U-Pb DETRITAL ZIRCON PROVENANCE OF THE PALEOGENE ORCA GROUP, CHUGACH-PRINCE WILLIAM TERRANE, ALASKA

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INTRODUCTION

The southern Alaska continental margin is comprised of highly deformed, offscraped, and underplated marine rocks that have been accreted from the Mesozoic to the present (Plafker et al., 1989; 1994). Rocks of the Upper Cretaceous to lower Tertiary Chugach-Prince William (CPW) terrane constitute one of the thickest subduction-related accretionary complexes in the world. The CPW terrane is composed of deep-water turbidites (flysch) and associated volcanic rocks exposed for ~2,100 km in southern Alaska (Garver and Davidson, this volume). The CPW terrane is intruded by near-trench plutons of the 61-50 Ma Sanak-Baranof belt (SBB) (Bradley et al., 2003; Haeussler et al., 2003). The location of the CPW at the time of SBB ridge interaction is not known and under debate (i.e. Cowan, 2003; Haeussler et al., 2003). There are two prevailing hypotheses for the location of the CPW accretion: 1) a northern option in which the CPW formed more or less in situ and ridge interaction was related to the now subducted Resurrection Plate; or 2) a southern option in which the CPW formed farther to the south where it interacted with the Kula/Farallon ridge and was subsequently translated along the continental margin. These hypotheses require entirely different source regions for the clastic sediment that fed the CPW flysch.

This paper addresses the provenance of the Orca Group (Fig. 1) and correlation to units along strike on Kodiak. U-Pb zircon age data from the Orca Group reveal maximum depositional ages from ~69 Ma to ~35 Ma (Fig. 2). This age range spans the period when the CPW terrane is proposed to have either interacted with the fixed (relative to North America) Kula/Farallon trench-ridge-trench (TRT) triple junction south of its present latitude, or interacted with the migrating Kula/Resurrection TRT triple junction near its present latitude (e.g. Cowan, 2003).

GEOLOGIC SETTING

The Orca Group

The Orca Group consists primarily of marine flysch, and includes plutonic intrusions and structurally imbricated oceanic volcanic rocks (e.g. ophiolites of Knight Island and Resurrection Peninsula). The Orca flysch is a structurally thick (6-10 km) sequence that lies between the static inboard Insular superterrane and the active elements of the modern accretionary complex (Plafker et al., 1994). The flysch consists of deformed, thin- to thick-bedded turbidites composed of quartzofeldspathic to volcanic-lithic sandstone, siltstone, and mudstone (Dumoulin, 1987; Kveton, 1989; Plafker et al., 1994). Sparse microfossils indicate a Paleocene to Middle Eocene age for the Orca Group (Plafker et al., 1985). Mafic volcanic rocks (mainly pillow basalts and sheeted dikes) constitute 15-20% of the Orca Group (see Miner, this volume).

Structural panels of the Orca Group are bound by faults that splay from the Contact fault system (Winkler and Plafker, 1981). Kveton (1989) identified three fault-bound belts of unique structure and stratigraphy. These belts include the Whale Bay belt, the Bainbridge mélange belt, and the Latouche belt (Fig. 1). Tysdal and Case (1979) map the Montague Strait Fault to account for the difference in metamorphic grade between the Latouche belt and the most outboard Montague belt (low grade to the SE; prehnite-pumpyllite to the NW) (Fig. 1).

U-Pb GEOCHRONOLOGY

Previous Work

Previous detrital zircon work from the CPW terrane includes studies on units that lie inboard of the Orca Group: the McHugh Complex (farthest inboard; Ama-

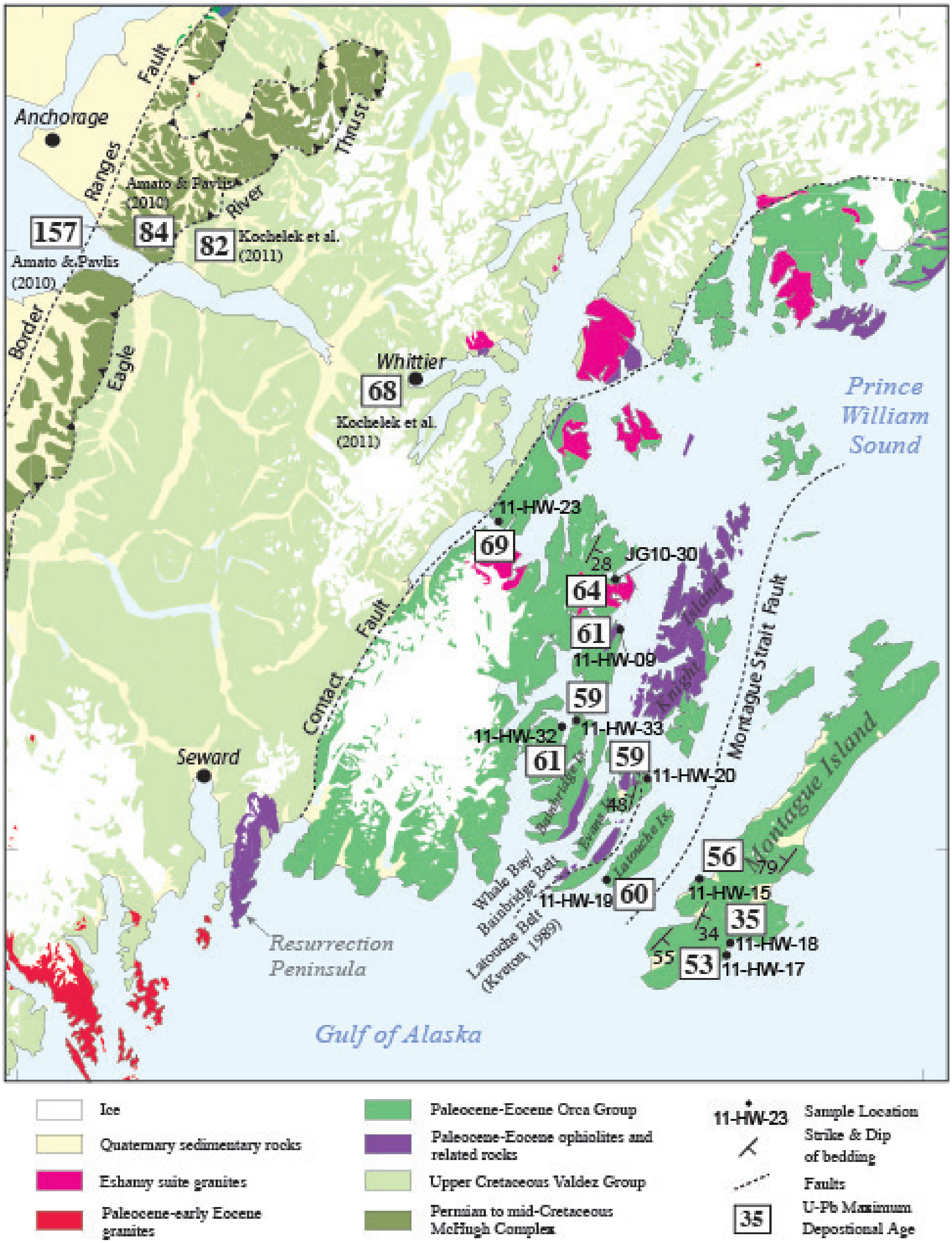

Figure 1. Geologic setting of the Chugach Prince William Terrane in western Prince William Sound, Alaska. Map modified from Bradley (2006). Maximum depositional ages shown in boxes (Ma) are from Fig. 2, Amato and Pavlis (2010), and Kochelek (2011).

to and Pavlis, 2010) and the Valdez Group (Kochelek et al., 2011; Bradley et al., 2009) (Fig.1). Maximum depositional ages from the McHugh Complex range from 157 to 146 Ma for inboard units, and from 91 to 84 Ma for outboard units (Amato and Pavlis, 2010). Bradley et al. (2009) reported the young zircons of the Valdez Group flysch at 69 Ma and 77 Ma, and no zircons older than Devonian. Kochelek et al. (2011) reported Valdez Group maximum depositional ages from 82 to 68 Ma.

METHODS

U-Pb detrital zircon ages were obtained from ten localities along a transect, roughly perpendicular to strike, in western Prince William Sound (PWS). U-Pb geochronology was conducted using LA-MC-ICPMS at the Arizona LaserChron Center (Gehrels et al., 2008). Zircons were separated using standard rock pulverization techniques, followed by density separation. In this study 100 zircons from each sample were randomly selected and individually dated to recognize major age components in approximately their original proportions.

In addition to a classic U-Pb detrital zircon study (i.e. 100 randomly selected grains), this research also selectively targeted Paleozoic and Precambrian grains in a subset of samples by preferentially hand picking rounded zircons and those in the pink series, qualities characteristic of old grains (see Garver and Kamp, 2002). Grains lacking euhedral characteristics are thought to have undergone significant transport and recycling. Metamictization of zircon, due to radia-

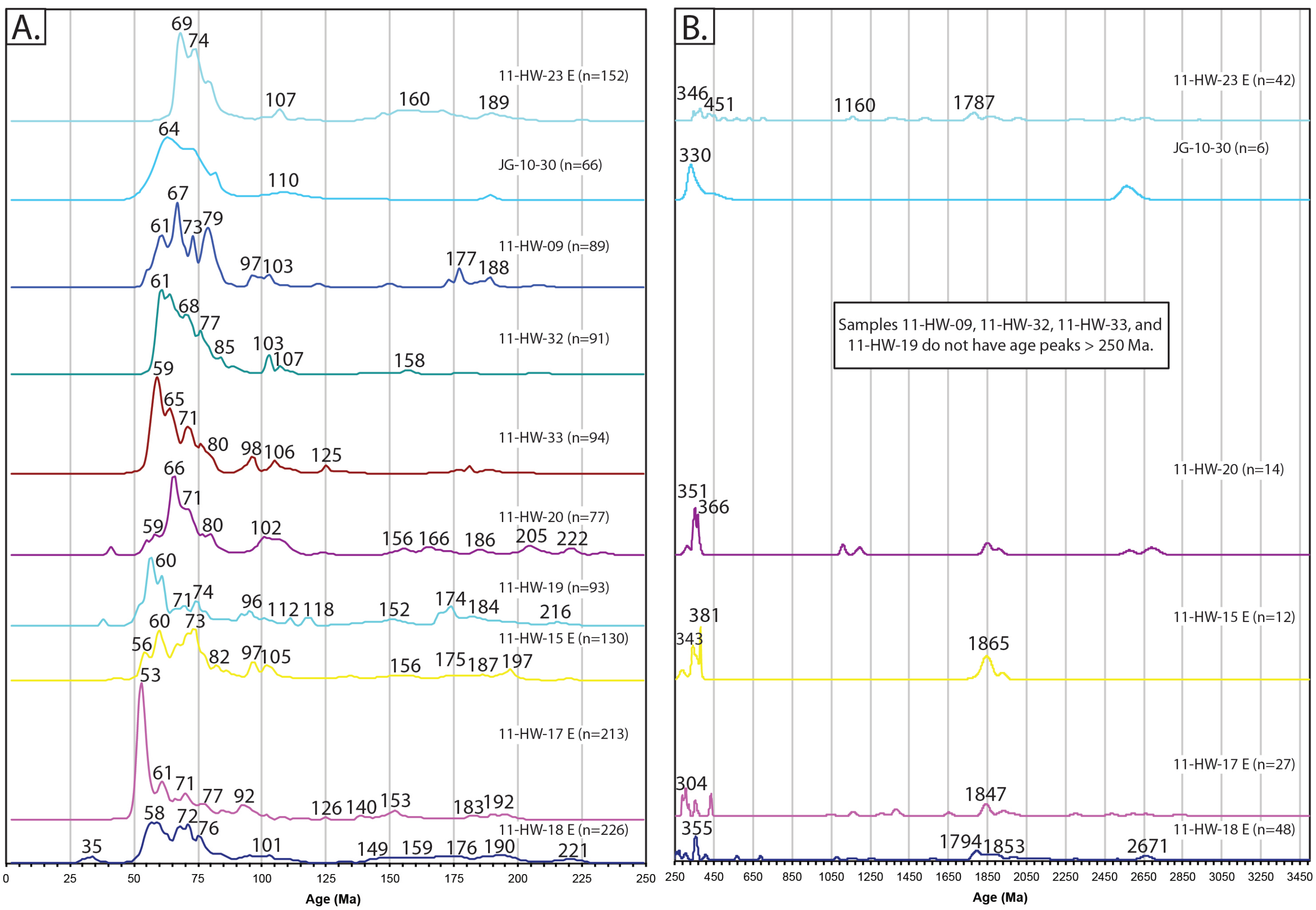

Figure 2. Normalized relative age probability plots of detrital zircon grain populations from the Orca Group in western Prince William Sound. A) Zircon populations from 0-250 Ma. B) Zircon populations from 250-3500 Ma. Peak ages were calculated using the Excel program Age Pick provided by the LaserChron Center at the University of Arizona. Note that the probability curves in A and B were normalized separately, so the peak heights in A cannot be compared with those in B. Samples labeled with an 'E' include both traditional and handpicked grains (see text).

tion damage, forms color centers ranging from pink to purple (Garver and Kamp, 2002). Except for samples 11SJO-34 and JG09-05, ~100 grains were selected for analysis. The Paleozoic-Precambrian grain populations identified using this new methodology have the potential to be a distinctive provenance fingerprint (Mahoney et al., 1999; Grove et al., 2003; Jacobson et al., 2011), as there are multiple potential source rocks along the Western North American margin with considerable Cenozoic and Mesozoic signal overlap.

RESULTS

The ten youngest zircons analyzed from 11-HW-23 (farthest inboard; Fig. 1) range from 61 to 68 Ma, with the youngest coherent population at 69 Ma (n=59). The ten youngest zircons analyzed from 11-HW-18 (farthest outboard; Fig. 1) range from 31 to 52 Ma, with the youngest age peak at 35 Ma (n=7). Figure 2 reveals the maximum depositional age progression of the Orca Group from inboard to outboard, as well as trends in zircon age populations throughout the flysch. It is important to note that Eocene grain populations are present only in the outermost samples from Montague Island (11-HW-17, -18). All samples contain Paleocene, Cretaceous, and either Jurassic or Triassic (or both) component ages. However, Triassic grain populations are less common in the more outboard samples (11-HW-19, -18). Inboard and outboard samples show Paleozoic grain populations, but these are absent from samples in the middle of the transect (i.e. 11-HW-09, -32, -33, -19).

Paleozoic to Precambrian grain populations were detected in each sample that was handpicked. Three of the ten samples from western Prince William Sound (11-HW-17, 18, and 23) and three of the six samples from Kodiak Island (11CD-60, 11SJO-34, JG09-05; see Olivas, this volume) were handpicked for rounded and damaged zircons. Traditional samples yielded between 1% and 15% Precambrian grains. Handpicked samples yielded between 17% and 95% Precambrian grains. This result is a significant increase in the representation of Precambrian grain populations, and useful for provenance analysis. Precambrian grains are dominantly between 1865 and 1787 Ma.

DISCUSSION

The 69 to 35 Ma range in maximum depositional ages is important because it spans the time when the CPW terrane either: 1) interacted with the fixed Kula/Farallon TRT triple junction south of its present latitude (Cowen, 2003); or 2) interacted with the migrating Kula/Resurrection TRT triple junction (Haeussler et al., 2003). These ages also demonstrate that deposition was more or less contemporaneous with the intrusion of the flysch by the near-trench plutons of both the 61 to 50 Ma Sanak Baranof belt and also with the ~37-40 Ma Eshamy suite. Pillow basalts from the Knight Island ophiolite are interbedded with shale from the Orca flysch (Fig. 3). The flysch probably covered the ridge responsible for producing the ophiolitic rocks, which were likely a product of the ridge subduciton that drove the near-trench plutonism of the Sanak-Baranof belt.

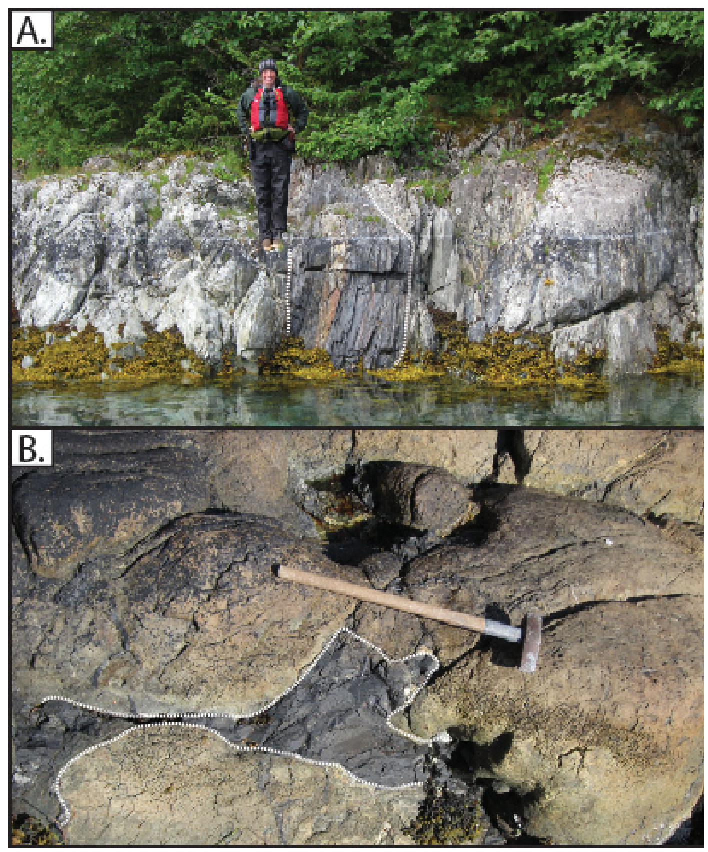

Figure 3. Field photographs showing depositional relationships between the Orca flysch and the Knight Island ophiolite. A) Interbedding of flysch (outlined in white) and deformed pillows from Thumb Bay on the south end of Knight Island. B) Delicate depositional contact between black shale (outlined in white) and pillows from the west side of Knight Island just north of Drier Bay.

It has been proposed that the contact between the Upper Cretaceous Valdez Group and the Paleogene Orca Group represents a major terrane boundary (e.g. Jones et al., 1981; Mitchell, 1979). Similarity in sandstone composition is evident across the Chugach/ Prince William terrane boundary in PWS and on Kodiak Island (Nilsen and Moore, 1979; Dumoulin, 1987). Isotope geochemistry suggests that both the Valdez and Orca groups were derived from the Coast Mountains Batholith (Farmer et al., 1993). Figure 1 demonstrates the continuous deposition of material in the CPW terrane from 91 Ma (greywacke of the McHugh Complex; Amato and Pavlis, 2010) to 35 Ma (outboard Orca Group; this study).

This study is the first to constrain the Eocene age of the most outboard Orca flysch at ~56 to 35 Ma. A combination of detrital zircon U-Pb age data and zircon fission track analyses (Carlson, this volume) suggest that there are three belts of the Orca Group: A) an inboard Paleocene belt deposited < 57 to 60 Ma; B) an Early Eocene belt on Evans and Latouche islands deposited < 38 Ma (before and during Eshamy suite intrusion); C) a Late Eocene belt on Montague Island deposited < 34 to 35 Ma (post all intrusions) (Fig. 1). Kveton's (1989) petrographic analysis revealed two compositionally distinct groups of the Orca flysch, suggesting that the fault separating the Whale Bay and Bainbridge belts from the Latouche belt, or in this case belt A from belt B, is a unit-bounding structure. Sample 11-HW-18 from Montague contains unequivocal 'young' zircon grains (34, 35, 35, 40 Ma) that define a population at 35 Ma. Also on Montague Island, sample 11-HW-17 contains a 42 ± 3.0 Ma grain, and sample 11-HW-15 contains a 43 ± 2.5 Ma grain. The 54.5 ± 1.8 Ma Sheep Bay pluton (Johnson, this volume) lies along-strike to the NE of Montague Island in eastern PWS and intrudes flysch of the Orca that obviously must be older. However, the young grains of 11-HW-18 demand that the outboard Orca flysch on Montague Island is younger than 54 Ma, and hence suggests a more complicated pattern of accretion of Orca tectonostratigraphic belts. U-Pb ages from 11-HW-19 and 11-HW-20 on Latouche and Evans islands both have single young grains (38 ± 0.6 Ma and 41 ± 1.6 Ma, respectively) and robust age peaks in the Early Eocene. 11-HW-19 has at least three grains that are pre-52 Ma, suggesting that this belt of the Orca flysch was also likely deposited after the intrusion of the Sheep Bay pluton (54.5 Ma). The maximum depositional U-Pb ages of all other Orca samples inboard of Evans Island are older than the Sheep Bay pluton. Zircon fission track samples from Chenega, Evans, and Latouche islands were partially to completely reset at about 38 Ma (Carlson, this volume). Belts B and C are almost indistinguishable with regard to U-Pb age signatures (they share a unique density of peaks between 222 and 155 Ma), but their thermal history sets them apart from one another.

The U-Pb data presented in this study supports the correlation of along-strike units within the CPW. U-Pb detrital zircon ages reinforce the following correlations: Kodiak Formation (67-63 Ma; Olivas, this volume) = Valdez Group (82-69 Ma; Kochelek, 2011 and Bradley, 2009); Ghost Rocks Formation (66 Ma; Moore et al., 1983) = inboard Orca Group (69-60 Ma; this study); Sitkalidak Formation (59-55 Ma; Olivas, this volume) = outboard Orca Group (56-35 Ma; this study).

One method for evaluating the provenance of the Orca Group is to compare the detrital zircon signal with those of same-age sedimentary basins (correla-

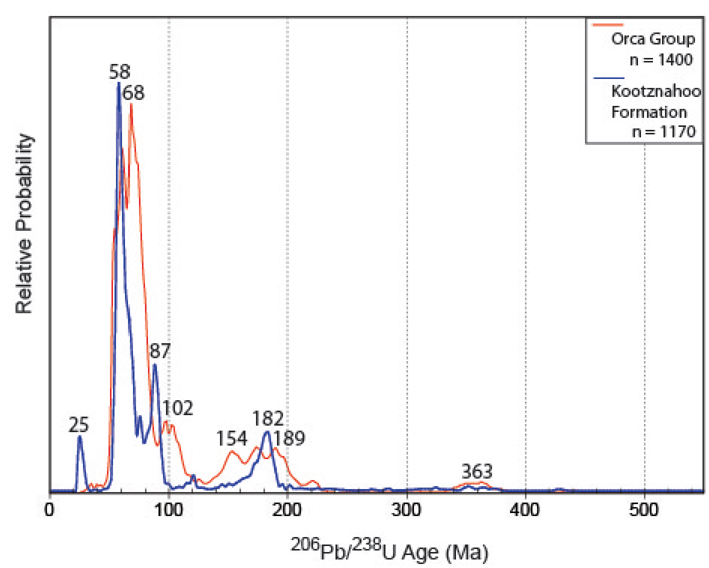

Figure 4. Cumulative relative age probability plots comparing detrital zircon grain populations from the Orca Group (this study) and the Kootznahoo Formation (Evenson, 2010). Peak ages calculated using the Excel program Age Pick provided by the LaserChron Center at the University of Arizona.

tive units). Many have suggested the plutonic and high-grade metamorphic complex of the Coast Mountains of British Columbia and southeastern Alaska as a source for the Orca Group (e.g. Hollister, 1979; Winkler and Plafker, 1981; Nilsen and Zuffa, 1982; Farmer et al., 1993; Sample and Reid, 2003). One of the best anchor points of similar age strata is the arkosic, Paleocene-Eocene Kootznahoo Formation of the Kootznahoo basin in southeast Alaska, which has accumulated on the Wrangellia and Alexander terranes. This unit is dominated by plutonic zircon populations at 65 to 50 Ma, 93 to 85 Ma, and 190 to 160 Ma, suggesting derivation from the adjacent Coast Mountains Batholith complex (Evenson, 2010). Orca Group detrital zircon populations overlap with those of the Kootznahoo Formation (Fig. 4), including

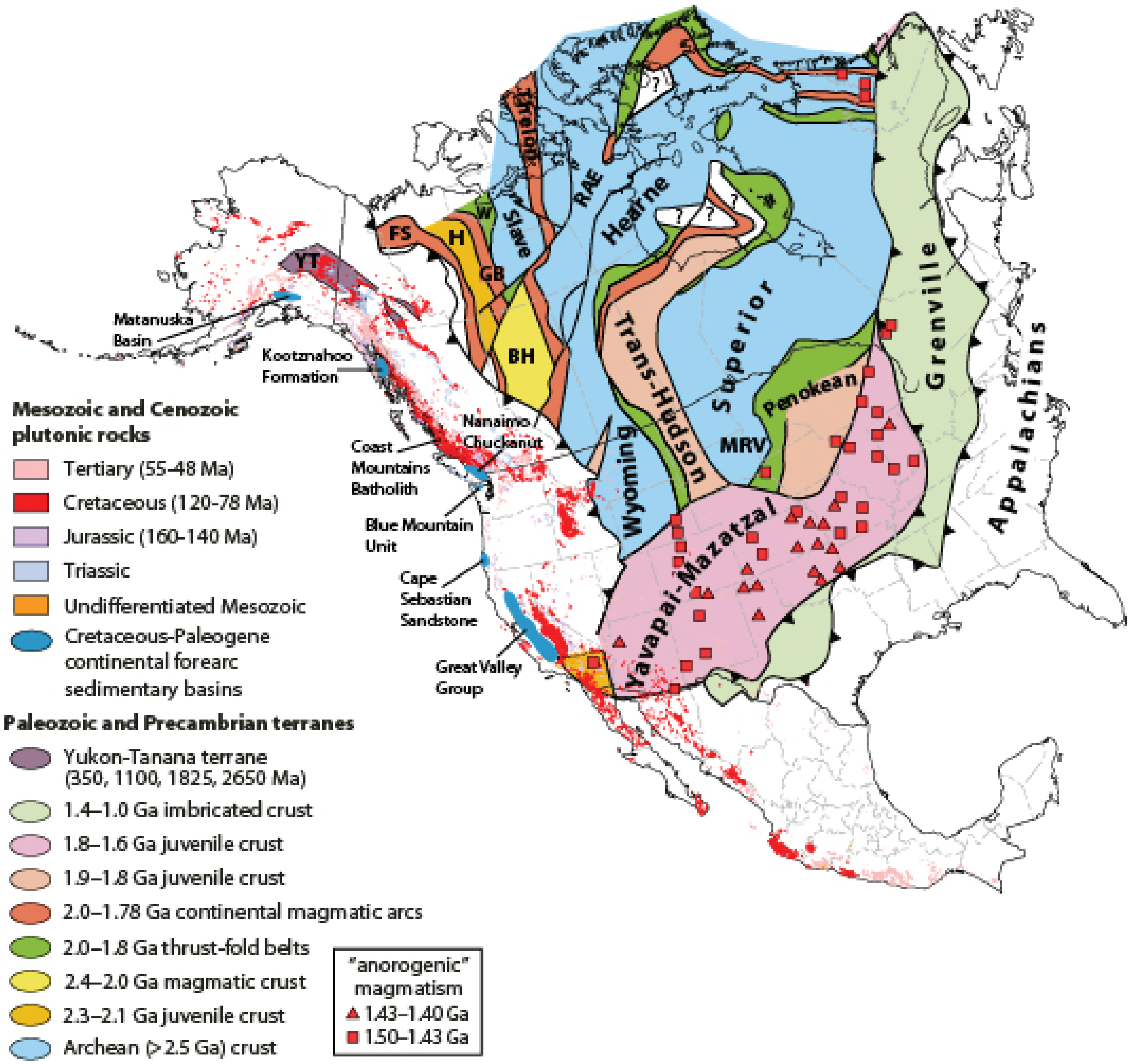

Figure 5. Simplified tectonic map of North America (modified from Hoffman, 1988; Piercey and Colpron, 2009), identifying age-correlative sedimentary sequences and potential Paleozoic and Precambrian source terrains for the Orca Group. Mesozoic and Cenozoic plutonic rocks are from Garrity and Soller (2009); dates indicate times of main igneous flare-ups in British Columbia and southern Southeast Alaska identified by Gehrels et al. (2009). Yukon-Tanana (YT) dates (four most abundant peaks on a probability distribution plot, n=1078) are from a U-Pb detrital zircon compilation by G. Gehrels (pers. comm.).

a population of zircon grains at ~ 363 Ma. A reasonable hypothesis is that that the Orca Group sediment was derived, at least partially, from the Coast Mountains Batholith.

To expand the search for potential source terranes for the Valdez and Orca Groups we are: 1) identifying potential deeply exhumed source terrains, and 2) considering the detrital zircon age signature of same-age basin strata deposited inboard of the CPW accretionary complex in Alaska and farther south along the North American margin. We have identified a number of these sedimentary sequences (Fig. 4). From north to south, these units include the: a) Matanuska basin in south central Alaska; b) Nanaimo Group in southern B.C. and Washington; c) Campanian to Maastrictian Cape Sebastian Sandstone, a thin (> 800 ft.) shallow marine unit (Dott, 1971); and d) Great Valley Group of California (Cretaceous age strata), derived from the adjacent Sierra Nevada and Klamath Mountains (DeGraaff-Surpless et al., 2002).

When considering potential source areas, we are interested in parts of the Cordillera that have: 1) near constant volcanism and plutonism from 85 to 55 Ma (this study; Dumoulin, 1987; Bradley, 2009); 2) a low proportion of pre-Mesozoic rocks; and 3) experienced profound exhumation throughout this interval. There are three areas in particular that meet these criteria: 1) central Coast Mountains Batholith (experienced exhumation from 65 to 50 Ma); 2) the Omineca belt (deeply exhumed during the Eocene); and 3) the Idaho Batholith (intruded between 118 and 85 Ma; see Brandon and Vance, 1992).

CONCLUSIONS

The maximum depositional ages of the flysch of the Orca Group range from 69 to 35 Ma, NW to SE, suggesting that clastic rocks of the CPW terrane were more or less deposited continuously from ~84 Ma to ~35 Ma. This age progression is corroborated by the observations of compositional uniformity based on petrographic analyses of Dumoulin (1987) and Kveton (1989) and the isotopic analyses of Farmer et al. (1993). The maximum depositional ages constrained by this study in combination with field observations suggest that the Orca Group was deposited contemporaneously with the intrusion of the flysch by near-trench plutons of the Sanak Baranof Belt and Eshamy Suite plutons (Johnson, this volume). Differences in sandstone compositions, U-Pb zircon age populations, and intrusive and thermal histories (Carlson, this volume) support the presence of at least three fault-bounded belts of Orca flysch in Western Prince William Sound. These belts probably represent successive units of the Orca flysch that were accreted to the margin before, during, and after the intrusion of the Sanak-Baranof plutons at ~54 Ma and the Eshamy suite plutons at ~38 Ma. Finally, U-Pb age spectra of the Orca Group were partially derived from exhumed rocks of the Coast Mountains Batholith. Successful hand-selection of Precambrian grains has also revealed the northwestern Laurentian margin as a potential sediment source.

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