KECK GEOLOGY CONSORTIUM

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

April 2009
Franklin & Marshall College, Lancaster PA.

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2008-2009 PROJECTS

THE BLACK LAKE SHEAR ZONE: A POSSIBLE TERRANE BOUNDARY IN THE ADIRONDACK LOWLANDS (GRENVILLE PROVINCE, NEW YORK)

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Students: *GARRISON LOOPE*: Oberlin College; *DOUGLAS MERKERT*: Union College; *JOHN LINDEN NEFF*: Amherst College; *NANCY PARKER*: Lafayette College; *KYLE TROSTLE*: Franklin & Marshall College; *BEVERLY WALKER*: Colgate University

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Project Faculty: ***DAVID SUNDERLIN***: Lafayette College
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DOUGLAS MERKERT: Union College
Research Advisor: J.I. Garver

INTRODUCTION

The Paleocene-Eocene Chickaloon Formation is one of the principle units in the Matanuska forearc basin, which is situated between the Lower to Middle Jurassic Talkeetna volcanic arc to the north, and the Cretaceous and younger Chugach terrane to the south (Trop et al., 2003; Trop and Ridgeway, 2007). This primarily clastic unit is a fluvial deposit that is particularly interesting to paleontologists because it contains well-preserved plant fossils that record conditions in the region at the time of deposition. Coal in the Chickaloon Formation has previously been mined at the study site and reserves of ~102 m metric tons are estimated to remain within the Wishbone Hill Syncline area (Barnes, 1967). The strata of the Matanuska forearc basin provide a stratigraphic record of deposition of both marine and non-marine sedimentation accompanied by syndepositional volcanism and faulting (Trop et al., 2003). The Chickaloon Formation is of particular interest in a regional context because it is the first non-marine unit overlying a major basin-wide angular unconformity above Cretaceous marine strata that is inferred to record the juxtaposition of the Chugach accretionary complex to the south (Trop et al., 2003).

This study examines infilling of the Matanuska basin by evaluating the sedimentary provenance of the sediment within the Chickaloon Formation, and the lowest part of the overlying Wishbone Formation. The sandstones of the Chickaloon Formation are well studied and three petrofacies are recognized in what is generally a quartzo-feldspathic unit (Trop et al., 2003). The provenance of the sediment may be inferred through using Detrital Zircon Fission Track (DZFT) analysis through a comparison of grain-age populations to known cooling ages of surrounding source rocks (Bernet and Garver, 2005). Age populations of zircons allows one to infer the unique thermal history of adjacent source rocks using the age of the cooled (below 240-250° C) zircons that have been exhumed and deposited in sandstones. Identifying source rocks that fed the basin provides insight into exhumation rates of source terranes and also provides clues regarding the basin geometry and tectonic activity in this region at the time of deposition (see Bernet and Garver, 2005; Enkelmann et al., 2008; Perry et al., 2009). The results of this study provide insight into thermal and tectonic evolution of the adjacent source terranes to the Matanuska basin.

REGIONAL TECTONIC SETTING

Southern Alaska consists of a number of allochthonous terranes accreted following translation relative to the margin (Plafker et al., 1989). The Wrangellia composite terrane is an allochthonous block that consists of three smaller terranes (Wrangellia, Alexander, and Peninsular) that represent island arc, and rifted continental margin assemblages that became amalgamated in the Jurassic (Plafker et al., 1989). The timing of the initial collision of this terrane with the pre-existing Yukon composite terrane to the north is controversial (Cowan et al., 1997). One key component of the Alexander terrane (basement in the study area) is a sub-terrane called the Talkeetna Arc, a volcano-plutonic complex that consists of Jurassic lava flows, tuff, and volcaniclastic strata related to calc-alkaline volcanism (Clift et al., 2005a, Draut and Clift, 2006; Draut et al., 2006; Trop and Plawman, 2006).

The Chugach composite terrane abuts the Wrangellia on its southern margin along the Border Ranges fault system (Trop et al., 2003; Trop and Plawman, 2006). This fault underwent Mesozoic and Cenozoic displacement, but the actual timing of juxtaposition between the Chugach accretionary complex and Wrangellia is not well known (Pavlis, 1982; Cowan, 2004). The Chugach composite terrane gets younger seaward, evidenced by Cretaceous rocks of the Chugach terrane, and Paleocene-Eocene rocks of the more outboard Prince William terrane to the south (Plafker et al., 1994). This large accretionary prism formed as a result of long-term northward subduction of Pacific oceanic lithosphere under the Wrangellia composite terrane. The proposed northward subduction of the Pacific plate in the early Tertiary occurred at the same time as the emplacement of the Chugach composite terrane. Widespread thermal metamorphism and abundant near-trench intrusions of the Chugach composite terrane by the Sanak-Baranof magmatic belt of forearc magmatism also occurred at this time (Cowan, 2003). Although this magmatic belt decreases in age from 61 Ma on Sanak Island in the north, to 50 Ma on Baranof Island to the south, plutons near the study area are 50-55 Ma (Cowan, 2003).

The Matanuska Valley contains part of the ~50 km wide trough with sedimentary strata that extends under Cook Inlet to the southwest (Payne, 1955). The Matanuska Basin consists of over 7 km of Upper Cretaceous marine and Paleocene-Oligocene non-marine sedimentary strata deposited in a forearc basin near an active volcanic arc. This older portion of the stratigraphy within the basin progresses from the Lower Cretaceous marine strata (Nelchina Limestone, and Matanuska Fm. mudstone) to overlying Paleocene-Eocene non-marine strata (Chickaloon Fm. Arkose Ridge Fm. & Wishbone Fm.), which all crop out in the Matanuska Valley. Although these strata are well-exposed in the east, they are in fact much more substantial than the outcrop extent would suggest because they extend west and underlie the entire Cook Inlet Basin. In the Cook Inlet Basin, five major oil- and gas-bearing units of Oligocene to early Pliocene strata unconformably overlie the lower stratigraphy.

The focus of this study is on the provenance of the strata of the lower sequence of stratigraphy within the Matanuska basin. The basal non-marine unit is the Chickaloon Formation, which overlies the Matanuska Formation on a basin-wide angular unconformity and consists of up to 1500 m of mudstone, sandstone and coal with minor conglomerate, carbonaceous shale, and tuffs (Flores and Stricker, 1993a, b). While the age of the lower portion of the Chickaloon Formation is poorly known (Trop et al., 2003), the upper strata of the Chickaloon Formation have been well-constrained to Late Paleocene-early Eocene age using plant megafossils (Wolfe, et al., 1966; Little 1988), palynomorphs (Little, 1988), isotopic ages of five dated airfall tuffs (55.8-52.2 Ma; Triplehorn et al., 1984), and fission track ages of two cross-cutting dikes (>47.8-41.3 Ma; Little and Naeser, 1989). Paleocurrents from the margins of this formation indicate deposition of sediment in alluvial fans radiating from both margins, that fed a longitudinal, west-southwest-flowing, high-sinuosity fluvial system (Trop et al., 2003). It has been suggested that syndepositional north-dipping normal faults played a major role in the evolution of deposition, and the formation of coal in the basin (Little and Naeser, 1989; Flores and Stricker, 1992; Trop et al., 2003).

The poorly-dated Eocene Wishbone Formation varies dramatically in thickness from <150 m north of the Castle Mountain Fault to over 1100 m south of the fault. It consists primarily of conglomerate and sandstone likely deposited in westerly-flowing braided streams exhibiting bimodal sediment transport and south-westerly prograding, transverse alluvial fans (Flores and Stricker, 1992; Trop et al., 2003). The Wishbone Formation is overlain by unnamed volcanic rocks, the Oligocene Tsadaka Formation, or Quaternary surficial deposits along a disconformity or angular unconformity (Trop et al., 2003). Deposition of the Wishbone Formation is inferred to have been affected by movement on the Castle Mountain strike-slip fault (Trop et al., 2003).

Collectively, the Chickaloon and Wishbone formations exhibit an upward-coarsening trend, and increase in volcanic clasts in the Wishbone Formation. Together they contain three distinct petrofacies: a volcanic petrofacies, a plutonic petrofacies, and a mixed volcanic-metamorphic petrofacies (Trop et al., 2003). Distribution of these petrofacies is generally dependent upon the nearby dominant source of deposition within the basin. Conglomerates along the northern basin margin consist predominantly of the volcanic petrofacies, and are made up of 84% volcanic clasts, with minor plutonic (12%), sedimentary (2%) and metamorphic (2%) clasts (Trop et al., 2003). Volcanic clasts consist of basalt/metabasalt, andesite, tuff and pumice. Conglomerates of the plutonic petrofacies are restricted to the Tsadaka and Arkose Ridge Formations (Trop et al., 2003). The most common clast types are granite, granodiorite, diorite, amphibolite, quartz-mica schist and quartz, which are generally recognized as having been derived from plutonic and metamorphic rocks along the northern basin margin of the forearc basin (Clardy, 1974; Ridgeway, 1999). The third and final petrofacies commonly in these strata is the mixed volcanic-metamorphic petrofacies, best-developed along the southern basin margin (Trop et al., 2003). Clasts in conglomerates within this petrofacies document abundant metabasalt/basalt, metasiltstone, quartz-mica schist, chert and granite clasts, which are consistent with source rocks in the metamorphosed accretionary prism deposits to the south and also some of the southern-most outcrops of the Talkeetna Formation. Northeastward-to-northwestward-oriented paleocurrent indicators in addition to the arrangement of alluvial-fluvial lithofacies transitions both support derivation of this petrofacies from various southerly volcanic and metamorphic source terranes of the Chugach composite terrane (Trop, 2003).

FISSION TRACK DATING

FT dating hinges on the fact that the 238U in the crystal undergoes spontaneous fission through time (Garver, 2008). The recoil of two sub-equal fission fragments create end-to-end zones of disorder – called fission tracks – from charged fission fragments stripping electrons off nearby atoms (Garver, 2008). These tracks record fission events that have taken place since the crystal underwent low-temperature cooling (Garver, 2008). Tracks are only retained within crystals if the temperature remains below the annealing temperature, which is about 240°± 50°C. If zircons are reheated and remain above this temperature for appreciable time, any previously existing tracks will begin to anneal at a rate highly influenced by the radiation damage of each crystal (Brandon et al., 2008).

DZFT analysis utilizes single detrital zircon grains as a record of the thermal evolution of the source rock that produced the sediment (Bernet and Garver, 2005). In practice, many grain ages are determined and assembled into statistically significant grain-age populations, where the youngest dated populations must represent a minimum depositional age for the sample (Bernet and Garver, 2005). Through comparison of the ages of the individual grain-age populations with adjacent source terranes it becomes possible to determine the provenance of sediment from each source. It is important to emphasize on the fact that DZFT analysis reveals the time of cooling of the source rock below 240-250°C, as opposed to the crystallization age as is recorded with U/Pb analysis, but the two techniques can be used together (Enkelmannn et al., 2008; Perry et al., 2009).

METHODS

Eleven sandstone samples weighing between 3-7 kg were collected from the Chickaloon Formation from the abandoned Evan Jones Coal Mine near Sutton, Alaska. One sample of the conformable overlying Wishbone Formation was collected from the same location. Five of the most promising samples from the Chickaloon were processed along with the sample from the Wishbone Formation. Rocks were crushed and pulverized into sand-sized particles. Samples were then sorted using a Rodgers table, and then magnetically and chemically separated using heavy liquids to concentrate zircons. Zircons were then mounted in Teflon with at least three mounts made for each sample to ensure an adequate number of countable grains exposed in a range of etch times. The mounts were polished using a Buehler Automet 2000 Powerhead and Ecomet 3000 Variable Speed Grinder-Polisher system to expose internal surfaces. Polished zircons were etched in a NaOH: KOH eutectic at 228° C in a covered Teflon dish for

15-25 hr. A low-uranium mica flake was affixed to each mount and the sample was irradiated at 2x10^{15} n/cm^2 at the O.S.U. nuclear reactor. After irradiation, the Teflon and the mica were separated, the mica etched in HF for 15 minutes, and both were mounted on a slide.

Counting fission tracks was performed using an automated stage on a BMAX-60 Olympus microscope and each slide was digitally aligned, and all suitable grains were marked. Grains with well-defined tracks, a lack of zoning, large counting areas, and easily-countable surfaces were selected for analysis. Both the spontaneous tracks (those in the crystal) and induced tracks (those induced during irradiation) were counted for each single grain at 1250x for individual grain-age determinations.

A zeta calibration factor was used for sample calibration, which is based on the independent calibration based on counting of the Fish Canyon tuff and the Peach Springs tuff age standards. Fluence values were determined by counting mica affixed to CN5. Using the ratio between spontaneous and induced tracks for each grain, grain ages were calculated, the results were evaluated in Binomfit to determine statistically significant populations, and were then plotted and presented using SigmaPlot.

RESULTS

In general, two populations are recognized in six samples from the two formations and here we also include notes on sandstone composition (see Table 1, 2, and Figure 1a and 1b).

(1) A ‘Paleocene-mixed’ distribution is characterized by an abundance of grains at c. 55 Ma, and a small proportion of older grains from the Early Cretaceous (c. 120-130 Ma) (DM1, DM4, DM7, and DM11: see Table 2). These are quartzo-feldspathic sandstones typical of the Chickaloon Formation and the single dated sample from the overlying Wishbone Formation. These are shown in Figure 1A.

(2) A ‘Cretaceous-mixed’ distribution in which most grains (~90%) are old (126 Ma), and only about 10%

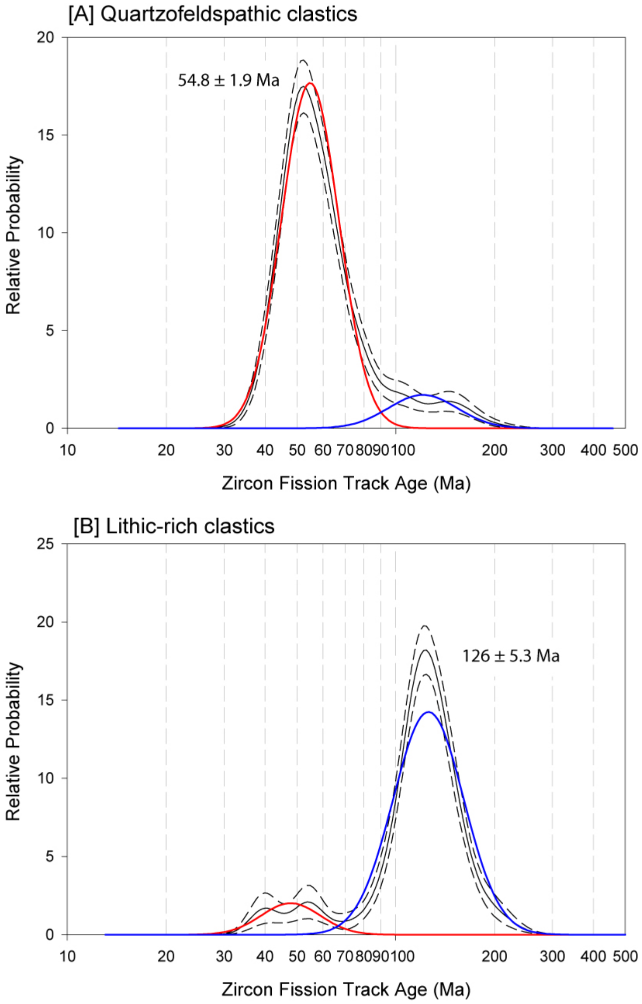

Figure 1. Graphs showing the grain-age distributions represented by the six samples analyzed from the Chickaloon and Wishbone Formations, divided into two distinct regimes indicative of distinctive source terranes and basin mixing. Figure 1A represents a ‘Paleocene-mixed’ distribution of quartzofeldspathic clastic deposition, evidenced in samples DM1, DM4, DM7 from the Chickaloon Fm. and DM11 from the Wishbone Fm., likely shed from the northerly Talkeetna Arc. These samples contain an abundance of Paleocene (~55 Ma), volcanic grains as well as a small proportion of older, Early Cretaceous-aged (c. 120-130 Ma) grains likely derived from pre-existing plutonic source terranes. Figure 1B represents a ‘Cretaceous-mixed’ distribution of lithic-rich clastic deposition represented by samples DM2 and DM8 of the Chickaloon Formation. These samples contain predominantly (~90%) Early Cretaceous-aged (~126 Ma) grains with a smaller proportion (~10%) of younger, Eocene-aged grains, and were both likely derived from the Chugach terrane to the south. In both [A] and [B] the solid black line represents the probability density of all observations (with 95% confidence interval). The red and blue peaks represent the statistically derived component populations modeled using a binomial peakfitting routine (BinomFit). These are statistically coherent populations discussed in the text.

Sample	ρ_s	N_s	ρ_i	N_i	ρ_d	N_d	n	χ^2	Age*	-1σ	+1σ	U ± 2se
Chickaloon Formation (Paleocene-Eocene)												
DM08-1	8.25×10^6	1734	8.11×10^6	1704	3.7×10^5	3733	30	0.0	56.8	-2.6	+2.7	268 ± 14
DM08-2	8.45×10^6	2211	4.52×10^6	1182	3.6×10^5	3615	30	0.0	49.3	-4.5	+4.9	152 ± 10
DM08-4	7.51×10^6	1890	7.70×10^6	1937	3.6×10^5	3615	30	0.0	55.3	-2.4	+2.5	262 ± 14
DM08-7	8.17×10^6	2020	8.15×10^6	2015	3.5×10^5	3512	31	0.1	56.8	-2.4	+2.6	283 ± 15
DM08-8	7.00×10^6	1768	3.68×10^6	0928	3.4×10^5	3453	30	0.0	55.9	-5.2	+5.8	130 ± 09
Wishbone Formation (Eocene)												
DM08-11	9.18×10^6	2062	9.14×10^6	2054	3.4×10^5	3453	30	2.8	56.2	-2.4	+2.5	329 ± 17

Note: In this table, Age* is the χ^2 age – which is the minimum population - if the χ^2 value is below 5%. This method isolates young grain ages and removes all older grain ages. This young age compares to the Binomial peak fit age (i.e. P1) in Table 1, but they are slightly different because of the way in which they are calculated. ρ_s is the density (cm^2) of spontaneous tracks and N_s is the number of spontaneous tracks counted; ρ_i is the density (cm^2) of induced tracks and N_i is the number of induced tracks counted; ρ_d is the density (cm^2) of tracks on the fluence monitor (CN5) and N_d is the number of tracks on the monitor; n is the number of grains counted; χ^2 is the Chi-squared probability (%). Zircon fission track ages (± 1σ) were determined using the Zeta method, and calculated using the computer program and equations in Brandon (1992). A Zeta factor of 328.9 ± 9.1 (± 1 se) is based on 6 determinations on standard samples from the Fish Canyon Tuff, and Peach Springs Tuff. Glass monitors (CN5) placed at the top and bottom of the irradiation package were used to determine the fluence gradient. All samples were counted at 1250x using a dry 100x objective (10x oculars and 1.25x tube factor) on an Olympus BX60 microscope fitted with an automated stage and a Calcomp digitizing tablet.

Table 1: Zircon fission track data, Chickaloon and Wishbone formations, Matanuska Valley

Sample	Unit	n	Age range (Ma)	P1	P2	Etch Time
Quartzofeldspathic facies						
DM1	Chickaloon	30	40-156	55.5 ± 2.7 84%	139.1 ± 15.7 16%	12-17 h
DM4	Chickaloon	30	36-185	52.9 ± 2.5 86%	107.6 ± 12.3 14%	12-22 h
DM7	Chickaloon	31	43-159	56.2 ± 2.5 94%	151.5 ± 27.8* 6%	7-17 h
DM11	Wishbone	30	42-110	54.6 ± 2.5 95%	103.2 ± 18.8* 5%	12-17 h
Quartzofeldspathic combined		121		54.8 ± 1.9 90% (108)	121.8 ± 9.6* 10% (13)	7-22 h
Lithic rich						
DM2	Chickaloon	30	40-199	49.3 ± 4.8* 10%	130.0 ± 6.5 90%	12-17 h
DM8	Chickaloon	30	39-203	44.4 ± 6.1* 10%	121.1 ± 6.6 90%	17-22 h
Lithic combined		121		47.9 ± 3.9* 10% (6)	126 ± 5.3 90% (54)	12-22 h

Note: Ages denoted with an astrix (*) are poorly approximated because the component population has few grains. n = number of dated grains; Uncertainties are cited at 68% confidence interval (about ±1 SE; asymmetric errors are averaged). Zircon grains were dated using standard methods for FT dating using an external detector. Zircons were extracted using standard separation procedures. Fission-tracks were counted on an Olympus BX60 microscope fitted with an automated stage and Calcomp digitizing tablet. Total magnification was 1250x (100x objective, 10x oculars, 1.25 tube factor). A Zeta factor of 328.9 ± 9.1 (± 1 se) was as computed from 6 determinations on standard samples (Fish Canyon Tuff, and Peach Springs Tuff). This table shows all binomial peak fitted ages using Binomfit 1.1.60 (Brandon, 1996).

Table 2: Binomial component ages of detrital zircon fission-track

of the grains are young (Eocene) (DM8 and DM2). These sandstones are more lithic than the other samples, which are richer in quartz and feldspar. These lithic-rich samples have abundant polycrystalline quartz and many large quartz grains that are highly undulose. They have abundant chert fragments and they have a high proportion of sedimentary rock fragments and metasedimentary rock fragments. Together the sedimentary rocks fragments, which are the distinctive component in these samples, include chert, sandstone and siltstone, some foliated sedimentary clasts and detrital epidote is common. These are shown in Figure 1B.

DISCUSSION

The ZFT data from the Chickaloon and Wishbone Formations indicate that there were dramatic differences in source terranes during the deposition of clastic input into the basin. Both units appear to have at least two distinct source regimes. All of the medium-grained, Arkosic sandstones (DM-7, DM-4, and DM-1from the Chickaloon and DM-11 of the Wishbone) have dominantly young zircons – near depositional age – likely derived from an active volcanic center on the Talkeetna Arc, which correspond to the Volcanic Petrofacies of Trop et al. (2003), which is tied to the northern basin margin by facies distribution, paleocurrents, and clast types. The small component of older grains in this facies that are Early Cretaceous to Late Jurassic (c. 125 Ma) in age likely represent cooling ages of the older rocks in the Talkeetna Arc that were intruded just before this interval (Rioux et al, 2007), or they represent a component of the lithic facies discussed below.

In contrast, the lithic, Arkosic samples (DM-8, and DM-2) contain predominantly (90%) old zircons (c. 126 Ma - early Cretaceous cooling ages) derived from erosion of an older-cooled terrane. Considering that these samples are distinctly rich in sedimentary rocks fragments including chert, sandstone, siltstone and some foliated sedimentary clasts, it is likely that this corresponds to the mixed volcanic-metamorphic petrofacies of Trop et al., (2003). A possibility for this source terrane is the Chugach terrane, which is dominated by Upper Cretaceous sedimentary rocks. The fact that P1 and P2 are statistically similar in both petrofacies suggests that there is a simple difference in the relative proportion of different source rocks. P1 can be used to constrain the depositional age provided there are a significant population of grains in that population, and for many this is not the case so these data must be viewed with caution. Nonetheless, where P1 dominated (DM1,4,7,11), it can serve as a constraint on depositional age.

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