Exhumation of the Copper River Corridor, Western Chugach Mountains, Southern Alaska.

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INTRODUCTION

The Western Chugach Mountains and the surrounding area in southern Alaska are located in a position of dynamic tectonic activity (Figure 1). Parts of this area are being rapidly exhumed predominantly due to shallow subduction of the Yakutat microplate (e.g., Arkle et al., 2013; Ferguson et al., 2014). This thick, buoyant microplate has been subducting under the Southern Alaska Block since the late Oligocene (Finzel et al., 2011) and is subducting presently at a shallow angle of ~6° (Eberhart-Phillips et al., 2006) in a NNW direction at a rate of ~4.6 cm/yr (Figure 1) (Freymueller et al., 2008).

Exhumation and deformation in the Chugach Mountains are occurring along arcuate fault systems that control the topographic grain, as strain is partitioned across a transition between strike-slip motion to the east and dip-slip motion to the west (Figures 1 & 2). To the east, rocks are being rapidly exhumed in the transform boundary area of the Chugach Mountains and Saint Elias area (Enkelmann et al., 2008); and to the west rocks are being exhumed less rapidly in a location where underplating is thought to be occurring (Figure 1) (Plafker et al., 1992 and Pavlis et al., 2003; Arkle et al., 2013).

The Copper River Corridor (CRC) lies at a key location for evaluating this transition between relatively slow and fast exhumation where the river cuts through the structural grain (Figure 1). The CRC is located between the Contact Fault and the Border Range Fault at the west end of the Chugach Metamorphic Complex (Figures 1, 2, & 3a). Geomorphic expressions of faults are represented in the topography locally, but no offset
expressions are available to help evaluate the dip-slip component of potential faulting (Figure 3a). Many studies have been conducted looking into the timing and rate of exhumation in the surrounding area of the Chugach Mountains and Prince William Sound: To the west Pavlis et al. (2003), studied outcrops along the Richardson Highway, and Spotila and Berger (2010) obtained apatite (U-Th)/He thermochronology (AHe) ages in the Saint Elias region to the east. Buscher et al. (2008) obtained additional rates in the area adjacent to the CRC. Additionally, Arkle et al. (2013) and Ferguson et al. (2014) obtained thermochronology ages in the Chugach core and Prince William Sound, respectively (Figure 3b). The critical site that links these two geologically contrasting locations has seen less study and further examination could aid in understanding deformation in this structurally complex region. The aim of this research is to evaluate the exhumation within the CRC region (Figure 3b).

HYPOTHESES

The CRC is a critical location that links regions of different structural characteristics. The focus of this study is to analyze the relationship between these regions. The study aims is to test two hypotheses: First, that the rocks of the CRC are being exhumed rapidly as part of the overall collision from the southeast. Secondly, that major faults cut the CRC and that these faults differentially uplift and exhume the rocks. These hypotheses are tested by evaluating uranium-thorium dating ((U-Th)/He) ages from samples collected along the CRC.
Southern Alaska is located in an area of dynamic tectonic plate collision. Here, the Pacific plate slides past and subducts under the North American plate. As the Pacific plate collides into the North American plate accretionary wedges are developed (Figure 2). Subducting microplates traveling on the Pacific Plate are “scraped off” and accreted onto the North American Plate creating a succession of seawardly youngening terrains, a process that began in the Middle Triassic, ~230 Ma (Plafker et al., 1994).

The youngest of the accreted terranes is the Yakutat terrane, which is now subducting under southern Alaska and is considered to be a separate microplate (Pavlis et al., 2003) (Figure 2). The Yakutat microplate is bordered by major arcuate fault systems that bend through the research area from east to west, transitioning from north-striking to west-striking (Figure 1). The southern boundary of the Yakutat is the Transition fault. The eastern boundary of the microplate is the Fairweather Fault, which is the contact between the Yakutat Microplate and Pacific Plate. The northern boundary is the Chugach-St. Elias Fault Zone; this is where the Yakutat meets the North American Plate (Figure 1 & 2) (Plafker et al., 1989).

Previous AHe studies have revealed a younging of exhumation ages in a southward direction. West of the Copper River, Buscher et al. (2008) determined AHe ages range
from ~24 Ma in the north to ~6 Ma to the south (Buscher et al., 2008). The area east of the Copper River have AHe ages that range from ~36.5Ma in the north to ~2Ma to the south (Figure 3b) (Spotila et al., 2010).

**Rocks of the Copper River Corridor**

The predominant lithology within the CRC is the Late Cretaceous Valdez Group Sandstones of the Chugach Terrain. The Valdez Group is composed of turbidite deposits (Dumoulin, et al., 1987). These deposits have been metamorphosed to zeolite-mid greenschist facies (Plafker et al., 1989) and are locally metamorphosed to higher grades in Chugach Metamorphic Complex (Pavlis et al., 2003). The Valdez Group sandstones contain sufficient apatite for (U-Th)/He dating.

**Structures along and adjacent to the Copper River Corridor**

The Copper River Corridor lies on the western border of the Chugach Metamorphic Complex (CMC) (Figure 2). The CMC is located in the eastern portion of the Chugach terrane and is a high temperature/low pressure metamorphic belt that developed within the accretionary prism in the Chugach terrane during an Eocene ridge subduction event (Scharman, et al., 2011.). The CMC is 10-50 km wide and ~350 km long (Gasser et al., 2011).

Several geomorphic lineaments cross the CRC that have been interpreted as major faults that are associated with the Yakutat collision/deformation zone. The most prominent of these geomorphic structures is the Stuart Creek Shear Zone (SCSZ) as described by
Pavlis et al. (2003). Locally the shear zone follows the Tiekel River that feeds into the Copper River form the west. The shear zone continues along Dewey Creek directly across the Copper River to the east (Figure 3d).

Previous studies have attempted to characterize deformation patterns across the transition between strike-slip motion to the east and dip slip motion to the west, across the CRC. Spotila and Berger (2010) described a region of rapidly exhuming rocks directly east of the CRC, within the St. Elias, which the authors refer to as “Miles Corner” (Spotila et al., 2010) (Figure 3c).

METHODS

Background on (U-Th)/He Thermochronology Using Apatite

Apatite (U-Th)/He thermochronology (AHe) is a low-temperature radiometric dating technique that can document the later stages of cooling in the uppermost crust (Ehlers and Farley et al., 2002). These ages are based on the intergrowth of alpha particles (4He) produced by uranium and thorium series decay. For time t the amount of helium produced from uranium and thorium in a mineral is:

\[ ^4 \text{He} = 8^{238} \text{U}(e^{\lambda_{238}t} - 1) + 7/137.88^{238} \text{U}(e^{\lambda_{235}t} - 1) + 6^{232} \text{Th}(e^{\lambda_{232}t} - 1) \]
Where \(^{4}\text{He}\) is the concentration of \(^{4}\text{He}\), \(^{238}\text{U}\) is the concentration of \(^{238}\text{U}\), \(\lambda_{238}\) is the decay rate of \(^{238}\text{U}\), \(\lambda_{235}\) is the decay rate of \(^{235}\text{U}\), \(^{232}\text{Th}\) is the concentration of \(^{232}\text{Th}\), and \(\lambda_{232}\) is the decay rate of \(^{232}\text{Th}\) (Wolfe et al., 1998). The ranges of these ages are limitless. AHe ages have been documented as young as a few hundred years in rocks from volcanic apatite crystals and as old as 4.56 billion years from a meteorite (Ehlers and Farley, 2003).

Apatite crystals exhibit three characteristics that make them ideal for this dating technique. First, in apatite crystals, helium is retained within the crystal structure below temperatures of \(\sim 70^\circ\text{C}\) (Ehlers and Farley, 2002). This provides a thermochronometer with the lowest known closure temperature of all radiometric-dating techniques (\(-60\text{ to }-75^\circ\text{C}\)) (Ehlers and Farley, 2002). Second, apatite crystals are rich with uranium and thorium. Third, they are abundant in Earth’s crustal rocks; the Valdez Group turbidite sandstone to be sampled along the CRC contains abundant apatite.

**Sampling Strategy**

During the summer of 2011 a total of 6 samples were collected from outcrops at somewhat evenly spaced intervals along the CRC (Appendix 2 & Figure 3d. These samples were collected from Miles Lake in the southern portion of the Copper River to Chitina in the north, a total distance of \(\sim 80\text{ km}\). Some samples were collected adjacent to major geomorphic trends that are potential locations of major faulting to analyze vertical offset. Sample sites were accessed via jet boat along the edges of the Copper River.
Sample Collection

Sample locations were accessed by 16 ft’ metal jet boat. Once at the sample location appropriate outcrops were selected and sampled. Sampling consisted of obtaining geographical coordinates, photographs, and in-field rock and location description. Next, samples of rock, weighing ~5-10 kg each, were extracted using a rock hammer and broken up to smaller cobble sized grains and collected in a canvass bag. Each bag was labeled with the date, general location, and sample name (Appendix 2).

After sample collection was completed samples were shipped to Dr. Phil Armstrong’s thermochronometery lab at California State University, Fullerton.

Apatite Separation Methods

To extract the apatite crystals the following steps were performed for each sample at California State University Fullerton Geology Department:

1. Raw rock samples were crushed using Braun Chipmunk Crusher.
2. The crushed portion was sieved using a 300 µm sieve.
3. The < 300 µm portion of post sieve material was collected.
4. This <300 µm portion was run through a Whifley Table to concentrate the denser materials.
5. Hand magnet was used to separate highly magnetic minerals.
6. Heavy liquid separation using lithium metatungstate (LMT) was performed to separate minerals with specific gravity (SG) of < 3 from those with SG > 3.

7. The portions of samples with SG > 3 were run through a Franz Magnetic Separator to separate out remaining magnetics.

8. Heavy liquid separation with methylene iodide (MEI) was performed on the remaining non-magnetic portion to separate apatite from zircon.

Grain Selection

After samples were processed, apatite crystals were hand selected under cross polars with a binocular microscope at 110x magnification. Selected apatite grains were photographed using an Infinity 1 camera mounted to the microscope. Strict grain characteristics were implemented in the study to minimize erroneous ages. For each sample, four (4) euhedral, zoning free, and inclusion free crystals, over 90 µm wide, were selected from each sample.

Determining Isotope Concentration

A selection of 3 to 4 apatite grains from each sample were sealed in platinum tubes and sent to Dr Kenneth Farley’s Nobel Gas Geochemistry Lab at California Institute of Technology (CalTech) for isotope concentration analysis. To determine isotope concentrations, each apatite grain was heated with a Q-switched Nd-YAG laser to diffuse all radiogenic helium. The helium is captured and then measured via mass spectrometer. Next, uranium, thorium, and samarium concentrations were measured by dissolving each grain in HNO3. The concentrations are measured via an inductively coupled mass
spectrometer (ICPMS). These measured concentrations are presented in table 3a and Appendix 1. The concentrations of U, Th, and He were used to calculate the raw AHe ages using the equation given above (Appendix 3).

**Ft Correction**

The raw ages were corrected for alpha ejection based on grain morphology and width (Ehlers and Farley, 2003). As uranium, thorium, and samarium decay they emit an α particle of helium, which can travel up to 20 µm through the apatite and may sometimes be ejected out of the crystal lattice completely (Ehlers and Farley, 2003). To account for this phenomenon, a retentivity correction, or Ft correction, is applied to the raw apatite age. This standard correction is based on a relationship between crystal size and typical travel distances for α particles, and assumes euhedral crystal form (Ehlers and Farley, 2003) (Figure 4).

**Age Rejection Criteria**

Certain considerations were taken into account when selecting appropriate ages. As discussed above, certain grain characteristics can produce erroneous calculated ages. Some of these characteristics can be difficult to identify during hand selection of grains. Statistical considerations were also used to eliminate potential errors. A two standard deviations (2σ) criterion was set for this research as a standard with an aim to rule out possible erroneous ages due to several factors, including: (1) micro zircon inclusions within the crystals, which could contain higher concentrations of the elements measured for AHe ages, and (2) mistakenly picking of zircon crystals due to similar physical
characteristics. AHe ages that fell outside of $2\sigma$ from the rest of the ages within a sample were rejected (Table 3b).

RESULTS

For this study, a total of eleven samples were collected along the CRC. The 74km long, north-northwest trending transect begins at Miles Lake to the south and ends ~30km southwest of the city of Chitina. The distance between sample locations range from 9km to 18km with elevation ranging from 38m to 122m above MSL. Of the eleven samples, six samples were processed to produce 3 to 4 grains each, for a total of 23 grains analyzed for AHe ages (Table 1). In general, sample ages range between 5.4 Ma and 33.4 Ma with an average age of 19.9 Ma. Ages show a general trend of younging in a southern direction with younger ages to the south-southwest and older ages to the north-northeast (Table 3b and Figure 3c).

Sample CR11-1: The sample was collected on the southeastern shoreline of Miles Lake and represents the southern most boarder of the research area (Appendix 2 & Figure 3d). Grains from this sample are characterized by widths ranging from 93.72 to 158.26 µm, length ranging from 126.43 to 199.05 µm, and $F_1$ correction range of 0.69 to 0.80 Ma (Tables 2 & 3a). The corrected AHe ages of grains from this sample range from 4.2 to 9.8 Ma. Three calculated AHe ages from the sample give an average age of 5.4 Ma. A forth single-grain age is 9.8 Ma and falls outside of the two standard deviation ($2\sigma$) range.
outlier criteria of 3.2 to 7.7 Ma (Table 3b). eU values for the sample range from 18.1 to 392.3 ppm (Figures 7a and 7b, and Table 3a).

**Sample CR11-4:** The sample was collected on the east bank of the Copper River at its confluence with the Tasnuna River (Appendix 2 & Figure 3d). Grains from this sample are characterized by widths ranging from 90.16 to 135.32 µm, lengths ranging from 104.37 to 157.40 µm, and Ft correction range of 0.67 to 0.76 Ma (Tables 2 & 3a). The corrected AHe ages of grains from this sample range from 11.7 to 20.1 Ma. Three calculated AHe ages from the sample give an average age of 13.0 Ma. A forth single-grain age is 20.1 Ma and falls outside of the 2σ range of 10.6 to 15.3Ma (Table 3b). eU values for the sample range from 31.8 to 42.8 ppm (Figures 7a and 7b, and Table 3a).

**Sample CR11-5:** The sample was collected on the east bank of the Copper River at its confluence with Cleave Creek (Appendix 2 & Figure 3d). Grains from this sample are characterized by widths ranging from 113.61 to 126.58 µm, lengths ranging from 112.89 to 171.99 µm, and Ft correction range of 0.72 to 0.76 Ma (Tables 2 & 3a). The corrected AHe ages of grains from this sample range from -1.26 x 10^{43} to 24.9 Ma. Three calculated AHe ages from the sample give an average age of 24.2 Ma. A forth single-grain age is -1.26 x 10^{43} Ma and falls outside of the 2σ range of 10.6 to 15.3Ma (Table 3b). The negative AHe age given by this grain suggest that it is zircon and not apatite. eU values for the sample range from 25.7 to 57.6 ppm (Figures 7a and 7b, and Table 3a).
Sample CR11-8: The sample was collected on the west bank of the Copper River 1.5 km north of the Tiekel River Confluence (Appendix 2 & Figure 3d). Grains from this sample are characterized by widths ranging from 73.25 to 131.91 µm, lengths ranging from 94.90 to 133.71 µm, and Ft correction range of 0.60 to 0.76 Ma (Tables 2 & 3a). The corrected AHe ages of grains from this sample range from 17.7 to 2498.7 Ma. Three calculated AHe ages from the sample give an average age of 18.1 Ma. A forth single-grain age is 2498.7 Ma and falls outside of the 2σ range of 17.2 to 19.0 Ma (Table 3b). eU values for the sample range from 9.7 to 14.4 ppm (Figures 7a and 7b, and Table 3a).

Sample CR11-9: The sample was collected on the east bank of the Copper River at its confluence with Cirque Creek (Appendix 2 & Figure 3d). Grains from this sample are characterized by widths ranging from 83.92 to 124.68 µm, lengths ranging from 114.82 to 142.49 µm, and Ft correction range of 0.65 to 0.74 Ma (Tables 2 & 3a). The corrected AHe ages of grains from this sample range from $-2.12 \times 10^5$ to 29.3 Ma. Two calculated AHe ages from the sample give an average age of 25.0 Ma. The third and forth single-grain ages are $-2.12 \times 10^5$ and 29.3 Ma, respectively, and fall outside of the 2σ range of 22.4 to 27.6 Ma (Table 3b). eU values for the sample are 12.2 and 47.2 ppm (Figures 7a and 7b, and Table 3a).

Sample CR11-11: The sample was collected on the East bank of the Copper River at its confluence with Canyon Creek (Appendix 2 & Figure 3d). Grains from this sample are characterized by widths ranging from 111.31 to 120.99 µm, lengths ranging from 97.65 to 126.97 µm, and Ft correction range of 0.71 to 0.73 Ma (Tables 2 & 3a). The corrected
AHe ages of grains from this sample range from 32.9 to 46.0 Ma. Two calculated AHe ages from the sample give an average age of 33.4 Ma. A third single-grain age is 46.0 Ma and falls outside of the 2σ range of 32.0 to 34.8 Ma (Table 3b). eU values for the sample are 10.1 and 90.1 ppm (Figures 7a and 7b, and Table 3a).

**Effective Uranium**

Figures 7a and 7b show plots of single grain effective uranium (eU) concentrations versus single grain AHe age result. Figure 7a consists of data separated by sample number, and Figure 7b displays the same data combined for comparison. eU is taken into account as an indicator of retentive helium traps within damaged areas of the apatite crystals. These areas trap helium and can often produce erroneously high AHe ages. A positive correlation between eU concentration and AHe raw age is indicative of these retentivity traps (Flowers et al. 2009). eU concentration is calculated using the following equation:

\[ [U] + 0.235[Th] \]

Where [U] is single grain uranium concentrations and [Th] is single grain thorium concentrations. There is no positive correlation here so these traps can be ruled out as unlikely.

**DISCUSSION**

**Relationship with Previous Work**
Figure 3c presents a map of the research area with an AHe age contour map from previous work; these contours do not include data from this study. The results demonstrate consistency with previous research in that the area is experiencing an increasing amount of rock uplift towards the tectonic boundary (The Aleutian Megathrust) to the south.

These exhumation patterns within the CRC seem to correspond with exhumation patterns described in previous work. The area east of the Copper River have AHe ages that range from $\sim$36.5 Ma in the north to $\sim$10.7 Ma to the south (Figure 3d). Ages in the west range from $\sim$38.5 Ma in the north to $\sim$18.1 Ma near the center of the study area. Ages from this study show ranges from 33.4 to 5.4 Ma, showing a similar trend of AHe ages decreasing in a seaward direction.

**Miles Corner**

Miles Corner, previously discussed in the GEOLOGY OF THE COPPER RIVER section of this report, is described as a narrow zone of rapidly exhuming rocks directly east of the CRC. Based on the data provided by this study, it is unlikely that this zone of rapid exhumation extends across the CRC since ages within the CRC are relatively older (33-5 Ma). The relatively young AHe age of CR11-1 ($\sim$5Ma) is possibly due to this sample location being in close proximity to Miles corner, the most southern sample location, and this study’s closest sample to the proposed Miles Corner.

Though, more data would need to be acquired to confirm this hypothesis.
**Relationship with the Stuart Creek Sheer Zone**

A notable aspect of the AHe age transect is the progression of ages across the Stuart Creek Sheer Zone (SCSZ). The AHe age this study trend towards younger ages to the south and older ages to the north, that is, as we progress northward from the shore along the CRC, ages progressively become older. However, across the SCSZ (between samples CR11-8 and CR11-5) there is a drop in age, in a northern progression. Since sample CR11-8 was taken just south of the proposed SCSZ and CR11-5 was sampled just north of the SCSZ it is reasonable to attribute this change in trend to be associated with movement along the SCSZ. Previous studies have suggested that the SCSZ is predominantly strike slip, though; this change in age progression suggests a dip slip component to this sheer zone.

To better define and analyze changes across the SCSZ, AHe ages were converted to time averaged exhumation rates (Figure 5b). To obtain these rates local closure depth was calculated to be 2.33 km, assuming closure temperatures of 70 C, average surface temperatures of 0 C, and dT/dz = 30 C/km. Then, this closure depth was divided by the AHe age to obtain sample exhumation rates in km/My.

The samples are divided into two groups comprised of samples south of the SCSZ as one group and samples north of the SCSZ as the other group. Sample CR11-1 was omitted from this calculation due to the sample’s relative location past a major fault system (the CFS) and the sample’s considerable geographical distance from the SCSZ.
Best-fit lines were calculated for each group and project towards the SCSZ to provide a quantitative difference in exhumation rate between the two groups. The southern group projected rates at the SCSZ to be 0.066 km/My, while the northern group projected rates to be 0.12 km/My, a 0.054 km/My difference. Also, note the relatively similar graphical trends of the two group’s best-fit lines: the slope for the southern group is 0.0041, and for the northern group it is 0.0033. Y-intercepts for the southern and northern groups are relatively similar at 0.51 and 0.49 km/My, respectively.

**SUMMARY**

Sampling within the CRC has provided a more complete and detailed understanding of the tectonic boundary between the North American and Pacific Tectonic Plates at the south central Alaskan coast, specifically, at the tectonic transitional corner between strike-slip motion in the east and dip-slip motion to the west. Furthermore, the findings of this study have provided better understanding of movement along a proposed shear zone within the study area.
REFERENCES


Ferguson, K.M., Armstrong P.A. Arkle J.C., Haeussler P.J., 2014 Focused rock uplift above the subduction décollement at Montague and Hinchinbrook Islands, Prince William Sound, Alaska. Geosphere; February 2015; v. 11; no 1; p. 144-159.


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FIGURE 1. Map of southern Alaska showing study area (within dashed red box), sample locations (red dots), local faults (bold black lines), proposed Yakutat Microplate boundary (yellow dashed lines), and relative tectonic plate rate of motion (yellow arrows). Adopted from Arkle et al., (2013).
FIGURE 3a. Tectonic map of southern Alaska showing the Copper River (red text), previous research sample locations (white dots), local faults (bold black lines), and proposed Yakutat Microplate boundary (bold green lines). Adopted from Arkle et al., 2013.

FIGURE 3b. AHe age contour map of southern Alaska. Contour map is represented by color gradient. As with figure 3A, figure 3B shows the Copper River (red text), previous research sample locations (white dots), local faults (bold black lines), and proposed Yakutat Microplate boundary (bold green lines). Adopted from Arkle et al., 2013.
FIGURE 3c. AHe age results from this study and previous work AHe age contour map of southern Alaska. Samples from this study are represented by white dots with red outlines, with corresponding AHe age in Ma. Contour map is represented by color gradient. As with figure 3A, figure 3B shows the Copper River (red text), previous research sample locations (white dots), local faults (bold black lines), and proposed Yakutat Microplate boundary (bold green lines). BRF: Border Range Fault, CF; Contact Fault, SCSZ, Stuart Creek Sheer Zone. Adopted from Arkle, et al., 2013.
FIGURE 3d. Map of AHe age results from this study. Samples from this study are represented by white dots with red outlines, and are titled with sample number and calculated AHe age. Ages from previous studies are represented by purple dots, and ages are given for previous samples that are close to the study site. Bold black lines represent local faults. BRF: Border Range Fault, BF: Bagley Fault, CF: Contact Fault, SCSZ, Stuart Creek Sheer Zone. Blue text is used to label local waterways. Base map from Google.
FIGURE 4. Ft correction figure. Alpha ejection can cause erroneously young raw ages due to alpha particles being ejected out of the crystal when parent isotopes are too close (≤20µm) to crystal edge. The raw age is multiplied by the correction factor (left y-axis) that corresponds with the prism cross section, or crystal size (x-axis). Figure from Ehlers and Farley (2003).
FIGURE 5a. Copper River Crossover Figure with AHe age versus distance from the ocean, showing sample ages (red diamonds) and comparative proposed fault locations (dashed black lines) of Contact Fault System (CFS), Stuart Creek Shear Zone (SCSZ), and Border Range Fault System (BRFS).

FIGURE 5b. Copper River Crossover with calculated exhumation rates (in km/My) versus distance from the ocean. Showing sample ages separated into two groups: Red diamonds noting the group south of the SCSZ, and blue triangles noting the group north of the SCSZ. Best-fit lines for the southern group and northern group are shown as orange and green best-fit lines, respectively. These lines were projected to contact with SCSZ. Comparative proposed fault locations noted by dashed black lines show the Contact Fault System (CFS), the Stuart Creek Shear Zone (SCSZ), and the Border Range Fault System (BRFS).
FIGURE 6. Plots of single grain AHe age results by sample. Blue diamonds represent points used in this study, red diamonds represent outliers that fall outside of 2σ range. Outlier values in samples CR11-5 (-1.26 x 10^13 Ma), CR11-8 (2499 Ma), and CR11-9 (-211690 Ma) lie well beyond the Y-axis and therefore have been omitted from the plots.
FIGURE 7a. Plots of single grain effective uranium versus single grain AHe ages. Points used in this study are represented by blue diamonds, outliers are represented by red diamonds. Outlier AHe ages in samples CR11-5 (-1.26 x 10^43 Ma), CR11-8 (2499 Ma), and CR11-9 (-211690 Ma) lie well beyond the X-axis and therefore have been omitted from the plots.
FIGURE 7b Plots of single grain effective Uranium versus single grain AHe ages.
### Table 3b. Sample Age Calculations

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** Ft corrects for alpha particle ejection (Farley et al., 1996)
*** Rejected grains shown in red