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Dr. Robert J. Varga, Editor
Director, Keck Geology Consortium
Pomona College

Dr. Holli Frey
Symposium Convener
Union College

Carol Morgan
Keck Geology Consortium Administrative Assistant

Christina Kelly
Symposium Proceedings Layout & Design
Office of Communication & Marketing
Scripps College

Keck Geology Consortium
Geology Department, Pomona College
185 E. 6th St., Claremont, CA 91711
(909) 607-0651, keckgeology@pomona.edu, keckgeology.org

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Robert J. Varga
Editor and Keck Director
Pomona College

Keck Geology Consortium
Pomona College
185 E 6th St., Claremont, CA 91711

Christina Kelly
Proceedings Layout & Design
Scripps College

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Keck Geology Consortium: Projects 2014-2015
Short Contributions— Tectonics of Prince William Terrane, AK Project

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DETRITAL ZIRCON U/PB AGES AND PROVENANCE STUDY OF THE PALEOCENE TO MIOCENE TOFINO BASIN SEDIMENTARY SEQUENCE, OLYMPIC PENINSULA, WASHINGTON

FRANK R. MOLINEK III, Carleton College
Research Advisor: Cameron Davidson, John Garver

INTRODUCTION

The Tofino basin sedimentary sequence of the northwestern Olympic Peninsula is a Paleocene to Miocene forearc basin that sits stratigraphically above the Crescent terrane and the Wrangellia terrane. The clastic strata are thought to be derived, at least in part, from the unroofing of the Coast Plutonic Complex (CPC) as determined through zircon fission-track thermochronology (Garver and Brandon, 1994). Several studies (Farmer et al., 1994; Haeussler et al., 2005; Hilbert-Wolff, 2012; Amato et al., 2013; Roberts et al., 2013) have also suggested that the CPC could be a primary source of the Chugach-Prince William terrane (CPW).

The paleogeographical location of the CPW's deposition, however, is currently unresolved and in debate. The dextral Border Ranges fault system implies coastwise translation of the CPW. Some translation is widely accepted in the literature, but the amount of translation is unknown, with proposed displacements of anywhere from a few hundred kilometers to over 3000 km (Haeussler et al., 2003; Cowan et al., 1997; Cowan, 2003). If U/Pb isotopic analysis can show that the young Orca Group and the Tofino basin sedimentary rocks share a source region, it would be strong evidence that the CPW was accreted far south of its current location and experienced significant coastwise translation. The purpose of this study is to conduct U/Pb geochronology on detrital zircon from the Tofino basin and discern what, if any, relationship exists between these strata and contemporaneous strata from the Orca Group of the CPW.

GEOLOGY OF THE TOFINO BASIN

The Tofino basin sedimentary sequence sits stratigraphically above the Crescent Formation on the northern edge of the Olympic Peninsula (Tabor and Cady, 1978) (Fig. 1).

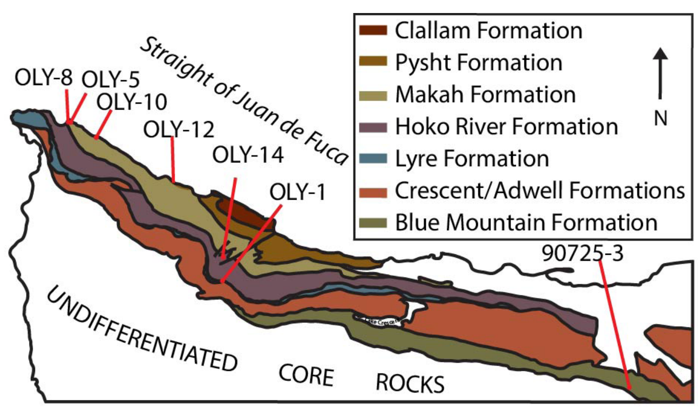

Figure 1. Geologic map of the northern Olympic Peninsula, with sample sites indicated. The Tofino basin sedimentary sequence is part of a broad syncline filled by the Strait of Juan de Fuca. Modified from Garver and Brandon, 1994 and Tabor and Cady, 1978.

The Tofino basin contains the Aldwell, Lyre, Hoko River, Makah, Pysht and Clallam Formations (Figs. 1 & 2). The Tofino basin is a forearc basin related to the Cascadia subduction, which began ~36 Ma (Garver and Brandon, 1994; Brandon and Vance, 1992). The Cresecent Formation consists of thick submarine and subaerial basalt flows. The deep-water basal pillow basalts that form the base of the Crescent overlie and interfinger with the lithic turbidite sandstone and mudstone of the Blue Mountain unit (Wells et al., 2014). The Tofino basin clastic strata, Crescent Formation, and Blue Mountain units are north-dipping on the northwestern Olympic Peninsula. They are part of a broad syncline that is presently filled by the Strait of Juan de Fuca.

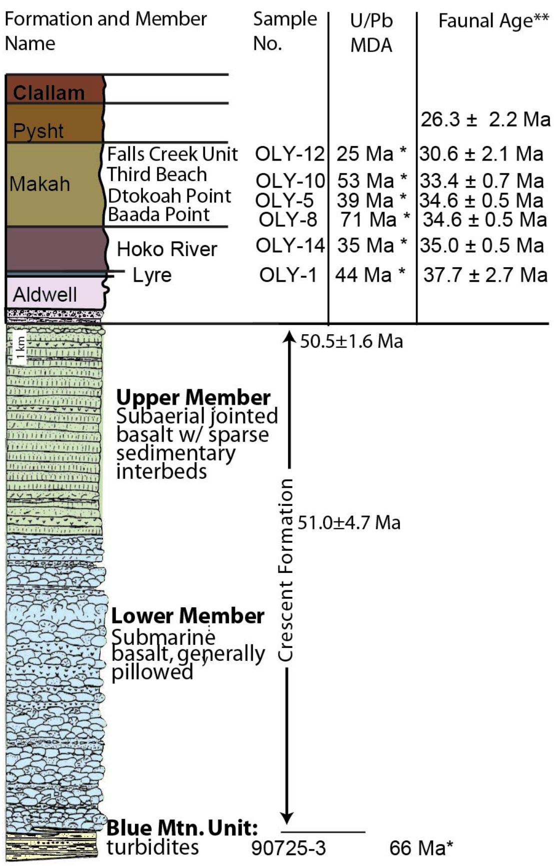

*Figure 2. Composite stratigraphic section for the northwestern Olympic Peninsula (From Hirsch and Babcock, 2009 and Garver and Brandon, 1994. Ages of dated spcimens are shown at their approximate stratigraphic position. * U/Pb MDA from AgePick. **Faunal age from Garver and Brandon, 1994. Ages from the Crescent Formation are from Hirsch and Babcock, 2009.*

GEOLOGY OF THE CHUGACH-PRINCE WILLIAM TERRANE

The southern Alaska margin consists of highly deformed, offscraped, and underplated deep-sea rocks that were accreted from the Mesozoic through the Cenozoic to the present day (Plafker et al., 1994). One of the complexes making up the margin is the Chugach-Prince William (CPW) terrane. The CPW is a Mesozoic-Tertiary accretionary complex that is well exposed for ~2200 km and may be one of the thickest accretionary complexes in the world (Plafker et al., 1994; Garver and Davidson, 2012). It is primarily composed of deep-water turbidites (~90%) consisting of quartzofeldspathic and volcanic-lithic sandstones and shales of the Orca and Valdez Groups. The remainder is a mélange separating the CPW from the Border Ranges fault system (10%), and minor greenschist/blueschist facies metamorphic rocks (Plafker et al., 1994). The Orca and Valdez Groups also incorporate igneous units, such as the Resurrection and Knight Island ophiolite complexes, as well as the plutonic rocks of the Sanak-Baranof belt, which intrudes the CPW along its entire strike.

Hilbert-Wolf (2012) grouped the Orca Group of the western Prince William Sound into three belts, based on thermal history, lithology, and U/Pb geochronology. The youngest, the Montague Belt, has one sample with 4 young grains (34, 35, 35, 40 Ma), but is otherwise indistinguishable from the Latouche Belt by U/Pb geochronology.

U/PB GEOCHRONOLOGY

U/Pb geochronology of detrital zircons in clastic sedimentary rocks has been used to study both the depositional age and provenance of those units (Gehrels, 2014). One of the most interesting and powerful uses of detrital zircon U/Pb radiometric dating is investigation of the maximum depositional ages (MDA) of the units sampled. The MDA is numerical result of the principle that a sedimentary unit cannot be older than the youngest detrital zircon grain(s) found in it (Gehrels, 2014). Another use of detrital zircon U/Pb radiometric dating studies is making use of grain age populations to gain insight into the provenance of sedimentary rocks and their terranes (Gehrels, 2014; Garver and Davidson, 2012). Each peak on the grain age distribution plot will correspond to a source component of the sedimentary rock sampled (Fig. 3). If multiple contemporaneous sedimentary units have the same detrital zircon source areas, it is likely that those units have the same provenance.

In this study, a total of 1829 U/Pb analyses of detrital zircon from seven sample locations from the Tofino basin of the Olympic Peninsula are reported; these samples were collected by Garver and Brandon (1994). Sample mounts were prepared with zircon standards from Sri Lanka which contains ~518 ppm of U and 68 ppm Th (used in measurement calibration).

U/Pb radiometric data were collected at the University of Arizona's LaserChron Center, in Tucson, Arizona. Laser ablation inductively coupled mass spectrometry (LA-ICPMS) was conducted using Photon Machines Analyte G2 excimer lasers for laser ablation, then mass spectroscopy was carried out using a Nu Plasma II Multicollector ICPMS and a ThermoScientific Element 2 single collector ICPMS according to methods described in Geherls (2008).

Data were reduced offline using the AgeCalc program in Microsoft Excel provided by the Arizona LaserChron Center. Corrections for concordance and instrument drift were carried out in the program, using data from standards which bracketed unknown samples during measurement. Normalized age probability plots, AgePick ages, and Kolmogorov-Smirnoff (K-S) tests were created and carried out using programs provided by the Arizona LaserChron Center and Cameron Davidson, Carleton College.

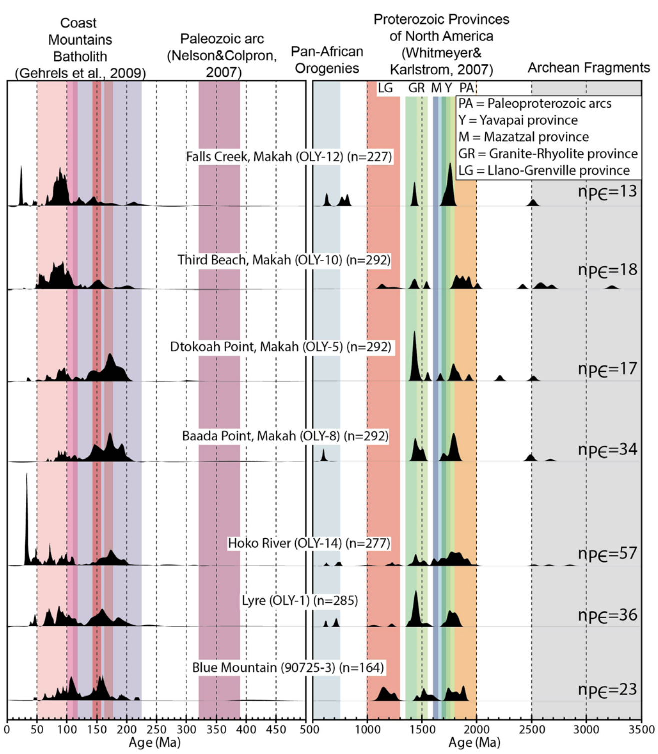

Figure 3. Comparison of normalized detrital zircon probability distributions of U/Pb ages from the Tofino basin, Washington, with known tectono-magmatic events in North America and elsewhere. Note there is a scale change in the abscissa and ordinate for the Precambrain.

RESULTS

The Tofino basin sedimentary units have major zircon age populations in the Jurassic (~200, 175, 160-150 Ma), the Cretaceous (~60, 115-70 Ma) and the Cenozoic (60-40 Ma, Oligocene in two units) (Fig. 3). There are also Precambrian populations in every unit with peaks around 1400 and 1800 Ma. Nearly all samples have Jurassic populations around 200 Ma (194-215), with the exception of the Lyre and Hoko River Formations. The Third Beach and Falls Creek units of the Makah Formation are missing major Jurassic populations around 175 Ma, which occur in the rest of the samples (Fig. 3). Every sample has a Late Jurassic population (150 – 160 Ma) but the relative magnitude of this population's peak decreases in the Third Beach and Falls Creek units.

The Blue Mountain, Lyre, Hoko River, Baada Point, and Dtokoah Point units all have populations in the Cretaceous spanning 70 to 115 Ma. The Third Beach and Falls Creek units have this same age span, but it is much higher in magnitude relative to the rest of the sample. The Baada Point Member has no ages younger than 70 Ma and the Blue Mountain unit has only 2 grains younger than 63 Ma. All other samples have populations from 40 – 60 Ma. The Hoko River and Falls Creek units also have large Oligocene populations (34 and 24 Ma, respectively).

Lower in the section (Blue Mountain, Lyre, Baada Point, Dtokaoh Point), the Jurassic signal is strong but these samples also contain Cretaceous to early Paleogene signals. In the Baada Point and Dtokaoh Point Members, this Jurassic signal is the main grain-age population seen. In the top two sampled units of the section the Cretaceous and Paleogene signal is dominant.

Every sample has significant populations around 1400 and 1800 Ma. The Blue Mountain and Third Beach units have smaller populations (or single grains) around 1070 Ma. The Hoko River and Makah Formations all have at least a single grain in the Archean.

DISCUSSION

Grain Age Distributions

The Tofino basin sedimentary sequence has major population in the Early and Late Jurassic, the Late Cretaceous, and the Paleogene. The grain age populations in the Jurassic match with a source that begins with the Bonanza arc, currently cropping out on Vancouver Island (202-165 Ma, Clift et al., 2005). The source then appears to shift to the Coast Plutonic Complex, which had periods of high magmatic flux 160-140, 120-80, and 60-48 Ma that match well with the grain populations seen in the samples from this study (Gehrels et al., 2009). The young populations (24 Ma, OLY-12; and 34 Ma, OLY-14) occur after the cessation of the CPC, and are likely sourced from the Cascade arc, which was active in that area beginning around 36 Ma (Brandon and Vance, 1992)

All of the units in the Tofino basin have a similar Precambrian grain age distributions with populations around 1400 and 1700-1800 Ma (Fig. 3). These populations are indicative of a southern Laurentian source, corresponding to the Granite-Rhyolite province and the Yavapai-Mazatzal province (Whitmeyer and Karlstrom, 2007). This is somewhat surprising given their current location, and the lack of proximity between the CPC and southern Laurentia. A southern Laurentian signature is also seen in the Yakutat Formation of the Chugach-Prince William terrane, and Roberts (2013) suggests that much of the Orca Group in Prince William Sound contains a mixed signal of Northern and Southern Laurentian zircons. The southern Laurentian signature in the Tofino Basin does not necessarily mean that the rocks containing it were once in southern Laurentia, as the zircons may have a long history involving burial, exhumation, and recycling, and thus were likely not deposited directly from igneous sources. However, the fact that both the Tofino basin and Yakutat units only have a southern Laurentian signature, with little trace of a northern component, should be considered in future work.

Implications of U/PB Maximum Depositional Ages

A lack of a consistent younging trend upsection, and discrepancies between the U/Pb MDAs and the reported faunal ages in Garver and Brandon (1994) suggests that the U/Pb MDAs are not good approximations of the depositional age for most of the formations or units in the Tofino Basin (Fig. 2). This implies that active arc volcanism was not occurring nearby at the time of deposition of the Tofino Basin, or that an active arc was not contributing material to the drainage basin at the time of deposition. Sample Oly-14 from the Hoko River Formation and Oly-12 from the Falls Creek unit of the Makah Formation are the two exceptions. In the case of the Falls Creek unit of the Makah Formation, the 24 Ma U/Pb MDA is younger than the reported 30.6 Ma faunal age (Fig. 2). In addition, Garver and Brandon (1994) give the Pysht Formation a faunal age of 26.3 Ma, with a range of 24.1-28.5 Ma. A U-Pb MDA age of 24 Ma for the Falls Creek unit of the underlying Makah Formation suggests that the upper part of the Makah and the Pysht Formations are younger than previously recognized and should be reevaluated.

Age of the Blue Mountain Unit

The Blue Mountain unit is in depositional contact and interfingers with the base of Crescent Formation pillow basalts on the Olympic Peninsula (Wells et al., 2014; Hirsch and Babcock, 2009). Figure 2 shows previously reported ages of the Crescent Formation. The youngest two grains from our sample of the Blue Mountain unit (90725-3) are 48.0 ± 0.9 and 50.5 ± 0.8 Ma. Because of the potential for lead-loss, these two young grains do not make a robust population that can be used to calculate the MDA of the Blue Mountain unit (Gehrels, 2014). Using AgePick, sample 90725-3 yields a maximum depositional age of 66 Ma. However, Wells et al. (2014) report detrital zircon ages from a sample of the Blue Mountain unit collected at Buckhorn Mountain (~18 kilometers to the southeast of 90725-3) that has four grains that yield an AgePick MDA of 48 Ma. The normalized relative probabilities of these two studies are compared in Figure 4. If these two samples are combined, then the resultant age from the weighted mean of the six youngest grains is 48.0±0.7 Ma. As this is within the error of previously reported ages of the top of the Crescent Formation, it implies a very short time for the accumulation of the Crescent (Hirsch and Babcock, 2009).

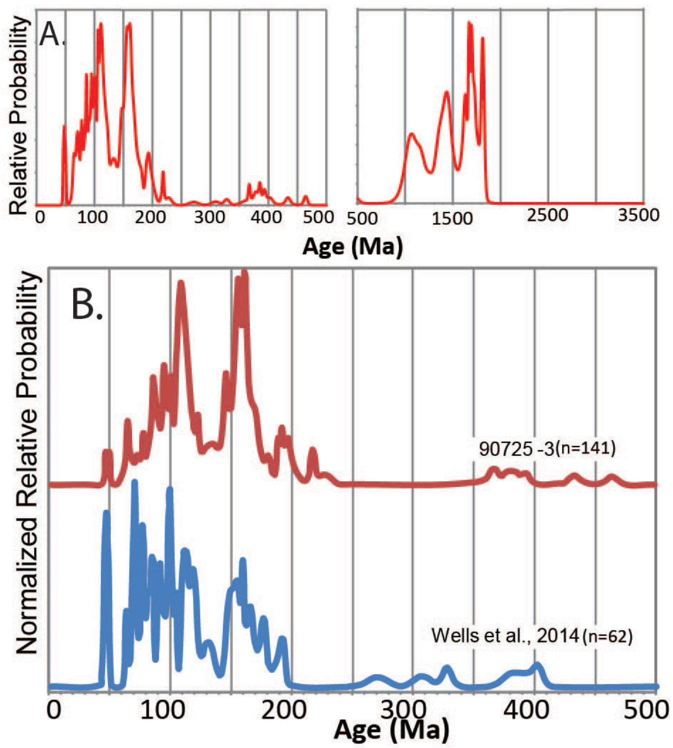

Figure 4. Probability density of detrital zircon U/Pb dates for the Blue Mountain unit. A: Combined dates from this study (sample 90725-3) and from Wells et al. (2014). Note the scale changes at 500 Ma. B: Probability density curves from this study and from Wells et al., 2014. The good fit between the data from this study and from Wells et al. was reason to combine the two data sets, and yeild an MDA of 48.0 ± 0.7.

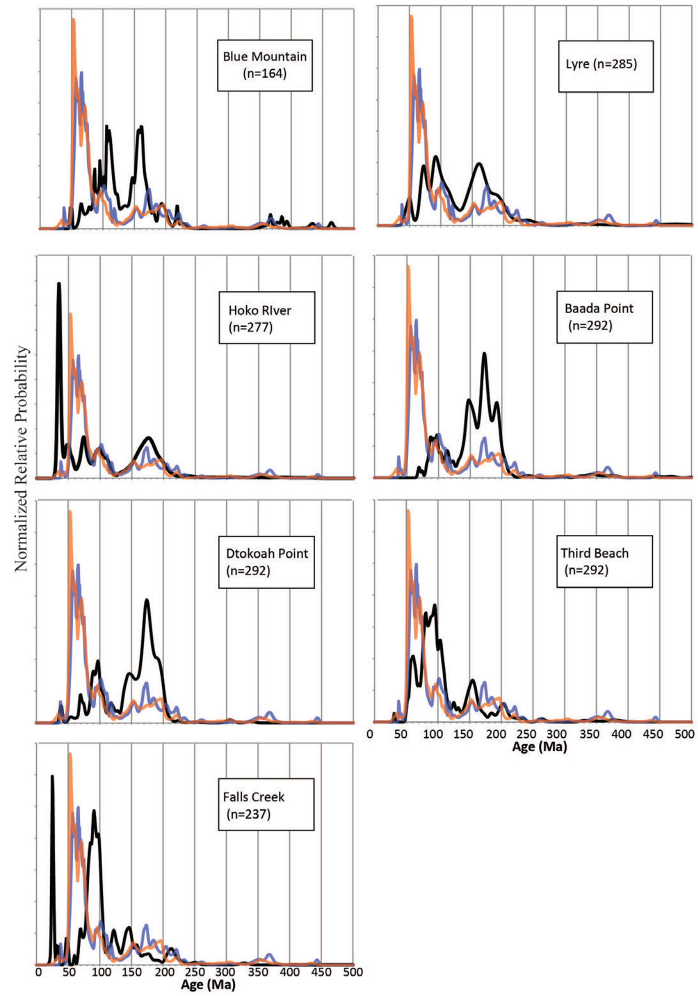

Figure 5. Comparisons between normalized relative probability curves. Light orange is data from the Montague Belt and light blue is data from the La Touche Belt (Hilbert-Wolf, 2012). Solid black line denotes the sample from this study named on each graph. The Y axis for each graph is normalized relative probability, note the scale change on each.

Comparison with the Latouche and Montague Belts

While none of the Tofino samples or the Blue Mountain unit are an exact grain age match with the Latouche and Montague Belts of Hilbert-Wolf (2012), they do have populations at similar ages (Fig. 5). The populations at 175, 150, 100, and the area from 60-40 Ma are present in both the Tofino and Orca units. However, the Jurassic is typically a larger population in the Tofino, and the Late Cretaceous and Paleocene populations are typically much larger in the Orca Group. The middle Cretaceous populations are of similar scale in both units. The Hoko River Formation stands out as having similar relative probabilities to the Latouche and Montague Belts in the Jurassic and middle Cretaceous.

This result likely means that although both the Orca and Tofino units are derived from the CPC, they are sourced from different localities of its ~1700km trace. Because the CPC spans almost the entire North American margin from Washington State to Alaska (Gehrels et al., 2009), variation in magmatic flux along the margin could create differences in relative abundance of certain age populations of zircons along its span. Thus, the Tofino and Orca units are both sourced heavily from the CPC, but a difference in relative abundance in age populations indicates that they were not deposited as runoff from the same spatial source.

CONCLUSIONS

This study concludes that the sedimentary sequence of the Tofino basin was derived mainly from the erosion of the CPC and its Precambrian zircons have a distinctly southern Laurentian signature. While the main Phanerozoic source of both the Tofino basin and the Montague and Latouche Belts of the Orca Group is the CPC, they are likely derived from different localities along the CPC's 1,700 km nearly continuous trace. The ~48 Ma maximum depositional age for the Blue Mountain unit implies a short (<1 m.y.) time span for accumulation of the Crescent Formation. Finally, U/Pb MDAs are generally not an accurate measure of true depositional age of the Tofino basin sedimentary sequence.

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