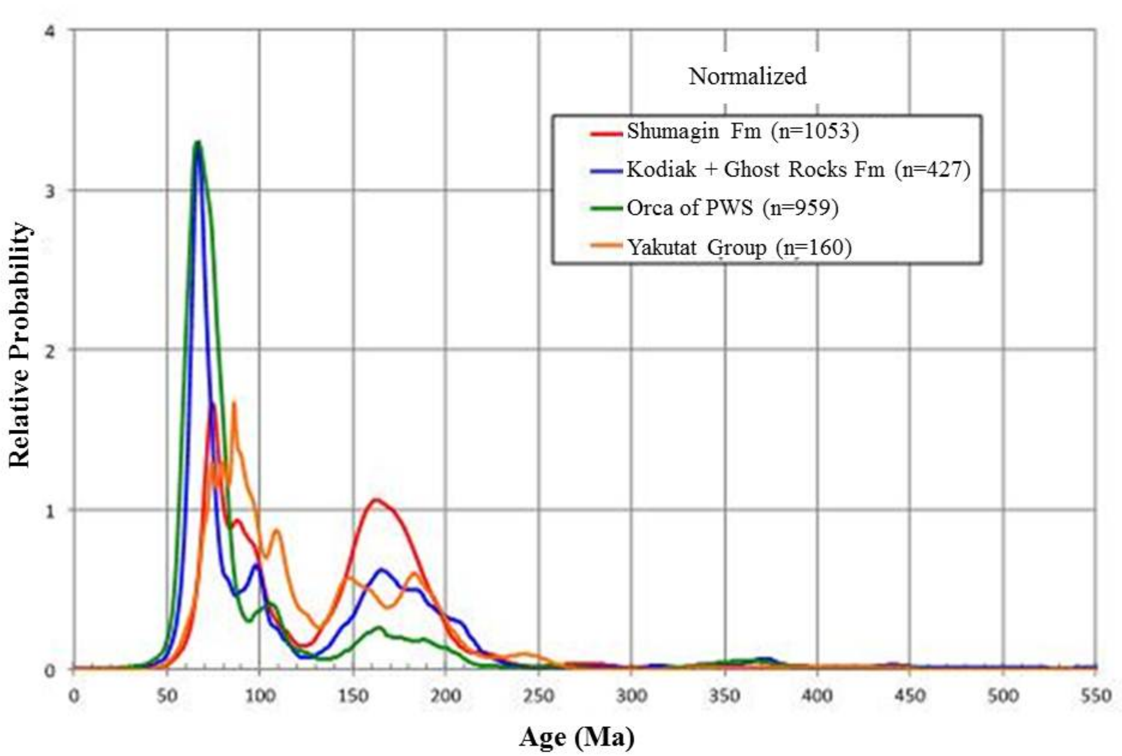

Figure 5. Comparison of the U/Pb detrital zircon age populations of the Shumagin Formation (Nagai Island), the Kodiak and Ghost Rocks Formations (Kodiak Island), older part of the Orca Group (Prince William Sound), and the Yakutat Group.

CONCLUSIONS

Detrital zircon data from Nagai Island in the Shumagin archipelago confirm that the Shumagin Formation is Upper Cretaceous. Detrital zircon U/Pb analysis of ten samples of volcanic-lithic and arkosic sandstone from Nagai Island yield tightly clustered maximum depositional ages ranging from 73-77 Ma. The U/Pb zircon age of an interbedded tuff yields an age of 73.7 ± 1.2 Ma, further confirming the Upper Cretaceous age of the Shumagin Formation and suggesting that the ages of the youngest detrital zircons in most of the samples are close to the depositional age of these rocks. Petrographic evidence—angular mineral grains and abundant feldspar and lithic fragments—indicates short-distance transport and immature sediment. The Shumagin Formation therefore represents the rapid deposition of a massive amount of sediment over a relatively short period of time. The volcanic contribution to the sediment supply also appears to increase up-section based on the increasing abundance of lithic fragment and magnetite.

Collectively, samples from the Shumagin Formation have three main populations of zircon ages, with modes at 74, 89, and 161 Ma. Variations between samples lie mainly in the relative number of grains making up these populations. Only 17 out of 1053 grains analyzed are Precambrian. These range from 1445 – 2760 Ma, with all but four falling between 1750 and 2000 Ma.

A comparison of detrital zircon populations between the directly inboard Kuskokwim Group and Shumagin Formation indicates that they did not share the same source terrane. Neither Mesozoic nor Paleozoic zircon age modes from the Kuskokwim Group match well with those in the Shumagin Formation. The Shumagin Formation zircon populations do, however, coincide closely with those of correlative rock units found along strike in Prince William Sound, Kodiak Island, and Yakutat, indicating that they shared a common source with the Shumagin Formation. This source region likely consisted of an active late Cretaceous arc built on a mostly Mesozoic age meta-plutonic basement. The Precambrian ages from the Shumagin Formation zircons are consistent with the Paleoproterozoic and Archean modes found in these correlative units. The paucity of Precambrian grains in the Shumagin Formation may indicate along strike variations in the meta-plutonic basement of the late Cretaceous arc source region.

Based on its U/Pb age spectra and its resemblance to correlative units along strike, we conclude that detrital zircon from the Shumagin Formation were partially derived from exhumed rocks of the Coast Mountains Batholith. Hf isotope data also point to the Coast Mountains Batholith as a possible source (Roberts, 2013). Given the location of the Coast Mountains Batholith, it is likely that location of this part of the CPW at the time of the intrusion of the Sanak-Baranof belt fits the model of Cowan (2003). Therefore, it appears that the Shumagin Formation was deposited south of its present location and has since been translated northward along the continental margin.

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