PROCEEDINGS OF THE TWENTY-SIXTH ANNUAL KECK RESEARCH SYMPOSIUM IN GEOLOGY

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DETRITAL ZIRCON AGES AND PROVENANCE OF COVER STRATA TO THE PALEOCENE RESURRECTION PENINSULA OPHIOLITE IN SEWARD, ALASKA

ROSE PETTIETTE, Washington and Lee University
Research Advisor: Jeffrey Rahl

INTRODUCTION

The southern margin of Alaska exposes a late Mesozoic to Cenozoic accretionary complex that comprises the Upper Cretaceous to Eocene Chugach-Prince William (CPW) terrane. The Upper Cretaceous Valdez Group and the Paleocene to Eocene Orca Group represent the bulk of the Chugach-Prince William terrane in the Kenai Peninsula and western Prince William Sound area. Sandstones of the Valdez Group and the Orca Group are feldspathic and volcanic lithic. During the Paleocene to early Eocene, ridge subduction at a trench-ridge-trench (T-R-T) boundary led to the formation and emplacement of the Resurrection and Knight Island ophiolites and subsequent migrating intrusion of the Sanak-Baranof belt (SBB) plutons along the 2200 km length of the CPW. However, competing hypothesis (cf. Cowan, 2003; Haeussler et al., 2003) propose varying plate geometry models for the trench-ridge-trench boundary that suggest two different possible locations of the CPW terrane prior to 50 Ma: one that is more or less in place, and one that places it south along the continental margin near Seattle or Vancouver. Previously published paleomagnetic data from the Resurrection and Knight Island ophiolites indicate that prior to ophiolite formation, the CPW terrane lay 1100 kilometers south of its present location (Bol et. al., 1992). Presently, the paleomagnetic results have not gained wide acceptance partly due to ambiguities in the relationship between the ophiolite and the flysch of CPW accretionary complex and due to structural complexity. This study is aimed at better understanding the age and provenance of that flysch unit.

GEOLOGIC SETTING

The Resurrection Peninsula Ophiolite

The Resurrection Peninsula ophiolite (Fig. 2) is a near full ophiolite sequence that begins with ultramafic rock, gabbro, sheeted dikes, and is topped on the western side by pillow basalts. Sandstone and shale surround the pillow basalts on the east side. On the western side of the ophiolite, near Humpy Cove, the sedimentary rocks interbedded in the ophiolite are heated and hornfelsed. At this location, controversy surrounds the age and stratigraphic relationship of the ophiolite with adjacent clastic strata (see Bradley and Miller, 2006).

Original mapping of the Resurrection ophiolite placed it with the Cretaceous Valdez Group, and hence it was thought to be Cretaceous in age (Tysdal and Case, 1979). A U/Pb zircon date from an intrusive plagiogranite from Killer Bay on the east side of the Resurrection Peninsula constrains the age of the ophiolite at 57 ± 1 Ma; the Knight Island ophiolite (in Prince William Sound) is undated but assumed to be the same age (Nelson et al., 1989). On the western side of the Resurrection Peninsula ophiolite, two hypotheses suggest different stratigraphic affinities of surrounding clastic strata (cf. Bradley and Miller, 2006; Kusky and Young, 2004). The core of the controversy is whether the strata are Cretaceous Valdez Group and fault bounded or whether they are Paleocene and essentially in stratigraphic continuity with the ophiolite.

To address the age of the clastic rocks and thus the ophiolite's western contact, U/Pb zircon ages were obtained from four sandstone samples in the Resurrection Bay area (RB12-01, 02, 04,08) at Thumb Cove, Humpy Cove, along Nash Road (across the end of the bay from Seward), and farther north along the Sterling Highway (Fig.1). Sample RB12-04 (Fig.2a) represents a critical contact relationship where a thin-bedded, medium-grained sandstone is interbedded with (and crosscut by) basaltic rocks, thus providing a key tie to the ophiolite. Raman spectroscopy was conducted on samples from the Valdez Group and two Orca populations (older aged sample from ophiolite and younger aged samples from Montague Island) to evaluate uranium damage and diagnose a potential provenance for the Chugach-Prince William terrane.

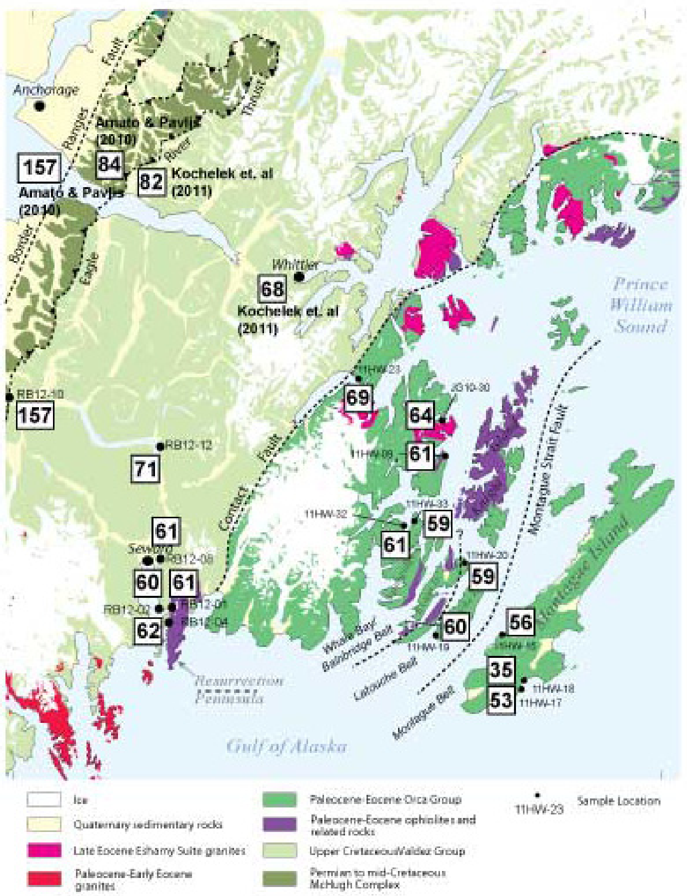


Figure 1: Geologic map of the Chugach-Prince William terrane in southern Alaska modified from Bradley (2006) and Kveton (1989) showing all current U/Pb maximum depositional ages from this study, Amato and Pavlis (2010), Kochelek (2011), and Hilbert-Wolf (2012).

U-PB GEOCHRONOLOGY

Previous Work

U/Pb zircon ages have been determined for zircons in flysch of the CPW on either side of the Resurrection Peninsula ophiolite. Inboard of the ophiolite in the Chugach terrane, several ages have been published for the Upper Cretaceous Valdez Group. The detrital grain-age distributions reveal grain populations ranging from 69 Ma to 77 Ma (Bradley et. al., 2009) and older grain populations ranging from 82 to 68 Ma (Kochelek et al. 2011). Outboard of the ophiolite, on rocks in the Prince William terrane, Hilbert-Wolf (2012) conducted U/Pb zircon dating of detrital zircon from the Paleocene-Eocene Orca Group of Prince William Sound. The samples are dominated by component populations between 57 and 75 Ma with grain ages younging outboard toward the modern trench. The samples collected farther inboard (Whale Bay and Bainbridge Belt) have an older population of grain ages between 61-69 Ma. The samples collected farther outboard (Latouche Belt and Montague Island) (Fig.1) yielded a younger population of grain ages between 31-52 Ma.

RAMAN SPECTROSCOPY

To understand provenance of some of the zircon from the clastic rocks, Raman spectroscopy was applied to dated zircons in samples from Resurrection Bay and surrounding areas. The Raman wavenumber of three main peaks whose position, intensity, and width are a function of the radiation damage inherent in the crystal (Marsellos and Garver, 2009). Damaged or partially annealed grains have a distinct relationship as radiation damage increases because wavenmubers get lower and lower. However, if the grains contains no damage, the Raman wavenumber remains at a constant high value (1007.5 to 1008.0 for v3(SiO_4) indicating that full annealing has occurred around temperatures of crystallization.

METHODS

U-Pb GEOCHRONOLOGY AND RAMAN SPECTROSCOPY

Isolation of zircon minerals involved initial crushing and pulverization, Rogers table, and heavy liquids density separation. For each sample, one hundred grains were randomly selected for analysis. The U/Pb ages were obtained using the LA-MC-ICPMS at the Arizona LaserChron Center (Gehrels et. al., 2008). The Sri Lankan age standard was used for calibration after every five grains. Subsequent provenance data was provided using lutetium-hafnium dating conducted on grains that yielded Precambrian U/Pb ages (see Roberts, this volume). Raman measurements were made with a Bruker Optics Senterra® Spectrometer coupled to an Olympus® BX51 reflected light microscope at Union College. Raman spectroscopy was performed using a 633 nm external He-Ne laser. After background subtraction, FitYK® was used for peak fitting of the v1SiO4 (~974 cm-1) symmetric stretching and the v3SiO4 (~1007 cm-1) antisymmetric stretching (i.e. Marsellos and Garver, 2010). Each grain was measured twice in slightly different spot locations that tended to vary by less than 20 um, and grains were oriented with c-axis in a N-S position.

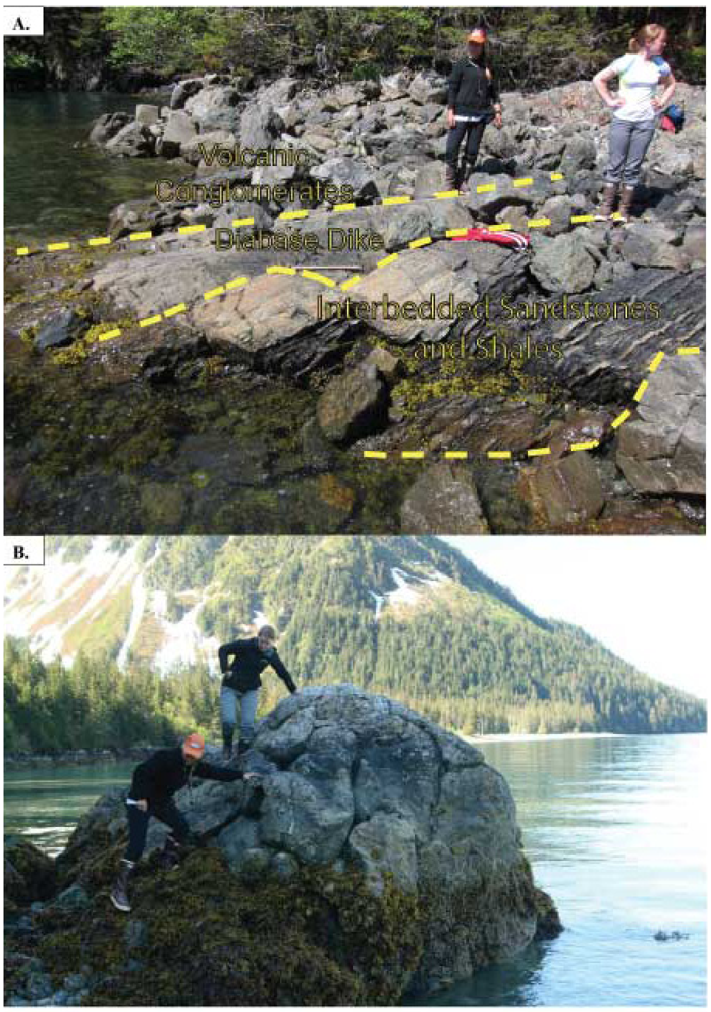


Figure 2: Location of RB12-04 on the western side of Resurrection Peninsula ophiolite in Humpy Cove; a) Highlighting sequence boundaries and location of sample RB12-04 from interbedded clastic sediment b) Outcrop of pillow basalts topping the ophiolite sequence.

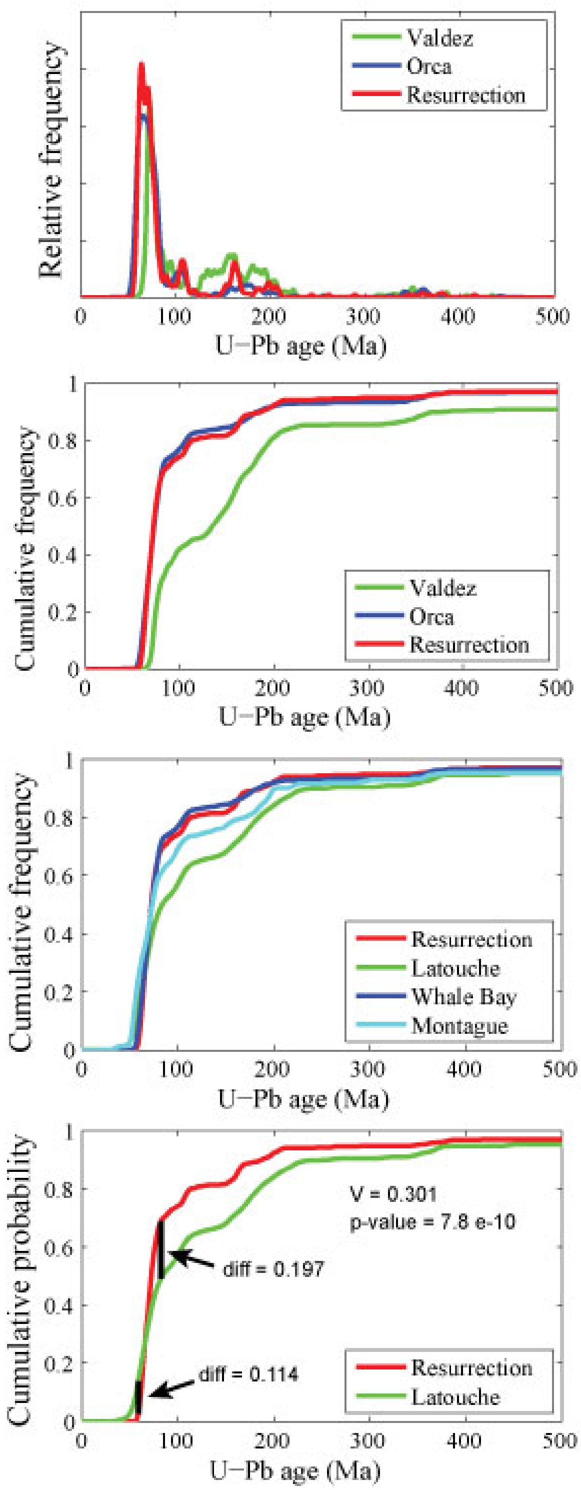
RESULTS

U-Pb GEOCHRONOLOGY

We successfully dated about 100 grains in five different samples, most in the northern part of Resurrection Bay. Samples from the Resurrection Bay area yield maximum depositional ages between 60-62 Ma. Samples RB12-04 from the end of Humpy Cove also yielded a young maximum depositional age of 57 Ma given by a robust mode formed from the youngest four zircons. The Resurrection detrital signal (Fig.3a) shows a clear correlation with strata of the Orca group 70-80 km to the NE in Prince William Sound. Cumulative frequency plots of the data were generated using the two-sample Kuiper non-parametric statistical test (modified from Kolmogorov-Smirnov technique). For this method, a p-value based on the data sets is defined for the null hypothesis. The p-value represents the confidence level at which we cannot reject the null hypothesis that the samples are similar. If the difference (V) between the data functions is great enough, than the null hypothesis is rejected and the distributions are different statistically (Press et al.,1992). The resulting analysis (Fig. 3b) shows Resurrection Bay was not different from the Orca Group with a p-value of .8112 (81% chance they cannot be proven different).

The ten youngest grains of each sample were averaged to represent the maximum depositional ages. U/Pb ages young in the outboard direction of the study area (Fig. 1) starting along the Sterling Highway (RB12-12) to the Nash Road (RB12-08) to those samples within Resurrection Bay (RB12-01,02,04). Sample RB12-12 has ten youngest grains ranging from 70 to 72 Ma with a maximum depositional age of 71 Ma. Farther south in the study area, sample RB12-08 has ten youngest grains that range from 59 to 61 Ma with a maximum depositional age of 60 Ma. Samples from Resurrection Bay show little variation in maximum depositional ages, and they are similar in grain age distribution.

Figure 3: Kuiper Statistical test on U/Pb grain-age distributions a): well-dated Orca Group from Prince William Sound with 95% confidence interval: a) PDP of U/Pb age distributions from RB toValdez (green) and Orca (blue). b) Cumulative frequency plot comparing difference in Valdez, Orca, and RB distributions. c) Cumulative frequency plot of Orca localities showing that Whale Bay belt is statistically same as those samples from RB d) Cumulative frequency curves showing that the Resurrection Bay samples are different from the Latouche Belt in Prince William Sound.



Sample RB12-01 and RB12-02 are from Thumb Cove with both samples ten youngest grains ranging in age from 59 to 62 Ma with a maximum depositional age of 61 Ma. Sample RB12-04, located within Humpy Cove on the Resurrection Peninsula ophiolite, is from a thin-bedded, medium-grained sandstone interbedded with pillow basalts of the ophiolite sequence (Fig. 2a). The maximum depositional age is 57 Ma and the ten youngest grains range in age from 57 to 65 Ma.

RAMAN SPECTROSCOPY

Raman spectroscopy was conducted on detrital Precambrian grains from the ~72 Ma Valdez Group, ~57 Ma Orca Group (Resurrection Peninsula Ophiolite), and ~35 Ma Orca Group (PWS Montague Island – from Hilbert-Wolf, 2012) (Fig.4). The Precambrian grains of the ~72 Ma Valdez Group exhibit a trend suggesting significant radiation damage accumulation with no crystalline grains. The Raman wavenumber of the Precambrian grains of the ~57 Ma Orca Group have a similar trend of radiation damage, but a single Precambrian grain is nearly crystalline, which represents 25% of the total grain population. The Precambrian grains of the ~35 Ma Orca Group essentially falls into two distinct populations: one with a damaged trend similar to the first two groups; and the other with a significant (45%) fraction of grains that are crystalline or nearly so. The grains then exhibit

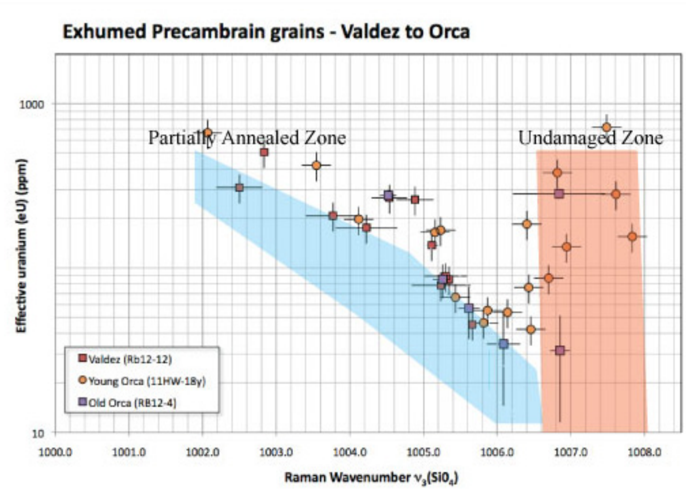


Figure 4: Raman spectroscopy results from Precambrian grains isolated from Upper Cretaceous Valdez (red), older Orca of the Resurrection ophiolite (purple), and younger Orca from Montague Island (yellow) showing gradual annealing in younging direction of CPW. Possible explanation could be exhuming source depositing grains of increasing metamorphic grade during terrane formation.

a boomerang pattern in which they spread across a partially annealed zone of damage into an annealed zone of zero damage. The overall Raman signal along the CPW terrane indicates that moving into younger units coincides with a gradual increase in the number of annealed Precambrian grains.

DISCUSSION

U-Pb GEOCHRONOLOGY

The samples from clastic units interbedded with and above the Resurrection Peninsula ophiolite are Paleocene and appear to be similar to those of the Orca Group. A key question is how well they compare to previously dated units of the Orca (Hilbert-Wolf, 2012). The cumulative probability plot of the Resurrection Bay samples were compared to U/Pb age populations (Hilbert-Wolf 2012) from different tectonostratigraphic belts of the Orca Group within western Prince William Sound (Kveton, 1989) by generating cumulative frequency plots. Results from the above data distributions (Fig. 3c) shows the Resurrection Bay samples and Orca Group in the Whale Bay Belt (and correlative units along strike) are identical with a 95% confidence level. The Resurrection Bay samples are different (Fig. 3d) with a 95% confidence from the farther outboard Orca Group in the Latouche Belt and those rocks on Montague Island.

These results definitively show that the clastic rocks in Thumb Cove and Humpy Cove are Paleocene or younger in age, and field observations show they are clearly interbedded with the pillow basalts mapped as part of the ophiolite. The Contact Fault separates the Upper Cretaceous Valdez Group of the more inboard Chugach terrane from the younger Paleocene-Eocene Orca Group of the Prince William terrane. The U/Pb ages of detrital zircon from four samples from the Resurrection Bay area show these strata can be correlated to the Paleocene-Eocene aged Orca Group of the Prince William terrane (Fig. 3b), and thus a strand of the Contact fault must exist to the west. Not only do these data complicate present terrane boundaries, but it addresses the controversy surrounding affinity of the clastic rocks associated with the Resurrection Peninsula ophiolite (cf. Bradley and Miller, 2006; Kusky and Young, 2004). The clastic strata that are interbedded with the ophiolitic rocks are Paleocene in age (c. 57 Ma) and this result is geologically consistent with the single age from the plagiogranite from the ophiolite in Killer Bay (there, 57 Ma), as such the timing is also consistent with stratigraphic continuity between the ophiolite and the clastic strata.

The Orca age from coarse-clastic strata interbedded with the top of the ophiolite stratigraphy (Fig. 2a) ties the PW flysch to the ophiolite: they are interbedded and in direct contact. This relationship is important to previously published paleomagnetic data from the Resurrection ophiolite that indicates an original paleoaltitude 13 ± 9° south of its present location (Fig.5) near present day northern Washington (Bol et al., 1992). Together these findings support the potential large coastal-parallel translation of the CPW terrane since the Paleocene and suggest the potential source of the clastic sedimentary rocks could be from terrains located farther south.

RAMAN SPECTROSCOPY

For Precambrian zircon grains to be reset, and achieve a high degree of crystallinity, they must have reached high temperatures capable of driving full annealing in the crystal structure. Potential mechanisms for this heating include deep burial and subsequent exhumation or intrusion of a nearby pluton. A potential reason for the increased annealing seen in Precambrian grains with younger depositional ages could correspond to erosion of the source terrain to increasing depths by exhumation over time. Because increasing depths coincide with increasing metamorphic grades, the potential source would be supplying sediment of increasing temperatures sufficient for annealing. Thus it is possible that the emergence and increase in the number of crystalline Precambrian grains up section may record unroofing in the source terrane.

CONCLUSIONS

Ages of detrital zircon from flysch of the Chugach-Prince William terrane were obtained along a transect starting inboard at the Sterling Highway near the Kenai River and ending in Resurrection Bay near Seward. Of the samples, only the inboard sample (RB12-12) proved to be part of the upper Cretaceous Valdez Group, with maximum depositional ages from 70 to 72 Ma. The rest of the samples (RB12-01, RB12-02, RB12-04, and RB12-08) yielded Paleocene-Eocene U/Pb ages similar to the Orca Group. These clastic strata are interbedded with the Ophiolite, which provides stratigraphic affinity and enhances our ability to constrain the relationship and emplacement of the ophiolite into the CPW accretionary wedge. Paleomagnetic data from the Resurrection Peninsula ophiolite indicated formation at a paleoaltitude 13 ± 9° south of its present location (Bol et al., 1992). Because the clastic sediment are interbedded with the ophiolite, it suggest the ophiolite formed adjacent the continental margin. Thus these findings support large coast-parallel translation of the CPW terrane during the Late Cretaceous through the Paleocene. The translation model suggests that at 57 Ma, the Resurrection ophiolite would be located off the present day coast of northern Washington (Fig.5).

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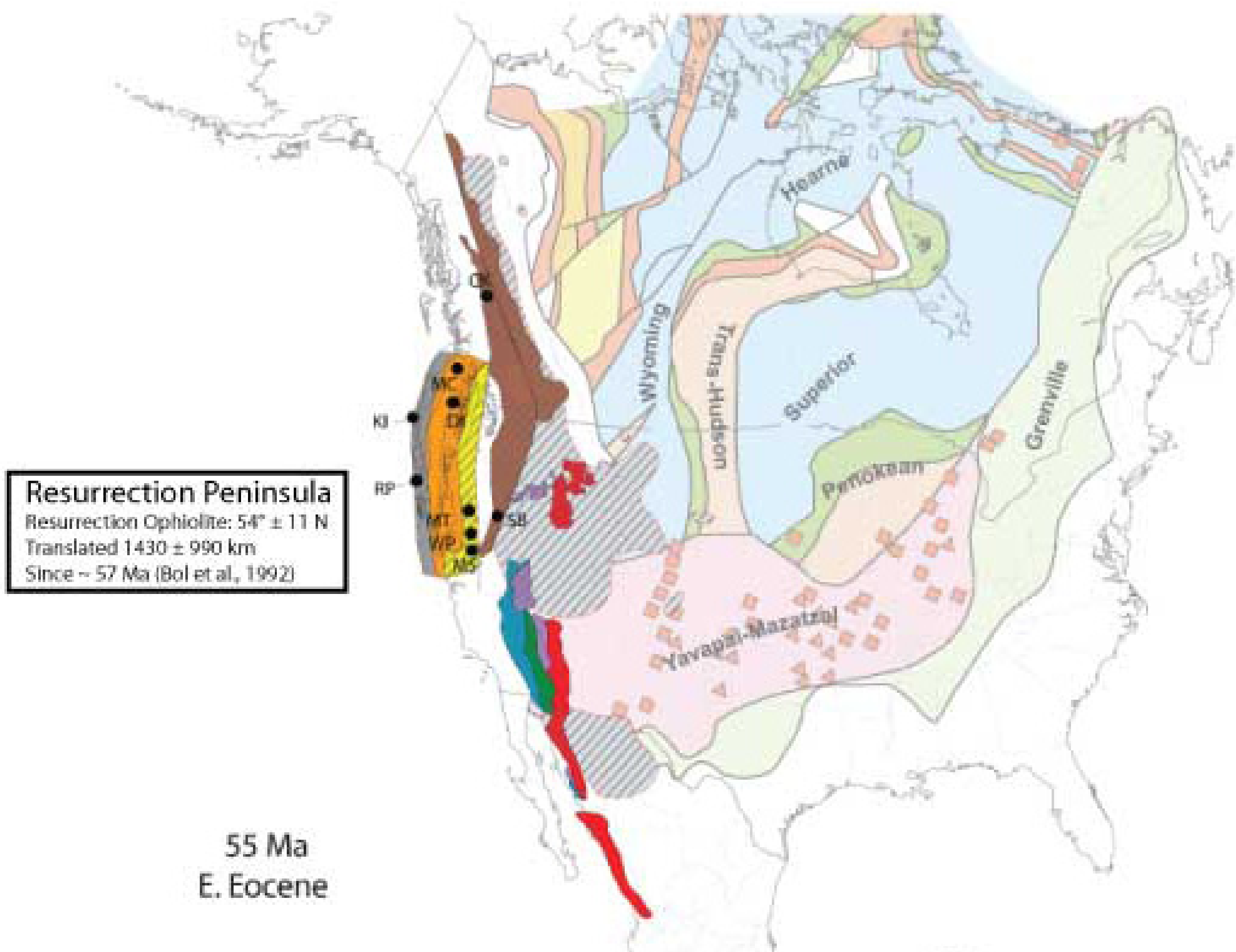
Figure 5: The figure (adapted from Miller et al., 2006) details the movement history of the Baja BC block. Included in this figure is the permissive position for the CPW from the new paleomagnetic results from Kodiak Island from Housen, Roeske, Galen and O'Connell that coincides with Bol et al., from the Resurrection Peninsula ophiolite.



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