5-12-2019

Reconstructing Miocene Paleogeography of the Middlegate and Eastgate Basins, NV through Geologic Mapping and Sedimentary Provenance Analysis

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Recommended Citation

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**Reconstructing Miocene Paleogeography of the Middlegate and
Eastgate Basins, NV through Geologic Mapping and Sedimentary
Provenance Analysis**

Isabelle Marcelite Bristol

B.A., Bucknell University, 2016

A Thesis

Submitted in Partial Fulfillment of the

Requirements for the Degree of

Master of Science

At the

University of Connecticut

2019

APPROVAL PAGE

Master of Science Thesis

**Reconstructing Miocene Paleogeography of the Middlegate and
Eastgate Basins, NV through Geologic Mapping and Sedimentary
Provenance Analysis**

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2019

ACKNOWLEDGEMENTS

First, I would like to thank Dr. Julie Fosdick, my advisor and mentor through this Master's Thesis project. Her insight, support, and mentorship has been invaluable to the scope of this research and completion of this document.

Thank you to the Geological Society of Nevada Elko Chapter which has graciously funded a portion of this research.

Special thanks to Joseph Colgan, David John, Chris Henry, and Margaret Berry from the U.S. Geological Survey. Their expertise in mapping volcanoclastic units during the reconnaissance mapping portion of the project and Joseph's assistance with geochemistry interpretations and writing of this thesis has been very helpful.

Many thanks to Jackie Giblin and Rebecca Vanderleest for serving as my field assistants during fieldwork in the summer of 2018. Their assistance in the field was crucial in sample collection and safety, and for that I am very grateful. Thank you to Andrea Stevens Goddard for serving as a mentor throughout the writing of this thesis. Additional thanks to the Fosdick Lab Group as a whole for their support throughout the data collection, analysis, and writing of this thesis. All of their assistance, feedback, and advice along the way significantly and positively influenced my growth as a researcher and helped in the completion of this project.

Special thanks to my committee members, Will Ouimet and Tim Byrne. Their instruction, expertise, and insight has been very helpful throughout my time as a student at the University of Connecticut and in guiding my writing for this project.

Thank you to the faculty, staff, and graduate students in Center for Integrative Geosciences at the University of Connecticut. I have learned so much in my two short

years here, and I am very honored and proud to have been a part of such an incredible thriving and growing program. The positive and enthusiastic energy through all areas of research in the soon to be Geosciences Department is contagious, and I am lucky call many of you my friends.

And finally, I am grateful for the immense love and support from my family and friends. Their encouragement throughout my time at the University of Connecticut and this project has been invaluable, and I am proud to have accomplished all that I have with them by my side.

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ABSTRACT

Continental lithospheric extension and magmatism produce topographic relief that alters sediment dispersal patterns and regional basin organization. Although these processes are broadly understood, little work has been done to provide a temporal model that sequences the onset of extension through basin reorganization in areas with differences in pre-extensional crustal magmatic addition and subsequent crustal thinning.

Middlegate and Eastgate Basins are two structurally bound, adjacent, non-marine basins in the northern Basin and Range Province (NV, USA) that exhibit similarities in sedimentology, paleoflow, geochronology, and geochemistry. Miocene stratigraphy of the two basins have been previously described and mapped, with the interpretation that Basin and Range segmentation occurred prior to deposition of the Middlegate and Eastgate stratigraphy. This study incorporates geologic mapping and new detailed sedimentology and stratigraphy, U-Pb zircon ages, U-Pb detrital zircon ages, and detrital zircon trace and rare earth element (TREE) geochemistry to determine if the Miocene basin fill is laterally continuous chronostratigraphically and lithostratigraphically between present-day Middlegate and Eastgate Basins and if so, when segmentation occurred.

Our data suggest that ca. 16-9 Ma, Middlegate and Eastgate stratigraphy belonged to a larger, connected depocenter with sedimentation patterns that were largely unaltered by Oligocene volcanic topography. After ca. 9 Ma, the uplift of the Eastgate Hills through high-angle normal faulting partitioned the two areas forming Middlegate and Eastgate Basins (*sensu stricto*) and the local basin and range

topography observed today. Results from this work may guide future studies tracking changes in basin connectivity and sediment transportation routes through various stages of rifting, especially in settings that exhibit complexities such as previously thickened lithosphere by silicic magmatic addition, inherited crustal shortening, are more ancient, or may not exhibit well-preserved sediment sources and basin fill.

INTRODUCTION

The effects of continental lithospheric extension and magmatism on sediment dispersal patterns are broadly understood (e.g. Leeder & Gawthorpe, 1987; Lambiase, 1990; Gawthorpe et al., 1994; Burbank, 1995; Allen and Allen, 2013), but complexities such as pre-existing topography and syndepositional deformation challenge efforts to understand basin evolution and sediment routing. In order for any basin to form, space is required for sediments to infill (e.g. Dickinson, 1988). In continental rift settings, space for rift basin formation may be created through the dominant subsidence mechanism of lithospheric and crustal thinning, or through minor subsidence factors such as sedimentary/volcanic loading, dynamic topography, or densification/phase changes in the crust (e.g. Dickinson, 1988; Allen and Allen, 2013). The Basin and Range Province, Western U.S. serves as an ideal place to study the influence of these minor subsidence factors on basin fill deposition in a continental rift setting. The Miocene basin sediments and Oligocene-age potential sediment sources in the region are very well-preserved, compared to areas that may be more ancient and may not have the same amount of preservation of sediment sources and sinks, such as the Jurassic Chon Aike Province in South America. Studying younger and more well-preserved sources and sinks allows for better understanding of any changes in sediment transport or basin reorganization through time due to pre-existing topography or structures.

The Basin and Range Province is a major continental extensional province of the Western U.S that extends over ~800 km from Sierra Nevada, CA the Wasatch Fault, UT, Colorado Plateau, and Rio Grande Rift. Within this province, there are regional differences in basin-range topographic elevation differences due to variations in crustal

thickness and composition related to differences between lithospheric composition and magnitude of both Mesozoic thickening and subsequent Cenozoic extensional thinning (Fig. 1). Furthermore, the Oligocene “ignimbrite flare-up” led to crustal magmatic addition in central Nevada prior to the main phase of Miocene extension. Because crustal extension in the Basin and Range Province occurred predominately during Neogene time (e.g. Fosdick and Colgan, 2008), there are extensive well-preserved potential sediment sources and sequences of basin fill that may be used to develop and refine tectonic models of sedimentary dispersal systems in continental rift settings with complexities such as silicic magmatic addition or pre-existing topography and structures.

Middlegate and Eastgate Basins are two structurally bound, adjacent, non-marine basins in the northern Basin and Range Province (NV, USA) (Fig. 1 and Fig. 2). These two study areas were selected as they exhibit similarities in sedimentology, paleoflow, geochronology, and geochemistry, but are presently partitioned by the Eastgate Hills, an Oligocene volcanic range that has been uplifted and exhumed by normal faulting on the Eastgate, Buffalo Creek, and West Basin Faults (Fig. 3). Previous work consists of geologic mapping of sedimentary units in Middlegate Basin by Stewart et al., (1999) and Eastgate Basin by Barrows (1971), but little work has been done since to try to correlate the Miocene strata between both basins as deposition of basin fill was inferred to have occurred following basin partitioning. Improved knowledge of the paleoenvironment conditions and physiography of these non-marine basins have important implications for our understanding of crustal extension, paleotopography, and paleoclimatic studies in the Western U.S.

Figure 2. Geologic map of the Stillwater Range, Clan Alpine Mountains, and western Desatoya Mountains (modified from Colgan et al., 2017). Red box indicates field area in relation to Oligocene volcanic deposits. These 28-31 Ma and 25-26 Ma deposits may serve as localized sources for Miocene volcanoclastic basin fill in Middlegate and Eastgate Basins.

Figure 3. Google Earth Image showing location of Middlegate and Eastgate Basin study areas relative to local potential sediment sources. Study areas (Yellow boxes- Middlegate, Orange boxes- Eastgate) include: (A) Central Middlegate, (B) South Middlegate, (C) East Middlegate, (D) Central Eastgate, (E) Eastgate, and (F) Inspiration Eastgate. See Figures 4 and 5 for geologic maps and sample locations in Middlegate and Eastgate Basins, respectively. See Figure 2 for mapped Oligocene sources by Colgan et al. (2017) relative to Middlegate and Eastgate Basins. See Figures 8-13 for detailed measured section information from each of the six study areas.

This study aims to address three main questions: (1) Did Middlegate and Eastgate Basins once belong to a larger continuous depocenter pre-Miocene extension? (2) How much of an influence did pre-existing Oligocene volcanic topography have on the sedimentation patterns and distribution of Middlegate and Eastgate stratigraphy? and (3) When did partitioning by the Eastgate, Buffalo Creek, and West Basin Faults (forming the present-day Eastgate Hills) occur?

Zircon U-Pb and detrital zircon U-Pb geochronology allows for age correlation of units between Middlegate and Eastgate Basins in addition to detailed sedimentology data and stratigraphic measured sections. Paleocurrent flow and modal clast analysis aids in the reconstruction of source regions to determine if the basins were connected or partitioned at the time of Miocene basin fill deposition. As volcanic sources in the area are similarly aged ca. 28-31 Ma, ca. 25-26 Ma, and ca. 19 Ma (Fig. 2), trace and rare earth element (TREE) analysis adds additional clarity to basin fill provenance. In other volcanic extensional provinces, TREE analysis may serve as a useful tool in further constraining volcanic sources with distinct geochemical signatures.

New detailed sedimentologic, stratigraphic, geochronologic, and geochemical data from this study in combination with previously collected data (e.g., Barrows, 1971; Stewart et al., 1999; Colgan et al., 2018; Colgan et al., 2019) suggest that Miocene Middlegate and Eastgate stratigraphy may be laterally correlative, contradicting previous work that interpreted Miocene strata as part of two isolated depocenters (e.g., Axelrod, 1985; Barrows, 1971). Newly proposed laterally correlative units modify the timing of extension and basin partitioning in this area of the Basin and Range Province. Thus, this would require reconsideration of the timing of processes associated with rift

basin segmentation in additional areas of thicker (>34 km) crust in the Basin and Range Province and other continental rift settings with a more detailed and integrative perspective— understanding the possibility that revisiting the sedimentology in rift basins may change the timing of rift processes (e.g. basin segmentation) and/or events (e.g. Basin and Range extension) than previous work may suggest. Stewart et al. (1999) suggested that correlation between Middlegate and Eastgate Miocene basin stratigraphy is plausible, but further work to attempt to study the stratigraphy in terms of lateral extent between both basins has not been done until this study.

Based on the new data collected in this study, we infer that these two basins once belonged to a continuous depocenter that was partitioned after ca. 9 Ma to form the modern day basin and range topography observed today.

GEOLOGIC SETTING

Regional Geologic Setting

Middlegate and Eastgate Basins are located in north-central Nevada in the Basin and Range Province (Fig. 1). The crust of central Nevada was thickened to ~45-50 km by Mesozoic thrusting and subsequently thinned to ~30 km by large magnitude (> 50%) Cenozoic lithospheric extension (Colgan et al., 2006). The Oligocene “ignimbrite flareup”, attributed to mantle welling from the subducted East Pacific Ridge, extended from northern Nevada during the Eocene to south-central Nevada in the early Miocene, forming a belt of densely concentrated calderas ranging in age from ca. 37-22 Ma (John et al., 2008; Best et al., 2013; Henry and John, 2013; Colgan et al., 2018) (Fig. 1 and Fig. 2). Volcanism in central Nevada peaked during the Late Oligocene- Early Miocene

(34-23 Ma) with voluminous calc-alkaline silicic magmatism and eruption of ash-flow tuffs (Henry and John, 2013). There was a lull in volcanism between Oligocene ignimbrite style magmatism and younger Middle Miocene bimodal rhyolite and basalt magmatism. Miocene magmatism is attributed to the onset of Basin and Range extension and development of the ancestral Cascade arc (e.g. du Bray et al., 2013). Miocene normal faulting formed the modern basin-range topography observed today (e.g. Miller et al., 1999; Surpless et al., 2002; Stockli, 2005; Colgan et al., 2006; Fosdick and Colgan, 2008; Fig. 1), causing crustal block rotation that has exposed early Miocene syn-rifting sedimentary rocks, Oligocene ignimbrites, and plutons from depths as great as ~10 km (John, 1995a; Hudson et al., 2000; Fig. 1 and Fig. 2). Exposed Oligocene ignimbrites and plutons, and Miocene volcanic rocks are thought to be prominent sources for Miocene basin fill in this area (Fig. 2).

The Middlegate and Eastgate Basins are in a unique area of the Basin and Range as they sit on the outer southern edge of the Stillwater complex, a major igneous complex composed of mostly Oligocene calderas, which also marks the transition from relatively low basin-range topography to the west and higher basin-range topography to the east (Fig. 1). The Stillwater complex is located in an area that is mostly comprised of Phanerozoic oceanic and island arc terranes, whereas to the east, the crust becomes more transitional-rifted crust (e.g. Henry and John, 2013) (Fig. 1). Calderas are part of the Oligocene ignimbrite flare-up that appears to be restricted to areas where the crustal thickness is >34 km (e.g. Henry and John, 2013; Colgan et al., 2019) (Fig. 1). The correlation of the calderas with relatively thick crust is consistent with the interpretation that these areas were more resistant during mid- to late Cenozoic extension. The

transition in basin-range topography is interpreted to be related to this difference in initial crustal thickness due to inherent crustal magmatic addition and subsequent crustal thinning due to extensional processes (Fig. 1).

Local Geologic Setting

Middlegate and Eastgate Miocene basin fill observed in this study formed outside of the nested caldera margins of the 25-26 Ma Eleven Mile Canyon caldera and the 28-31 Ma Campbell Creek Caldera of the Stillwater Complex (e.g. Colgan et al., 2018) (Fig. 2). Middlegate Basin and Eastgate Basins are present-day structurally-bound and separated from each other by the Eastgate Hills formed by the range-bounding Eastgate Fault and West Basin Fault (Fig. 2 and Fig. 3). The Buffalo Creek Fault trends NW-SE and connects the Eastgate and West Basin faults, juxtaposing different Oligocene volcanic units and is thought to have also impacted the formation of Eastgate Hills (e.g. Barrows, 1971) (Fig. 3). Exposures of Miocene sediments are most well-preserved closer to the ranges, Eastgate Hills and Desatoya Mountains, and range-bounding faults (Fig. 4 and Fig. 5). The majority of Miocene outcrops in the center of both basins have experienced substantial weathering and erosion, or are covered by Quaternary alluvial-fluvial deposits (Fig. 4 and Fig. 5), thereby limiting the continuity of exposure and stratigraphic correlation throughout Middlegate and Eastgate areas.

Basin Stratigraphy and Previous Chronostratigraphic Work

Both Middlegate and Eastgate Basins contain extensive exposures of Miocene sedimentary rocks that were studied by Axelrod (1956, 1985), Barrows et al. (1971),

Figure 4. A) Geologic map of Middlegate Basin overlain on topography (modified from Stewart et al., 1999), with study areas from this study: 1) East Middlegate area, 2) Central Middlegate area, 3) South Middlegate area. B) East Middlegate area with sample locations (red square and text). C) Central Middlegate area. D) South Middlegate area with sample locations (red or yellow boxes with text) and measured sections. See Figures 8-10 for detailed measured sections from these three areas. See Figures 15 and 16 for zircon U-Pb geochronologic data. See Stewart et al., (1999) for further geologic map information on additional mapped units not included in this figure.

Figure 5. Eastgate Basin Geologic Maps from Barrows (1971). A) Barrows (1971) geologic map of Eastgate Basin overlain on topography, modified with study areas from this study (boxed areas): (1) East Middlegate area (See Figure 4 for further Middlegate study area information), (4) Central Eastgate area, (5) Eastgate area, (6) Inspiration Eastgate area. B) Eastgate and Inspiration Eastgate areas. Note sample locations (red or yellow boxes with text) and measured sections. C) Central Eastgate area. Note Measured section. See Figures 11-13 for detailed measured sections from these three areas. See Figures 15 and 16 for zircon U-Pb geochronologic ages from these samples. Refer to Barrows (1971) for further geologic map information on additional mapped units not included in this figure.

and Stewart et al. (1999) (Fig. 4 and Fig. 5). The Middlegate Formation of Middlegate Basin is particularly known for its well-preserved fossil flora (e.g. Axelrod 1985, Smith et al., 2014). The Monarch Mill Formation of Middlegate Basin is well-known for its preservation of stickleback fish fossils, which can be found at the base of the formation (e.g. Axelrod 1985). Both Middlegate and Eastgate Basins are also known for their preservation of Miocene mammal fossils in the Monarch Mills Formation and the Buffalo Canyon Formation, respectively (e.g. Barrows et al., 1971; Axelrod, 1985; Smith et al., 2014).

The Middlegate Formation is described as the oldest Miocene-age formation exposed predominately on the edges of Middlegate Basin near the range-bounding faults (Axelrod, 1985; Stewart et al., 1999) (Fig. 4). It is characterized by lacustrine and deltaic deposits that received large particle megabreccias from nearby escarpments (Stewart et al., 1999). The widely-exposed Monarch Mill Formation lies uncomfortably on top of the Middlegate Formation and is characterized by lacustrine, fluvial, and alluvial-fluvial deposits that is ~700 m thick in the central part of Middlegate Basin (Stewart et al., 1999). The Middlegate and Monarch Mill Formations are split into multiple mapping units based on differences in lithologic character (Axelrod 1956; Stewart et al., 1999). The units observed in detail in this study are Tmu of the Middlegate Formation and Tmmcs, Tmmrb, Tmmr, and Tmmc of the Monarch Mill Formation. Tmu is the upper member of the Middlegate Formation and is characterized by yellow to gray papery to platy siltstone, and thin layers of medium-grained tuffaceous sandstone, reworked tuff, and granule to small pebble conglomerate. Tmmcs is only present in the East Middlegate area and is classified as clayey sandstone and siltstone,

with minor amounts of granule and small pebble conglomerate. Tmmrb is a reddish-brown to light-brown weathering sandstone, with ~0.5-1m conglomerate packages that make up about 10-20% of the unit. Tmmrb is considered a lateral facies of Tmmr. Tmmr is the rhyolite-clast-bearing sandstone and conglomerate, siltstone to silty sandstone, and minor tuff unit. It has thick to thin interbedded layers and some channels, and is distinguished by the amount of flow-banded vitrophyric rhyolite clasts and pumice clasts. Tmmc is the conglomerate, sandstone, and siltstone unit. It is classified as only having conglomerate with boulder-size clasts in the northernmost area of Middlegate Basin, but was found in the South Middlegate area in this study capping Tmmrb. It is generally not well consolidated and exhibits a general fining upward sequence to sandstone. Further detailed information about these units and others of the Middlegate and Monarch Mill Formations may be found in Axelrod (1956) and Stewart et al. (1999).

The Buffalo Canyon Formation of Eastgate Basin is characterized by lacustrine and fluvial deposits that uncomfortably overly older Miocene volcanic units of the Desatoya and Skull Formations (Barrows, 1971). Based on the extent and variety of the Buffalo Canyon Formation in Eastgate Basin, Barrows (1971) split the formation into 5 separate mapping units: Tbc1, Tbc2, Tbc3, Tbc4, and Tbc5 (Fig. 5). Tbc1 is an ash-flow tuff member dated at 19.5 ± 0.6 Ma (conventional K-Ar from Barrows, 1971), with moderately to densely-welded vitric ash-flow tuff overlain by interbedded tuff, diatomite, mudstone, and chert. Tbc2 is characterized by the dominate layer of diatomite as well as siltstone, sandstone, and organic rich lignite layers, with interbedded vitric tuff and diatomite. Tbc3 is the light brown mudstone member that consists of chiefly mudstone, some loosely consolidated vitric tuff, sandstone, and pebbly conglomerate. Tbc4 is the

salmon mudstone member containing mostly mudstone, some sandstone, and pebbly conglomerate. Lastly, Tbc5 is the conglomeratic mudstone member consisting of mudflow and fan detritus. Tbc2, Tbc3, Tbc4, and Tbc5 were observed in this study.

Previous work by Barrows (1971) suggested that the Buffalo Canyon Formation of Eastgate Basin is older than the Middlegate Formation and Monarch Mills Formation of Middlegate Basin. Stewart et al. (1999) suggests that Barrows (1971) Tbc2 of the Buffalo Canyon Formation may correlate to the Middlegate Formation based on lithology and tephrochronology of the two formations from Perkins et al. (1998) and Stewart et al. (1999), respectively. Through sedimentology, stratigraphy, zircon U-Pb and detrital zircon U-Pb geochronology, and TREE geochemistry, this study aims to determine if specific members of the Middlegate and Monarch Mill Formations and units of the Buffalo Canyon Formation are in fact similar laterally continuous units between both basins. If these units are correlated through the techniques listed above, this will suggest that the Buffalo Canyon Formation is younger than previously thought and Middlegate, Monarch Mill, and Buffalo Canyon Formations are laterally connected units that were partitioned post-deposition.

SEDIMENTOLOGY

Methods

Geologic mapping and measured sections in four primary study areas and two minor distal study areas in the center of each basin were used to refine the sedimentology and test lateral stratigraphic correlations of Miocene volcanoclastic units within and between members of the Middlegate and Monarch Mill Formations, and

members of the Buffalo Canyon Formation presently exposed in Middlegate Basin and Eastgate Basin, respectively (Fig. 4 and Fig. 5). Geologic mapping of exposed bedrock consisted of using relatively classic mapping tools (Brunton compass, handheld GPS, USGS topographic maps, and Jacob staff) and a mapping tool (Midland Valley FieldMove Clino) on an iPad. Detailed sedimentologic data were recorded while measuring a total of 17 well-exposed stratigraphic sections bed-by-bed with a Jacob staff (Fig. 4 and Fig. 5); typical bed thicknesses range from ~0.1-3 m, with differentiation between individual beds based on grain size, composition, sedimentary structures, and color. Mean particle sizes in conglomerate packages were obtained by measuring the long axes of ~10 of the largest pebble- to cobble- boulder-sized clasts. Full measured sections range in thickness from ~10-90 m. stratigraphic data were then categorized into lithofacies and lithofacies associations based on grain size, lithology, fossil content, and types of sedimentary structures, following established lithofacies schemes for fluvial and lacustrine deposits (e.g. Miall, 1978; Cohen, 1989; Miall, 1996; Basilici, 1997; Miall, 2013; DeCelles et al., 2015) (Table 1). A new lithofacies scheme was also developed for classifying volcanoclastic units. Lithofacies were then grouped into lithofacies associations based on repeated observations and interpreted depositional environment interpretations.

Results and Interpretations

Five lithofacies associations (FA) were identified in the 17 measured sections collected in well-exposed Middlegate and Eastgate stratigraphy (Table 1 for lithofacies code descriptions; Fig. 6 and Fig.7 for representative lithofacies association images;

Table 1. Lithofacies Code Descriptions

Facies Code	Lithofacies	Sedimentary Structures	Interpretation
L	Latite, fine to coarse grained	N/A	Airfall and sediment gravity in proximal setting to caldera source
C	Organic-rich carbonaceous layer, lignite	N/A	Vegetated floodplain, lake setting with abundant organic debris
D	Diatomite, very fine, could have some ash	Finely bedded	Suspension fallout in a quiet aqueous setting
T	Tuff, very fine	Massive to very finely bedded	Airfall
Tv	Vitric tuff	Massive, predominately glass shards	Airfall/ suspension fallout
Tm	Tuff, very fine reworked with mud	Vague bedding	Suspension fallout in quiet aqueous setting like a lake
Ts	Tuff, very fine reworked with sand	Vague cross bedding	Low velocity unidirectional water flow in deltaic setting
Fsc	Carbonaceous silt, mud	Massive, sparse laminae	Vegetated abandoned channel
Fsl	Silt, mud	Laminated siltstone, mudstone	Suspension fallout in quiet aqueous setting like a lake
G	Gypsum	Thinly bedded	Margin of perennial playa lake
Sm	Sand, fine to coarse	Massive, or faint lamination	Sediment gravity-flow deposits
St	Sand, fine to very coarse, may be pebbly	Solitary or grouped trough crossbeds	Low velocity unidirectional water flow in deltaic setting
Gcm	Pebble-boulder conglomerate	Vague stratification on 10s of meters scale, poorly organized on meter scale	Deposition in sheet floods and clast-rich debris flows
Gmm	Matrix supported, massive gravel to boulder conglomerate	Weak grading, poorly sorted, massive, unstratified	Deposition by plastic debris flows (high-strength, viscous), and hyperconcentrated flows.
Gm	Pebble to cobble conglomerate, typically lenticular	Massive	Channel lag or pool deposit

Table 1. Lithofacies and sedimentary structures observed in the basin fill strata of Middlegate and Eastgate Basins. Some facies codes modified from Miall (1978, 2010) and DeCelles et al., (2015) and others were created (this study) to describe the volcanoclastic units observed. See lithofacies codes with detailed measured sections of Middlegate and Eastgate stratigraphy in Figures 9-14.

Figure 6. Representative images of lithofacies FA1 (A-E), FA2 (F-K), and FA3 (L-N). A) Note finely interbedded reworked tuff and sandstone units on ~0.1 m scale in South Middlegate area. Hammer for scale. B) Finely interbedded reworked tuffs and tuffaceous mudstone in East Middlegate area. Person for scale (yellow box). C) Close-up of reworked tuff and tuffaceous mudstone. Gypsum layers are also sporadically present in some areas (yellow layers). Hammer for scale. D) Well-preserved partial stickleback fish fossil. Ruler for scale. E) Well-preserved leaf fossil from East Middlegate area. Ruler for scale. F) Layered reworked tuffaceous sandstone with trough cross-bedding and lenticular sandstone units in measured section EG1 in Eastgate study area. G) Note prominent ~0.5-1 m scale low angle crossbedding in FA2 upper part of section MG1 in East Middlegate study area. FA3 is present in the lowermost part of the section. H) Close-up image of vaguely stratified reworked tuffaceous sandstone in upper portion of MG1 in East Middlegate area. Hammer for scale (yellow box). I) Fresh surface of trough crossbedded sandstone with reworked rounded tuff fragments in measured section EG1 in Eastgate area. Hammer for scale. J) Trough crossbedded grey sandstone with small granules in measured section EG2 in Eastgate area. Sandstone lies above a reworked tuffaceous unit and minor lignite layer. Hammer for scale. K) Cliniform in reworked tuffaceous sandstone in MG6 of East Middlegate area showing westward shore migration. Compact thickness of ~7ft. Person for scale. L) Platy, finely-laminated mudstone with minor lense of reworked tuffaceous sand in EG5 Inspiration Eastgate area. Hammer for scale. M) Darker more organic-rich mudstone and lignite from MG7 in East Middlegate area. Hammer for scale (yellow box). N) Organic plant debris, predominately twigs and sparse coalified material, preserved in mudstone layers from East Middlegate area. Ruler for scale.

Figure 7. Representative images of lithofacies associations FA4 (A-E) and FA5 (F-H). A) Image of measured section MG8 in South Middlegate area. FA1 (white reworked tuff and airfall ash) is overlain by FA4 (orange sandstone) and FA5 (brown capping conglomerate). Outcrop is ~90 from base to top. B) Pebble-cobble lags and sandstone of FA4 lying above FA1 in EG3 of Central Eastgate Basin study area. Note similarity to MG8 South Middlegate area image (A). People for scale (yellow boxes). C) Close-up of sandstone with granules and cobble lenses in South Middlegate study area. Hammer for scale. D) Close-up of pebble-cobble conglomerate lense in EG3 of Central Eastgate. Hammer for scale. E) Close up of orange sandstone in MG8 of South Middlegate area. Note calcified root and minor lignite layer, suggesting a former more-developed surface or paleosol horizon. Pencil for scale. F) Image of South Middlegate area outcrop directly across drainage from measured section MG8, showing FA5 conglomerate overlain on FA4 orange sandstone. Note the vague stratification of large cobble to boulder-sized clasts. G) Note small unit of FA5 preserved sitting above FA4 sandstone and FA1 reworked tuffaceous unit in EG3 of Central Eastgate area. H) Close-up image of the boulder clasts in FA5 of MG9 in the upper conglomeratic unit of the South Middlegate area. Hammer for scale.

Fig. 8- Fig. 13 for detailed measured sections). FA were determined based on prominence and consistency of lithofacies, stratigraphic architecture, bedding contacts, bedding geometries, bed thicknesses, grain size, sedimentary structures, and presence of specific fossilized flora and fauna. These sedimentology data were then used to reconstruct depositional process and environment interpretations as described below.

FA1 Interbedded Diatomite and Reworked Tuff

Description

The interbedded diatomite and reworked tuff facies association makes up a substantial portion of the exposed stratigraphy in East Middlegate, South Middlegate, and Eastgate areas (Fig. 4 and Fig. 5). Measured sections MG7 (Fig. 9, top of section), MG8 (Fig. 10, base of section), and EG4 (Fig. 12) and representative images from Figure 6 are diagnostic of this facies association. Bed geometries are fairly planar and can be traced in some directions 10s of m; lenticular bed geometries and scours are not observed this facies association. Individual interbedded layers are predominantly < 1 m in thickness, with few layers reaching up to ~0.5 m in thickness. In some areas, minor thin bedded (<0.5 m) sandstone layers are present. The most abundant lithofacies include Tm, Tv, Fsl, and D, with minor amounts of G and Sm (Table 1). Gypsum beds are present but uncommon, and are ~0.1-0.2 m in thickness and typically extend ~1-10 m laterally. Mudstone layers that have not undergone reworking are also uncommon, and are ~0.3-0.5 m in thickness.

Central Middlegate Area

Legend

Lithologies

- Volcanic glass-rich ash (no reworking)
- Lignite
- Glauconite
- Gypsum Beds
- Reworked diatomite
- Cover/inferred covered interval
- Crossbedded reworked tuffaceous sand with lags of pumice fragments (coarser grainsize)
- Crossbedded sand/sandstone
- Crossbedded reworked tuffaceous sand
- Lithified tuff/ash (little to no sand)
- Massive intermixed tuff/ash and sand
- Intermixed medium sand and gravel/pebbles
- Massive sandstone/sand
- Bedded sandstone/sand
- Interbedded sandstone/sand with reworked tuff
- Carbonaceous mudstone/organic-rich mudstone
- Interbedded mudstone and reworked tuffaceous material
- Cobble to boulder conglomerate

Sample Symbolology

- Petrography sample
- U/Pb detrital sample
- U/Pb crystallization
- TREE sample

Sedimentary Structures and Fossils

- Fossil leaves
- Coalified plant material
- Fossil plant debris/twigs
- Rootlets
- Chert/chertified organics
- Calcified burrows/roots
- Fossil fish

Other Symbolology

- Paleocurrent Measurement
- Clast Count
- Maximum Clast Size
- Large clinoform
- Folded/deformed strata

Clast Counts

- Plutonic/ intrusive igneous
- Volcanic/ extrusive igneous
- Metamorphic
- Sedimentary

Colored Facies Associations

- FA1-** Finely interbedded reworked tuff and sand units with gypsum beds and well-preserved leaf and fish fossils.
Interpretation- arid lacustrine depositional environment
- FA2-** Reworked tuffaceous sand and mudstone with trough crossbedding. **Interpretation-** low-energy fluvio-deltaic depositional environment
- FA3-** Mudstone with abundant plant debris and coalified material.
Interpretation- floodplain depositional environment
- FA4-** Medium to coarse sandstone with pebble lags and trough crossbedding. **Interpretation-** sandy braided fluvial depositional environment
- FA5-** Erosive, lenticular cobble to boulder conglomerate.
Interpretation- high-energy braided fluvial depositional environment

Figure 8. Detailed measured section EG3 of Central Middlegate stratigraphy in Tmmss of the Monarch Mill Formation. Note upsection coarsening from FA1 to FA3. See Figure 17 for correlated stratigraphy.

South Middlegate Area

Figure 10. Detailed measured sections MG8, MG9, and MG10 of South Middlegate stratigraphy in Tmmrb (MG8) and Tmmr (MG9 and MG10) of the Monarch Mill Formation. Note general upsection coarsening in all sections from FA1 to FA4 to FA5. See Figure 15 for 18IBMG25 zircon U-pb age data. See Figure 17 for correlated stratigraphy. Detailed modal clast count data is located in Figure 14.

Legend

Lithologies

- Volcanic glass-rich ash (no reworking)
- Lignite
- Glauconite
- Gypsum Beds
- Reworked diatomite
- Cover/inferred covered interval
- Crossbedded reworked tuffaceous sand with lags of pumice fragments (coarser grainsize)
- Crossbedded sand/sandstone
- Crossbedded reworked tuffaceous sand
- Lithified tuff/ash (little to no sand)
- Massive intermixed tuff/ash and sand
- Intermixed medium sand and gravel/pebbles
- Massive sandstone/sand
- Bedded sandstone/sand
- Interbedded sandstone/sand with reworked tuff
- Carbonaceous mudstone/organic-rich mudstone
- Interbedded mudstone and reworked tuffaceous material
- Cobble to boulder conglomerate

Sample Symbolology

- Petrography sample
- U/Pb detrital sample
- U/Pb crystallization
- TREE sample

Sedimentary Structures and Fossils

- Fossil leaves
- Coalified plant material
- Fossil plant debris/twigs
- Rootlets
- Chert/chertified organics
- Calcified burrows/roots
- Fossil fish

Other Symbolology

- Paleocurrent Measurement
- Clast Count
- Maximum Clast Size
- Large clinoform
- Folded/deformed strata

Clast Counts

- Plutonic/ intrusive igneous
- Volcanic/ extrusive igneous
- Metamorphic
- Sedimentary

Colored Facies Associations

- FA1-** Finely interbedded reworked tuff and sand units with gypsum beds and well-preserved leaf and fish fossils. **Interpretation-** arid lacustrine depositional environment
- FA2-** Reworked tuffaceous sand and mudstone with trough crossbedding. **Interpretation-** low-energy fluvio-deltaic depositional environment
- FA3-** Mudstone with abundant plant debris and coalified material. **Interpretation-** floodplain depositional environment
- FA4-** Medium to coarse sandstone with pebble lags and trough crossbedding. **Interpretation-** sandy braided fluvial depositional environment
- FA5-** Erosive, lenticular cobble to boulder conglomerate. **Interpretation-** high-energy braided fluvial depositional environment

Figure 12. Detailed measured section EG3 of Central Eastgate stratigraphy in Tbc4 and Tbc5 of the Buffalo Canyon Formation. Note upsection coarsening from FA1 to FA4 to FA5. See Figure 14 for detailed modal clast analysis. See Figure 17 for correlated stratigraphy.

Inspiration Eastgate Area

Legend

Lithologies

- Volcanic glass-rich ash (no reworking)
- Lignite
- Glauconite
- Gypsum Beds
- Reworked diatomite
- Cover/inferred covered interval
- Crossbedded reworked tuffaceous sand with lags of pumice fragments (coarser grainsize)
- Crossbedded sand/sandstone
- Crossbedded reworked tuffaceous sand
- Lithified tuff/ash (little to no sand)
- Massive intermixed tuff/ash and sand
- Intermixed medium sand and gravel/pebbles
- Massive sandstone/sand
- Bedded sandstone/sand
- Interbedded sandstone/sand with reworked tuff
- Carbonaceous mudstone/organic-rich mudstone
- Interbedded mudstone and reworked tuffaceous material
- Cobble to boulder conglomerate

Sample Symbolology

- Petrography sample
- U/Pb detrital sample
- U/Pb crystallization
- TREE sample

Sedimentary Structures and Fossils

- Fossil leaves
- Coalified plant material
- Fossil plant debris/twigs
- Rootlets
- Chert/chertified organics
- Calcified burrows/roots
- Fossil fish

Other Symbolology

- Paleocurrent Measurement
- Clast Count
- Maximum Clast Size
- Large clinoform
- Folded/deformed strata

Clast Counts

- Plutonic/ intrusive igneous
- Volcanic/ extrusive igneous
- Metamorphic
- Sedimentary

Colored Facies Associations

- FA1-** Finely interbedded reworked tuff and sand units with gypsum beds and well-preserved leaf and fish fossils. **Interpretation-** arid lacustrine depositional environment
- FA2-** Reworked tuffaceous sand and mudstone with trough crossbedding. **Interpretation-** low-energy fluvio-deltaic depositional environment
- FA3-** Mudstone with abundant plant debris and coalified material. **Interpretation-** floodplain depositional environment
- FA4-** Medium to coarse sandstone with pebble lags and trough crossbedding. **Interpretation-** sandy braided fluvial depositional environment
- FA5-** Erosive, lenticular cobble to boulder conglomerate. **Interpretation-** high-energy braided fluvial depositional environment

Figure 13. Detailed measured sections EG5, EG6, and EG7 of Inspiration Eastgate stratigraphy in Tbc3 (EG5 and EG6) and Tbc4 (EG7) of the Buffalo Canyon Formation. Note general upsection coarsening in all sections. See Figure 15 for 18IBEG10 zircon U-Pb age data and Figure 17 for correlated stratigraphy. See Figure 14 for detailed modal clast count data.

Diatomite and tuffaceous mudstone layers in some areas contain well-preserved leaf and stem fossils (Fig. 6). Fish fossils are present but rare. The observed specimens, however, are mostly still intact and exhibit only slight disarticulation (Fig. 6).

Interpretation

Based on the planar bed geometries, presence of very well-preserved leaf, stem, and fish fossils, and interbedded gypsum tuffaceous mudstone, reworked tuffs, diatomite, and minor sandstone, it is likely that FA1 was deposited through suspension fallout in a subaqueous arid lake depositional environment (e.g. Cohen, 1989; DeCelles et al., 2015). The presence of gypsum beds found above and below units of well-preserved leaf, stem, and fish fossils indicates that the area likely underwent periods of drought in which the gypsum was able to develop on the exposed lakeshore, much like a salt flat (e.g. Cohen, 1989; DeCelles et al. 2015). The minor amounts of sandstone likely are attributed to debris flow or storm events that brought in larger grained sediments into the arid lacustrine setting. The lack of scoured bed base and coarser grain sediments such as pebble-cobble conglomerate units suggests that the depositional environment was low-energy with very little disturbances (e.g. Cohen, 1989; Basilici, 1997; DeCelles et al. 2015). The presence of well-preserved leaf and fish fossils also corroborates this interpretation of a quiet, low-energy lacustrine environment.

FA2 Reworked tuffaceous sandstone with trough cross-bedding and minor tuffaceous mudstone

Description

This facies association makes up a substantial portion of almost all measured sections in both the Middlegate and Eastgate areas (Figure 4, 5). Measured sections MG1 and MG6 in Middlegate (Fig. 9, top of sections), EG1 and EG2 in Eastgate (Fig. 12, base of sections), and representative images from Figure 6 are diagnostic of this facies association. The most abundant lithofacies include Ts, St, and T, with minor amounts of Fsc (Table 1).

Lenticular reworked tuffaceous sandstone beds are ~1-3 m thick, and more planar sandstone layers are ~0.5 m thick. In some areas, reworked tuffaceous sandstone beds are massive with vague subhorizontal bedding. Lenticular strata exhibit trough cross-stratification, though the fragile outcrop precludes robust paleoflow measurements. Planar laminated mudstone layers are very fissile and less commonly preserved, typically containing casts of fragmented plant stems and twig debris. Rootlets are observed intermixed in the coarser reworked tuffaceous sandstone layers.

Interpretation

Based on the presence of lenticular reworked tuffaceous sandstone, trough cross-stratification, and minor mudstone with fragmented plant stem and twig debris, these sediments may have been deposited in a low-energy meandering fluvio-deltaic depositional environment (e.g. Miall, 1977; Miall, 1996; Sambrook Smith, 2006; Miall, 2013). In Middlegate Basin, the range of paleoflow directions (from S-W-NW-N) and lack of floodplain mudstone facies in FA2, points to a low-energy deltaic environment rather than a single, large meandering channel (e.g. Gilbert, 1885; Smith et al., 1997;

Rohais et al., 2008; Edmonds et al., 2011). In Eastgate Basin, FA2 exhibits the same lithology character as that in Middlegate Basin; however, paleoflow directions are more or less in the same direction and larger (~3-5 m wide and ~0.5-1.5 m thick) lenticular beds and overbank deposits suggest a confined fluvial system, rather than a braided fluvial or deltaic system (e.g. Miall, 2013).

FA3 Carbonaceous and Coalified Mudstone

Description

The carbonaceous and coalified mudstone facies association is found sparingly at the base of measured sections in Middlegate and Eastgate areas underneath or intermixed with the coarser-grained FA2 (Fig. 4 and Fig.5). Measured sections MG7 (Fig. 9, base of section) and EG5 (Fig. 13, base of section), and representative images in Figure 6 are diagnostic of this lithofacies association. Bed geometries are sub-planar and can be traced ~10s of m, though some sections exhibit localized disruption of original bedding and soft-sediment deformation.

The most abundant lithofacies include Tm, T, Fsl, and Fsm with abundant plant debris and coalified material (Table 1). Organic plant debris, predominately twigs and sparse coalified leaf debris are commonly preserved within the mudstone layers. In some areas, the mudstone beds are interbedded with 1 cm thick tuff lamina or lenses.

Less abundant lithofacies in FA3 include Sm, St, and Ts with sparse tuffaceous sandstone lenses < 0.5 m thick. The sandstone beds have scoured bases into the underlying mudstone (Table 1). There are sparse and thin-bedded (~0.1 m) lignite

layers in some places. The fine-grained nature and lack of current structures preclude measurement of paleoflow directions within these units.

Interpretation

Based on the presence of mudstone with substantial amounts of preserved plant stem and twig debris, as well as minor sandstone scours, we interpret FA3 as a floodplain depositional environment with plant-covered banks (e.g. Miall, 1977; Miall, 1996, Nichols and Fisher, 2007). Plant debris likely accumulated in place as evident by ~0.1-0.3 m thick lignite layers. Coarser sediment containing plant debris may have been derived from nearby low-energy fluvial or deltaic dispersal systems during flooding events.

FA4 Orange Pebble Lag Sandstone

Description

This facies is found within the South Middlegate area of Middlegate Basin and the Central Eastgate and Inspiration Eastgate areas of Eastgate Basin (Fig. 4 and Fig. 5). Measured sections MG8 (Fig. 10) and EG3 (Fig. 11), and representative images in Figure 7 are diagnostic of this facies association. Sandstone beds commonly exhibit trough cross-stratification and some planar cross-stratification, and scour into the underlying finer-grained interbedded reworked tuff and mudstone lithofacies (FA1 and FA3). The orange color of the sandstone is not a weathering feature, but rather a provenance feature as fresh surfaces are also a distinct tan-orange color compared to the grey sandstones observed in FA2. Matrix-supported pebble-to-cobble conglomerate

lenses are typically ~1-3 m wide and ~0.5-1.5 m thick. The most abundant lithofacies include St and Sm with minor amounts of Ts, T, Gm, and Gmm (Table 1). Pebble-to-cobble clasts within the conglomerate lenses are subrounded to rounded, and exhibit imbrication in some localities.

Interpretation

Based on the presence of interbedded and lenticular sandstone and pebble-cobble conglomerate lenses, we interpret these strata to record a moderately high-energy sandy braided fluvial or sandy floodplain depositional environment. The lack of finer-grained intervals such as overbank mudstones suggest either erosional removal during fluvial deposition or a sustained higher energy environment. Conglomerate lenses were likely deposited within the thalweg or middle of the channel or during episodic flooding events (e.g. Miall, 1977; Cant and Walker, 1978; Miall, 1996; Lunt and Bridge, 2004). We note the lack of preserved fish and plant debris fossils compared to finer-grained facies associations to support our interpretation of a higher energy environment than those deposited in low energy fluvial or lacustrine settings.

FA5 Cobble-Boulder Conglomerate

Description

The cobble-boulder conglomerate facies association is found in the South Middlegate area of Middlegate Basin and the Central Eastgate and Inspiration Eastgate areas of Eastgate Basin (Fig. 4 and Fig. 5). Measured sections MG8 (Fig. 10) and EG3 (Fig. 11), and representative images in Figure 7 are diagnostic of this facies association.

Bed geometries are lenticular and erosive into the underlying units. Most beds can be traced for 10s of m and are ~3-10 m thick. Cobbles and boulders are subangular to subrounded. The average clast size is ~8-10 cm, with maximum clast sizes reaching more than ~20 cm in length. Conglomerate units of all clast sizes are matrix-supported. The predominant lithofacies observed in this facies association is Gcm (Table 1). Paleoflow is very difficult to parse out from these units, but imbrication is observed and measureable in some areas. This unit exhibits normal grading from boulder-sized conglomerate to smaller pebble-conglomerate into potentially more sandy-matrix conglomerate and sandstone.

Interpretation

Based on the presence of larger cobble- to boulder-sized clasts, vague stratification in some areas, and a lack of finer grained sediments or preserved plant debris or fish fossils, it is likely that these conglomerate packages were deposited in a higher energy alluvial-fluvial environment (e.g. Nemec & Steel, 1988; DeCelles et al., 1991). Some conglomerate packages may have been deposited as debris flows based on the angularity of the clasts, though most are fairly well-rounded which suggests more distal or through-going transport. These were likely sporadic events that may have been caused by localized tectonic activity, which were then eventually inactive due to the observed normal grading and lack of coarser bolder conglomerates at the top of FA5.

Facies Associations Summary

The distribution of FAs varies slightly in percentages and character between the Middlegate and Eastgate stratigraphy. FA1 and FA2 are the most prominent of the facies associations in both Middlegate and Eastgate study area. FA1 in Eastgate contains more diatomite, whereas diatomite was uncommonly observed in Middlegate. FA2 in Eastgate has more of a fluvial architecture with observable overbank floodplain scours. In Middlegate, FA2 exhibits more of a deltaic system that feeds into a lacustrine setting, as seen by the westward prograding clinoform structures (~2 m compressed burial height) (Fig. 6). FA3 is fairly similar between both basins and exhibits slightly varying amounts of interbedded mudstone, tuffs, and reworked tuffaceous mudstone. FA4 and FA5 exhibit the most resemblance of the five facies associations between the Middlegate and Eastgate stratigraphy. FA4 in both Middlegate and Eastgate are a distinct orange to light-brown color and contain pebble conglomerate lags and reddish-brown units that may be early development of paleosols. FA4 in Middlegate exhibits more interbedded white reworked tuffaceous layers compared to FA4 in Eastgate. FA5 is similar between both Middlegate and Eastgate study areas. FA5 is more well-preserved in the South Middlegate area compared to the Central Eastgate area that only has a small knob and a few extra meters preserved. FA5 in the South Middlegate shows the character of normal grading in this facies association well.

Overall, there is an observable and gradual upsection change from FA1-3 to FA4, and subsequently to FA5 in both Middlegate and Eastgate stratigraphy. Based on contacts between some of the facies associations and within some of the facies associations, there are likely a number of different unconformities that exist in the stratigraphy. Major unconformities are known between FA1-3 and FA4, and between

FA4 and FA5. There is an unconformity that exists between FA1-3 of Middlegate Formation and FA1-3 of the Monarch Mill Formation in East Middlegate. It is unclear if this unconformity is related to or connects with other observed unconformities between FA1-3 and FA4 in Middlegate and Eastgate.

Paleocurrent Analysis

Methods

We collected paleoflow orientations from trough cross-stratification, planar cross-stratification, pebble lags, and imbricated clasts to determine sediment transport direction and assist with provenance analysis of the sedimentary basin fill. Paleocurrent measurements were collected in the field with a Brunton compass by measuring the orientations of imbricated clasts, trough cross-stratification, and planar cross-stratification. Measurements were compiled in Stereonet 10.1 (Allmendinger, 2018), and corrected for post-depositional tilting by horizontal-axis according to the average bedding strike and dip at each locality. For imbrication, ~10 measurements were collected on the orientation of imbricated clasts. For trough cross-stratification, ~10 right and left limb measurements from 3D surfaces were collected to obtain an intersection lineation (e.g. DeCelles et al., 1983). For planar cross stratification, ~10 measurements from 3D surfaces were collected on inclined crossbedding surfaces. Calculated paleoflow directions are shown as rose diagrams or arrows to indicate the direction of sediment transport and changes in paleoflow direction upsection and between both Middlegate and Eastgate Basins. See detailed measured stratigraphic sections in Figures 8-13 for calculated paleoflow directions.

Results and Interpretations

In both Middlegate and Eastgate Basins, the lower parts of the basin fill exhibit N-NW-striking paleoflow (Fig. 8-13). Towards the middle of the exposed basin fill in Middlegate and Eastgate, the paleoflow direction changes to a W-NW direction (Fig. 8-13). Lastly, towards the top of the basin fill in both basins, the paleocurrent measurements indicate a S-SE striking paleoflow direction (Fig. 8-13). As the field areas for this research were located predominately on the south-southeastern margins of Middlegate and Eastgate where there are thick sections (up to ~90 m) of well-preserved stratigraphy, it is likely that the paleoflow is only representative of those specific areas and not of the entire basin as a whole (e.g. Axelrod, 1986; Stewart et al., 1999). However, similarities in general paleoflow in the same general margin area of both basins may indicate that both basins were sourcing sediment from similar areas.

Overall, there has been very little tilting and rotation or folding in the Middlegate and Eastgate areas. The Miocene Monarch Mill Formation in Middlegate Basin has been tilted ~20 degrees and the Miocene Buffalo Canyon Formation has been tilted ~30 degrees (Barrows, 1971; Stewart et al., 1999; this study), which likely occurred as a result of active normal faulting on the Eastgate Fault, Buffalo Creek Fault, and West Gate Fault (Fig. 3). However, the general trend of N-NW Middle Miocene sediment transport mimics present day drainage patterns. This suggests that nearby faulting along the Eastgate, Buffalo Creek, or West Basin Faults or uplift of the Eastgate Hills did not significantly alter sediment transport patterns from Middle Miocene to present time.

Modal Analysis of Clast Lithologies

Methods

We performed modal analysis of clast compositions of conglomerate units in FA4 and FA5 to identify variations in coarse-grained sediment sources. The aim was to count ~100 clasts that had mean particle sizes of ~4-6 cm or greater using a random walk method focusing on clasts within the same lateral unit.

Results and Interpretations

Clast lithologies include airfall tuffs, a variety of different colored welded and unwelded tuffs, metaconglomerate, scoria, gabbro, mica-covered obsidian, quartzite, and chert. The majority of the observed clasts in all areas are volcanic, such as unwelded tuffs, welded tuffs, and flow-banded rhyolite (~60-95 %) (Fig. 14). The next most observable clast type is metamorphic clasts, including gneisses and quartzites (1-50 %) (Fig. 14). The last and least common clast type is plutonic clasts, consisting of granites (0-20%) (Fig. 14). Clast compositions in the south Middlegate area conglomerates are predominately volcanic, with secondary amounts of metamorphic and plutonic clasts. These compositions diversify upsection, and then become fairly restricted to volcanic compositions within FA5 (Fig. 10, Fig. 11, and Fig. 13). In Eastgate, the clast compositions are more diverse compared to those in the South Middlegate area. Both clast counts in the Central Eastgate area and Inspiration Eastgate area yielded a larger variety of volcanic clast compositions than those in Middlegate Basin. There appears to be more chert and quartzite in the Inspiration

Detailed Modal Clast Count Analysis

South Middlegate- FA4, MG8

Central Eastgate- FA4, EG3

South Middlegate- FA5, MG9

Inspiration Eastgate- FA5, EG7

South Middlegate- FA4, MG9

Figure 14. Compiled summary figure of all detailed modal clast count analyses from South Middlegate, Central Eastgate, and Inspiration Eastgate stratigraphy. The vast majority of clasts are volcanic and plutonic, with a smaller percentage of metamorphic clasts. In some areas sedimentary clasts are observed, but are fairly uncommon.

Eastgate area conglomerate, whereas the Central Eastgate conglomerate exhibits an overall higher percentage of clasts comprised of air-fall tuffs and a purple welded tuff.

GEOCHRONOLOGY

Methods

We conducted zircon U-Pb geochronologic analyses via Laser Ablation- Single Collector- Inductively Coupled Plasma-Mass Spectrometry (LA-SC-ICP-MS) on zircons collected from two sandstone samples and three tuff samples to evaluate sediment provenance and improve timing of sedimentation. Samples were selected based on similar sedimentology and stratigraphy correlations between Middlegate and Eastgate stratigraphy. Detrital zircon U-Pb samples were selected from FA3 and zircon U-Pb samples were selected from FA1 from both Middlegate and Eastgate stratigraphy, with an additional zircon U-Pb sample from FA4 in the Inspiration Eastgate area.

All samples used for zircon U-Pb geochronology and TREE geochemistry analyses were prepared using standard mineral separation techniques at the University of Connecticut following those outlined by the University of Arizona LaserChron Center. Samples were crushed by hand using an industrial stainless steel mortar and pestle and sieved to $<300\ \mu\text{m}$. Sieved samples were individually water panned to concentrate heavy minerals. Dried heavy mineral concentrates were further separated using a Frantz magnetic separator and sodium polytungstate and methylene iodide heavy liquids to extract apatite and zircon. Zircon separates were sent to the University of Arizona LaserChron Center where they were mounted in a 1" diameter round epoxy with sample standards FC, R33, and SL for U-Pb crystallization analyses on tuff samples and FC, R33, SL, NIST, and 91500 for detrital U-Pb analyses on sandstones.

Epoxy sample mounts were then polished and imaged using Cathodoluminescence (CL) for all samples and additional Backscattered Electron (BSE) imaging for the two detrital sandstone samples to assist with TREE analysis.

Zircon U-Pb analyses and trace and rare earth element analyses (TREE) were collected via LA-SC-ICP-MS using a Thermo Element 2 at the University of Arizona LaserChron Center for characterization and identification of primary sediment provenance (e.g., Fryer et al. 1993, Košler et al. 2001, Košler & Sylvester 2003, Gehrels et al. 2014, Pullen et al. 2018). From the 50+ mounted zircon crystal unknowns in the tuff samples, ~30 zircon crystals were selected for analysis. From the 300+ mounted zircon crystal unknowns for the detrital sandstone samples, we randomly selected ~170 detrital zircon for analysis. A supplementary set of laser ablations were made for ~30 additional detrital zircon crystals for each sandstone sample for simultaneous U-Pb and TREE analysis (See TREE Geochemistry section for U-Pb and TREE analysis methods). Selections for all analyses were made by loading in Chromium, a pre-randomized spot picking program, and then moving each labeled spot to its respective location (e.g. R33, FC, SL, and unknown). Care was taken to not place spots on cracks, inclusions, or edges of the unknown zircons and zircon standards in all samples to achieve the most accurate age results.

The Element 2 SC-ICP-MS at the LaserChron Center is coupled to a Teledyne (Photon Machines) Analyte-G2 Excimer (ArF) laser-ablation system, which is equipped with a HelEx-2 dual-volume chamber (e.g. Pullen et al., 2018). For each analysis, the laser beam ablated the zircon crystal with a cleaning spot of ~30 μ m and an analysis ablation spot of ~10-20 μ m (e.g. Pullen et al., 2018).

Completed Zircon U-Pb geochronologic data are reported in Appendices 1-3. Discordant data was rejected from further analysis. Concordant U-Pb analyses were plotted using E2AgeCalc at the LaserChron Center. Probability distributions and weighted mean U-Pb ages were generated using the Excel Add-In, Isoplot 4.1 (Ludwig, 2006). Maximum depositional ages of the two detrital samples, 18IBMG01 and 18IBEG03, were calculated using a TuffZirc Age calculation and Weighted Mean Age calculation from a selection of 3 or more of the youngest population of grains. Youngest grains that did not resemble the same ages as other young grains were rejected from the selection on the basis that they may have undergone Pb loss.

Results

New zircon U-Pb crystallization ages from air-fall tuff (18IBEG10 and 18IBMG25) and tuff (18IBMG07) ages were collected from both Middlegate and Eastgate Basins (Fig. 15). Sample 18IBEG10, a minimally reworked ~50 cm thick air-fall tuff in the Buffalo Canyon Formation from the Inspiration Point Eastgate (Fig. 5, Tbc4) area measured section EG7 (Fig. 13, FA4) yields a crystallization age of 15.59 ± 0.27 Ma ($n=18$) (Fig. 15). Sample 18IBMG25, a ~100 cm thick air-fall tuff collected in the Monarch Mill Formation from the South Middlegate area (Fig. 4, Tmmr) measured section MG8 (Fig. 10, FA1) yields a crystallization age of 14.82 ± 0.27 Ma ($n=17$) (Fig. 15). Sample 18IBMG07, a ~20 m thick minimally reworked unwelded tuff collected from the Middlegate Formation from the East Middlegate area (Fig. 5, Tmu) measured section MG6 (Fig. 9, FA1) yields a crystallization age of 16.14 ± 0.15 Ma ($n=18$) (Fig. 15). Both samples 18IBMG07 and 18IBEG10 also contain older zircon crystals that

Zircon U-Pb Crystallization Ages

Figure 15. Zircon U-Pb LA-SC-ICP-MS geochronology and calculated eruptive ages of interbedded tuffs. Newly dated air-fall tuffs (18IBEG10 and 18IBMG25) and unwelded tuff (18IBMG07) from both basins yield crystallization and depositional ages of ~14.8-16.2 Ma. See Figure 17 for generalized correlation of Middlegate and Eastgate stratigraphy based on lithology and age constraints.

were excluded in sample weighted mean ages. In the Middlegate sample, the two older grains are ~25-26 Ma, whereas the Eastgate sample has two older grains at ~18-19 Ma. These older grains in both samples are interpreted to be either xenocrystic or detrital zircons that were incorporated into the Miocene tuff samples.

Detrital zircon U-Pb ages from sandstones yield TuffZirc maximum depositional ages of ca. $14.34^{+0.37}_{-0.04}$ Ma for the Middlegate sample (18IBMG01) and ca. $16.21^{+0.09}_{-0.12}$ Ma for the Eastgate sample (18IBEG03) (Fig. 16). Weighted mean ages calculated on the youngest zircon (at least 3 grains of similar age) in both samples yield maximum depositional ages of ca. 11.6 ± 1.6 Ma for the Middlegate sample (18IBMG01) and ca. 16.208 ± 0.079 Ma for the Eastgate sample (18IBEG03). As the Middlegate sample does not have a tuff crystallization age located and sampled above it, the sample could potentially be as young as ca. 11.6 Ma; however, this age was calculated on one 9 Ma zircon and two ca. 11 Ma zircon. Without a clear age control higher in the section, we conservatively infer the maximum depositional age for the Middlegate sample is ca. 14 Ma. Both detrital samples contain a substantial Middle to Early Miocene (14-22 Ma) age population, with very few Oligocene (25-26 Ma and 28-31 Ma) and Cretaceous (80-100 Ma) grains.

Detrital sample 18IBMG01 was collected from a ~1-1.5 m tan fine to medium-grained reworked tuffaceous sandstone in the Middlegate Formation in the East Middlegate area (Fig. 4, Tmu) measured section MG1 (Fig. 9, FA3). A total of 176 detrital zircon crystals were analyzed from this sample and yielded U-Pb ages ranging from ca. 9-91 Ma. This sample exhibits well-defined prominent Miocene age peaks at 15.5 Ma and 19 Ma, with minor Oligocene peaks at 25-26 Ma and 28-31 Ma (Fig. 16).

Figure 16. Relative probability curves and TuffZirc ages for detrital sample 18IBMG01 from Middlegate and 18IBEG03 from Eastgate of detrital U-Pb zircon LA-SC-ICP-MS data. Detrital zircon U-Pb ages from sandstones yield mean depositional ages of ~14.34 Ma for the Middlegate sample (18IBMG01) and ~16.21 Ma for the Eastgate sample (18IBEG03). Both detrital samples contain a significant Middle to Early Miocene age population, with very few 28-31 Ma and 25-26 Ma Oligocene grains, and a few Cretaceous grains. Note colored bars that signify 25-26 Ma (blue) and 28-31 Ma (orange) age ranges for potential Oligocene sources.

Miocene ages between 9 and 22 make up 83% of measured U-Pb ages, with Oligocene ages making up 13%, Eocene ages contributing 1%, and Cretaceous ages making up the remaining 2%.

Detrital sample 18IBEG03 was collected from a ~0.5 m grey medium to coarse-grained sandstone in the Buffalo Canyon Formation in the Eastgate area (Fig. 5, Tbc3) measured section EG1 (Fig. 12, FA3). A total of 195 detrital zircon crystals were analyzed from this sample and yielded U-Pb ages ranging from ca. 14.5-165 Ma. This sample exhibits well-defined prominent Miocene age peaks at ca. 16 and ca. 19 Ma, with minor Oligocene peaks at 25-26 Ma and 28-31 Ma (Fig. 16). Miocene ages between ca. 14.6-22.3 Ma make up 87% of the measured U-Pb ages in this sample, with Oligocene ages making up ~3%, Cretaceous grains contributing 9%, and Jurassic grains contributing ~1%.

Interpretations

The detrital zircon U-Pb maximum depositional ages of the two samples are consistent with the three dated U-Pb tuff crystallization ages from this study. All ages range from ca. 14-16 Ma and suggest deposition during Middle to Late Miocene time. The detrital zircon U-Pb age spectra exhibit a dominance of relatively restricted Miocene and Oligocene sources, suggesting more local and regional sources within the Basin and Range Province, versus extrabasinal North American sources such as the Proterozoic Grenville, major Paleozoic sources, or Mesozoic arc (e.g. Link et al., 1993) (Fig. 16).

These new U-Pb crystallization and detrital zircon ages also suggest that Tbc3

and Tbc4 of the Buffalo Canyon Formation in Eastgate Basin (Barrows, 1971) was deposited at the same time as Tmu of the Middlegate Formation in Middlegate Basin (Stewart et al., 1999) in contrast with previous work that suggested the Buffalo Canyon Formation is older than the Middlegate and Monarch Mills Formations (Barrows, 1971) (Fig. 17). New data presented in this study suggests they are comparable in age giving rise to an interesting tectonic story of both Middlegate and Eastgate areas accumulating basin fill and evolving simultaneously rather than Eastgate area basin fill deposition superseding deposition in the Middlegate area (Fig. 17). The prevalence of Miocene detrital zircons suggests there was major localized Miocene volcanism ca.14-16 Ma that inundated and was coeval with sedimentation in both Middlegate and Eastgate areas.

DETRITAL ZIRCON TRACE AND RARE EARTH ELEMENT GEOCHEMISTRY

Methods

Trace and rare earth element (TREE) concentrations in zircon can vary based on magma chemistry, temperature, and other conditions (e.g. Hoskin and Schaltegger, 2003). In general, zircons crystallized from a single body of magma will have similar TREE concentrations that define a trend with increasing Hf concentration (e.g. Hoskin and Schaltegger, 2003), providing a potential means to discriminate between detrital zircons of similar age that grew in different magma reservoirs.

Some Oligocene and Miocene volcanic rocks in the study area exhibit diagnostic TREE geochemical signatures for similarly aged (31-28 Ma and 26-25 Ma) caldera centers and associated plutons, outflow tuffs, and lava flows (Colgan et al., 2018; Colgan et al., 2019). The Middlegate and Eastgate Basins contain detrital zircon grains

of this age range (Fig. 16), which do not correlate to individual unique sources based on age alone as there are a significant amount of local Miocene, and 25-26 and 28-31 Ma Oligocene sources. For this study, we compared detrital zircon TREE geochemical signatures collected from the Middlegate and Eastgate Basins to published data from potential Oligocene and Miocene sources to refine provenance signatures. Oligocene calderas in the Stillwater-Clan Alpine complex (Fig. 2) exhibit potentially distinct TREE geochemical signatures unique to tuffs and plutons of different caldera eruptive cycles (Colgan et al., 2018), specifically ratios of U/Yb, Yb/Gd, and Eu/Eu* vs. Hf. Miocene (ca. 19 Ma) volcanic sources also exhibit distinct TREE geochemistry that can be used as a provenance indicator.

The two detrital samples analyzed for TREE, Middlegate sample 18IBMG01 and Eastgate sample 18IBEG03, were prepared using the same mineral separation and mounting techniques as those described for zircon U-Pb geochronologic analyses. The singular difference in the mounting is in the addition of two more standards specific to TREE geochemistry analyses, NIST and 91500.

For TREE analysis, ~30 unknown zircon grains per detrital sample were randomly selected for coupled TREE and U-Pb analyses. Analyses were collected via LA-SC-ICP-MS using a Photon Machines G2 laser (193 nm) connected to a Thermo Element 2 ICPMS and equipped with a Jet pump and interface (Pullen et al., 2018; Gehrels et al., 2018). Analyses measured 23 trace and rare earth elements while also collecting eight U-Th-Pb isotopes used for U-Th-Pb geochronology. Unknown zircons from the detrital sandstone samples were all cross compared to known zircon standards FC1 (~1099 Ma) and R33 (~419 Ma) for the U-Pb analyses and NIST612 (trace element

glass) and 91500 (reference zircon) for the TREE analyses. NIST612 is used as an Si-calibration assuming zircon contain 15.3% Si and the NIST612 glass contains 34.3% (Pullen et al., 2018). 91500 reference zircon is used as an external calibrator during the analysis phase (Pullen et al., 2018). Complete TREE Analysis data for both 18IBMG01 and 18IBEG03 are provided in Appendices 4 and 5.

Results and Interpretations

Randomly dated TREE zircons from 18IBMG01 yielded predominately Miocene (n=22), a few Oligocene (n=5), one Eocene zircon, and one Cretaceous zircon. The Oligocene (28-31 Ma) zircon grains in the Middlegate sample, 18IBMG01, yield ~7500-8000 ppm of Hf (Fig. 18). They exhibit Yb/Gd ratios between ~12-22, U/Yb ratios between ~0.8-2.0, and Eu/Eu* ratios between ~0.2-0.5 (Fig. 18).

Miocene zircon grains from sample 18IBMG01 range from ca. 9-22 Ma, with major age population peaks at ca. 14-16 Ma and ca. 17-22 Ma. Discordant Miocene grains were excluded from the dataset. For comparison with available TREE data from potential sources (Colgan et al., 2019), the ca. 17-22 Ma population was selected for plotting as local ca. 15 Ma TREE data is not available. Hf in these selected grains range from ~6500-11000 ppm (Fig. 19). U/Yb ratios range from ~0.2-1.8, with half exhibiting ratios between 0.2-0.5. Yb/Gd ratios range from ~2.5-30 and Eu/Eu* values range from ~0.1-0.6 (Fig. 19).

Randomly dated TREE zircons from 18IBEG03 yielded mostly Miocene (n=24), very few (n = 1) Oligocene, and a few (n=3) Cretaceous zircon. Unfortunately, the low yield of Oligocene grains in this sample (Fig. 16), resulted in few TREE data from

Figure 18. Oligocene (28-31 Ma) TREE geochemistry data from Middlegate and Eastgate Basins. Published data from Colgan et al. (2017) include potential Oligocene sources of similar age. Oligocene zircon grains from the ~14 Ma Middlegate sample were likely sourced from the Tuff of Campbell Creek, the post-caldera dacite, or the pre-caldera andesite. The single Oligocene Eastgate zircon from the ~16 Ma Eastgate sample may have been sourced from the Tuff of Job Canyon to the northwest. See appendix for all available compiled local Oligocene TREE data.

Figure 19. Miocene (ca. 16-22 Ma) TREE geochemistry data from Middlegate and Eastgate stratigraphy. Published data from Colgan et al. (2019) include a potential Miocene source of similar age— the ca. 19 Ma Fairview Peak Tuff. Note similarities in trace element ratios and Hf ppm between the Fairview Peak data and the 18IBMG01 data. Based on available data, the 18IBEG03 16-22 Ma zircon were also likely sourced from the Fairview Peak caldera complex.

Oligocene grains) (Fig. 18). The singular Oligocene grain in the Eastgate sample, 18IBEG03, is ca. 30 Ma and yields ~5000 ppm of Hf (Fig. 18). The resulting Yb/Gd ratio is ~6, U/Yb is ~1.2, and Eu/Eu* is ~1.05 (Fig. 18).

18IBEG03 yielded more Miocene grains for the TREE analysis. Miocene TREE grains cluster into two main populations ca. 15 Ma and ca. 18-20 Ma, with a few 16-17 Ma grains. Similar to the Middlegate sample, discordant Miocene grains in the Eastgate sample were first removed from the dataset. The next selection from the remaining data was to plot the ca. 18-20 Ma based on the known geochemistry data and ages from the Fairview Peak Tuff (Colgan et al., 2019). Hf in these selected grains range from ~5000-7500 ppm (Fig. 19). U/Yb ratios range from ~0.75-3.25. Yb/Gd ratios range from ~11-48 and Eu/Eu* values range from ~0.3-1.1 (Fig. 19).

Interpretations

Figures 18 and 19 summarize our single-grain TREE results for diagnostic rare-element ratios for resolving different Oligocene and Miocene magma geochemistry (U/Pb, Yb/Gd, and Eu/Eu*). For calculating Eu/Eu*, we used chondrite values in ppm of Sm (0.148), Eu (0.0563), and Gd (0.199) from McDonough and Sun (1995) and the following equation:

$$\frac{Eu(ch)}{\sqrt{Sm(ch) * Gd(ch)}}$$

Where $Sm(ch) = Sm(ppm)/0.148$, $Eu(ch) = Eu(ppm)/0.0563$ (ppm), and $Gd(ch) = Gd(ppm)/0.199$.

We compared our detrital zircon TREE data with published data from nearby Oligocene (Colgan et al, 2017) and Miocene (Colgan et al., 2019) igneous rocks to assess potential source contributions from these silicic eruptive centers. Based on similarities in Hf vs. U/Yb, Yb/Gd, and Eu/Eu* ratios (Fig. 18), TREE data from the Oligocene zircons collected from Middlegate stratigraphy may come from the Campbell Creek Caldera or Job Canyon Caldera (Fig. 2). Other potential Oligocene volcanic sources were excluded based on their differences in the three TREE discrimination plots. The single Oligocene grain from the Eastgate stratigraphy sample does not match any potential sources particularly well due to low Hf ppm (Fig. 18); however, it may have still been sourced from the ca. 29 Ma Job Canyon Caldera (Fig. 2). The differences between the Middlegate and Eastgate Oligocene zircon may suggest different sediment routing or sourcing of different levels within the same caldera complex that may be affected by fractionation of trace and rare earth elements. While this scenario is possible, an overarching take-away from our new TREE data is that prominent local Oligocene caldera sources – which are extensively exposed in the surrounding ranges today – were a negligible sediment source to the Miocene basins.

Miocene grains (17-22 Ma) in the Middlegate sample share similarities with the ca. 19 Ma Fairview Peak tuff in U/Yb, Yb/Gd, and Eu/Eu* ratios, but the Eastgate Miocene grains (17-22 Ma) are slightly offset to lower Hf concentrations (Fig. 19). Based on their age, the 17-22 Ma Miocene grains are highly likely to have been sourced from the ca. 19 Ma Fairview Peak caldera complex, which is the only known source of that age range anywhere in the region. Other Miocene-age zircon younger than 17-22 Ma are likely sourced from ca. 16 and younger bimodal volcanism in the area. Lower Hf

concentrations in the 17-22 Ma Miocene Eastgate grains may be derived from a less evolved part of the Fairview Peak magma chamber—such as the upper part of the tuff or related intrusive rocks—but a geochemical study of the actual caldera would be necessary to test this hypothesis.

DISCUSSION

Revised Basin Chronostratigraphy and Correlations between the Middlegate and Eastgate Stratigraphy

Based on similarities in geochronology, sedimentology, stratigraphy, and geochemistry of the strata exposed in the Middlegate and Eastgate areas, it is probable that these two areas were once part of a continuous depo-center prior to partitioning. New U-Pb zircon ages of airfall tuffs and detrital U-Pb zircon ages of reworked tuffaceous sandstones presented in this study suggest that the Middlegate Formation exposed in present-day Middlegate Basin (e.g. Stewart et al., 1999) and unit Tbc3 of the Buffalo Canyon Formation exposed in present-day Eastgate Basin (Barrows, 1971) are correlative. The new U-Pb age data yield depositional ages from ca. 16-14 Ma (Fig. 17) for this integrated interval (Interval 1 and 2). In addition, based on key upsection sedimentologic and stratigraphic features, and previous work by Stewart et al. (1999) and Barrows (1971), it is likely that members Tbc4 and Tbc5 of the Buffalo Canyon Formation and members Tmmr, Tmmrb, and Tmmc of the Monarch Mill Formation are contemporaneous as well (Fig. 17; Fig. 20).

New chronostratigraphic constraints presented in this study allow for reconstruction of the depositional and tectonic histories of the Middlegate and Eastgate

Figure 20. Proposed stratigraphic correlation across Middlegate and Eastgate Basins, modified from Barrows (1971) and Stewart et al., (1999). Previous work to constrain stratigraphy and timing of deposition in Middlegate and Eastgate Basins is compared to the work done in this study. Certain locals within Middlegate and Eastgate Basins exhibit unique similarities in sediment transport, lithology, and structure. This study suggests that at least two of the intervals may be traceable in both basins (Intervals 3 and 4). Intervals 1 and 2 may be related laterally. Interval 1 exhibits more fluvially-dominated deposition whereas Interval 2 consists of predominately deltaic into lakeshore facies. Disconformity between Intervals 3 and Unit 4 with unconstrained timing occurring after ca. 14 Ma. Deposition of Interval 4 and scouring of underlying Interval 3 likely occurred between 13 Ma-9 Ma. New zircon U-Pb LA-SC-ICPMS crystallization ages from interbedded tuffs (red circles) and maximum depositional ages from youngest detrital zircon U-Pb ages from sandstone samples (yellow boxes) from this study are shown with error bars.

areas as a larger continuous depocenter (Fig. 20). Miocene Lacustrine deposits exposed and preserved in the northern Eastgate Hills also suggest that Middlegate and Eastgate areas were likely connected during Middle to Late Miocene deposition. Barrows (1971) notes that these lacustrine deposits belong to Middlegate area lacustrine stratigraphy, but do not correlate with the presently-exposed Middlegate or Monarch Mill Formation lacustrine units exposed in Middlegate Basin present day. These preserved lacustrine sediments may suggest that partitioning of the basins through exhumation of the Eastgate Hills occurred after the deposition of upper Monarch Mill Formation lacustrine sediments, units that are no longer preserved in this area of the Middlegate Basin likely due to Quaternary cover and erosion.

FA4 and FA5 are distinct changes in paleogeographic setting that can be traced laterally and temporally connected between both the Monarch Mill Formation of Middlegate Basin and Tbc4 and Tbc5 of the Buffalo Canyon Formation in Eastgate Basin (Fig. 20). Coarser deposits observed in both basins indicate localized high relief related to the development of faults and present day basin and range topography (Fig. 21), occurring ca. 14 Ma based on tephrochronologic correlation (Stewart et al., 1999; Perkins et al., 1998), and stratigraphic and U-Pb geochronologic correlations (this study) (Fig. 20). The N-NW trending paleocurrent directions found within medium grained sandstone and pebble lags of FA4 (Unit 3, this study) indicate two plausible scenarios: (1) coarser deposits were generated and sourced from a major active fault to the S-SW or (2) the coarser conglomerate deposits may have come from the Buffalo Canyon Formation Tbc5, just ~10 km east of FA4 in the South Middlegate Area (Stewart

Figure 21. Aerial Google Earth images of modern depositional environment analogs. (A) Representative modern analog for Late Oligocene to Early Miocene (ca. 25-19 Ma) time. Image from the Altiplano, Chile, South America shows unfaulted high plateau topography not significantly influencing the sediment transport directions and deposition of aluvial-fluvial sediments. (B) Representative modern analog for Early to Middle Miocene (ca. 19- 9 Ma) time. Image from Dixie Valley, Basin and Range Province, NV just ~50 km northwest of the East Middlegate study area. Note the braided fluvial system (FA4 box) grading into a fluvio-deltaic system (FA3 box) into a lacustrine (FA1) depositional environment. Both Middlegate and Eastgate stratigraphy capture this upsection change from finer-grained distal sediments to coarser-grained, more proximal to high topography sediments.

et al., 1999) (Fig. 4). Tbc5 of the Buffalo Canyon Formation yields a W-NW paleoflow direction, indicating that alluvial deposits may have been sourced from the Desatoya Mountains and carried westward to the Middlegate area (Stewart et al., 1999). In order for coarse sediments to be transported and reworked from the Buffalo Canyon Formation into the Monarch Mill Formation in the present day South Middlegate area, it would require that the Eastgate Hills were not uplifted and exhumed at the time of FA5 deposition in both basins.

Volcanic Sediment Provenance and Influence of Oligocene Volcanic Topography

Prior to collecting and analyzing data, we previously hypothesized that Oligocene volcanic topography may have had a significant influence on sediment dispersal patterns in the Middlegate and Eastgate areas. Through detrital U-Pb geochronology and TREE analyses, however, we find that the deposition of Middlegate and Eastgate stratigraphy was not significantly impacted by volcanic topography associated with the Oligocene ignimbrite-flareup. The zircon in sandstone samples from both basins are largely from Miocene sources, with very little influence from Oligocene and Cretaceous sources. Based on the lack of ~25-26 Ma grains in the Middlegate and Eastgate stratigraphy detrital zircon U-Pb samples and maximum depositional ages of ca. 16-14 Ma, it is possible that the Middlegate and Eastgate areas were: (1) separated from the latest Oligocene volcanic rocks (28-31 Ma) through topographic isolation to the north where 25-26 Ma volcanic rocks are located relative to the basins, and/or (2) those Oligocene units were not as prominently exposed at the surface during ca. 16 Ma basin fill deposition. We prefer the second option because the changes in paleoflow observed

in measured sections of both areas are likely due to minor shifting within the fluvial system rather than sediment transport around topographic highs. Therefore, it is more likely that local Oligocene volcanic topography was fairly low-lying, unlike their prominent exposure at the surface in high fault blocks present-day, thereby not influencing the deposition of or becoming heavily reworked into the Miocene basin fill in both areas (Fig. 21).

If Oligocene volcanic sources had higher topographic exposure and did significantly influence the deposition of Miocene basin fill, we would have expected to see more 25-26 Ma and 28-31 Ma zircons in the detrital sandstone samples. Collecting further detrital sandstone samples for detrital zircon U-Pb analyses higher in the correlated measured sections may be able to resolve if the Oligocene volcanic sources continued to not significantly influence the deposition of the Miocene basin fill. If there is an increase in 25-26 Ma and 28-31 Ma Oligocene ages in detrital samples, that would possibly indicate that Oligocene sources were being exhumed at that time and reworked into the Miocene basin fill, possibly after ca. 14 Ma. Should the samples still lack 25-26 Ma and 28-31 Ma Oligocene-age zircon, it may indicate that the present-day basin and range topography formed much later than currently inferred by this study, after ca. 9 Ma based on the single youngest zircon in the Middlegate Formation sample (ca. 9.1 Ma, Sample 18IBMG01, Appendix 2) and the youngest geochronologic date from the Monarch Mill Formation (Stewart et al., 1999).

Oligocene volcanic topography and pre-existing structures did not significantly impact the formation and sediment routing of Miocene basin fill in Middlegate and Eastgate Basins, but these factors may exhibit more of an influence on the deposition of

basin fill and overall basin evolution in other Cenozoic or ancient rift settings. With regions that are significantly impacted by volcanism, TREE geochemistry may be used as a provenance tool to further refine and pinpoint volcanic sources that have been reworked into basin fill.

Timing of Basin and Range Normal Faulting and Basin Partitioning

The Buffalo Creek drainage system is present day situated in an incised notch that runs from Eastgate Basin through the Eastgate Hills, and continues through Middlegate and Westgate Basins, also forming incised notches in the high topography. It is likely that present-day Buffalo Creek is inherited from a larger paleodrainage system that shared the same sediment transport direction during Pliocene to Pleistocene time, yet maintained its W-NW course despite uplift of various fault blocks that should have been obstacles (Barrows, 1971). Based on newly presented interpretations from this study and the location of Buffalo Creek today, it is possible that the former, and likely larger, W-NW paleodrainage system may have shifted northwards as Eastgate Hills was progressively and obliquely exhumed and uplifted by northward propagating normal faulting. Oblique normal faulting and propagation of the faulting of Eastgate Hills likely ceased and then experienced vertical uplift to allow for incision of the high topography, creating the Eastgate notch. Barrows (1971) suggests that the drainage was blocked by Eastgate Hills at ~19.5 Ma to close and form Eastgate Basin; however, based on the data from this study, closure of Eastgate Basin did not occur until after ca. 14 Ma and more likely not until after ca. 9 Ma (Stewart et al., 1999, this study), but well before recorded historic time based on the lack of active vertical

displacement on the Eastgate Fault.

The Desatoya Mountains, the range on the east-most side of present-day Eastgate Basin, were likely no more than ~150-250 m at their highest in elevation during the deposition of lacustrine sediments of the Buffalo Canyon Formation in the Eastgate area due to their very fine-grained character (Barrows et al., 1971). There has been ~1,200-1,525 m of displacement on the high-angle normal faults to the west of the Desatoya Mountains since the Middle Miocene. This is based on studies by Axelrod (1956) that suggest the Eastgate Basin flora (Buffalo Canyon) must have resided at ~900-1,050 m in elevation during the Miocene, and they now reside at ~1,675 m in elevation, with present-day highest elevations of the Desatoya Mountains at ~600-1,200 m higher than the Eastgate flora exposures. It is possible that with activity along the high-angle normal faults on the western side of the Desatoya Mountains that there was an influx of coarser sediment into Eastgate Basin, thereby shifting the deltaic and lacustrine depositional environments further to the W-NW into the Middlegate area (Fig. 21).

Based on results from this study, it is likely that modern-day partitioning of the two basins by the uplift and exhumation of the Eastgate Hills did not occur until after deposition of the upper Buffalo Canyon Formation and the coarser-grained units of the Monarch Mills Formation (Intervals 3 and 4, this study) sometime after ca. 14 Ma, and plausibly after 9 Ma (Fig. 22). Similarities in lithology that are correlative both laterally and temporally, together with paleoflow measurements, geochronologic, and TREE geochemical data require that these two areas belonged to a larger continuous depocenter. In the Middlegate stratigraphy, the presence of W-NW gilbert-style

Figure 22. Schematic tectonic diagrams showing the evolution of Middlegate and Eastgate Basins. A) Formation of the Campbell Creek caldera complex and low-lying Oligocene volcanic topography. B) Formation of the Eleven Mile Canyon caldera complex and low-lying Oligocene volcanic topography. Note how both calderas slightly overlap. C) Formation of the Fairview Peak caldera complex and low-lying Early Miocene topography. D) Uplift of the Desatoya Mountains along a high-angle normal fault, forming Buffalo Lake which covers the area of future Middlegate and Eastgate Basins. Deposition of the gilbert-style delta front in the Middlegate Formation, and deposition of Tbc2 and Tbc3 members of the Buffalo Canyon Formation. E) Uplift of the region south of the field area causing sediment transport to shift from W to more N-NW; the Buffalo Lake also migrated to the W-NW. Coarse-grained sediments arrive in the basin, including the pebble-conglomerates and alluvial-fluvial sandstones of the Monarch Mill Formation and Tbc4 and Tbc5 members of the Buffalo Canyon Formation. F) Uplift of the Eastgate Hills in the middle of Buffalo Lake along north-striking normal faults, forming the Middlegate and Eastgate Basins. The obliquity between the north-striking Eastgate Hills and the northwest-trending paleodrainage system likely forced the flow to channelize, forming Buffalo Creek. Incision of the Eastgate Hills by Buffalo Creek was apparently rapid enough to outpace uplift of the Eastgate Hills as the creek cuts obliquely through the high-topography range today.

prograding lacustrine delta fronts in the Middlegate Formation, just ~0.25 km away from the present day range-bounding Eastgate Fault, would suggest that the fault along Eastgate Hills was inactive during the time of deposition. Should Eastgate Hills have been uplifted prior to or during deposition of the Middlegate Formation, we would have observed much coarser alluvial material in the lacustrine and deltaic units near the range bounding fault. Based on the lack of Oligocene-age zircon in the detrital zircon U-Pb and TREE analysis samples, we can also infer that the uplift and exhumation of Oligocene volcanics, via crustal extension and formation of the Basin and Range topography, post-date 16-14 Ma sedimentation in Middlegate and Eastgate Basins.

Thick basal megabreccia in the Middlegate Formation (18IBMG06, this study) is located adjacent to the Eastgate Fault and to the south of the Schweis Mine Canyon (Fig. 3), and thins to the N-NW, inward toward the center of the basin (Barrows 1971). This may also indicate that normal faulting and uplift of the Eastgate Hills may have occurred obliquely, initially beginning to the south and propagated to the north in an almost zipper affect with Middlegate Basin as the hangingwall block. Additional dating of the younger basin fill and paleoflow measurements will help to resolve precise timing of post 14 Ma Miocene basin partitioning. Alternatively, collecting vertical transects of thermochronology samples or dating fault mineralization along strike in the Eastgate Hills may also provide insight as to when they were exhumed and uplifted.

CONCLUSIONS

Based on new sedimentologic and stratigraphic analysis, U-Pb geochronology, TREE geochemistry, and paleocurrent data from this study, together with previous work, we propose the following.

- 1) Based on new data presented in this study, Middlegate and Eastgate Basins belonged to a larger, integrated depocenter with contemporaneous sedimentation in fluvio-deltaic-floodplain-lacustrine depositional environments that encompassed both areas. The lacustrine depositional center propagated westward due to active normal faulting along the faults of the western Desatoya Mountains ca. 14 Ma. The connected depocenter was then partitioned by normal faulting on the range-bounding Eastgate Fault and uplift of the Eastgate Hills likely after ca. 9 Ma.
- 2) The lack of 25-26 Ma and 28-31 Ma Oligocene zircon in detrital sandstone samples from both basins suggests that Oligocene volcanic topography and pre-existing structures did not greatly influence the deposition and distribution of Miocene sediments. We infer that Oligocene volcanic topography therefore was low-lying and did not affect the deposition of Miocene sediments in the Middlegate and Eastgate areas.
- 3) Uplift of the Eastgate Hills may have been initiated by exhumation and faulting to the S-SW. Therefore, it is possible that exhumation of the Eastgate Hills, due to vertical displacement along the Eastgate Fault, migrated from the south to the north gradually. This would allow for the incision and present day location of Buffalo Creek, a remnant preserved drainage from a larger paleodrainage system, as well as the preservation of lacustrine deposits in the northern Eastgate Hills.

In conclusion, the complexities in continental rift settings are unique to each individual region, and differences in rifting styles and basin reorganization may exist

within each rift system. In knowing this, it is important to combine sedimentology, stratigraphy, geochronology, and other diagnostic datasets like TREE geochemistry to potentially correlate sedimentary basin fill between neighboring rift basins. Further detailed work in these types of basin fill correlations may give refined insight into timing of partitioning (e.g. Mukhopadhyay et al., 2010). The tectonic model presented in this study (Fig. 22) serves as a preliminary interpretation for basin formation and reorganization as continental-scale basins and ranges form during continental rifting. These models may then be applied to other Cenozoic or even more ancient rift provinces to determine the extent of lateral correlations in basin fill in these complex continental rift settings.

Based on the data collected from this study and in comparison with previous work, it is imperative to collect a range of datasets that include but are not limited to sedimentology, stratigraphy, geochronology, geochemistry, and any additional data that may help to further constrain changes in basin fill deposition and provenance through time. Studies that integrate these types of data may better understand if formations within continental rift settings are more laterally extensive or if they are heavily influenced by pre-existing volcanic topography or structures.

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Appendix 1. 18BEG10-18BMG07 181BMG25 Zircon U-Pb geochronologic analyses.

Analysis	U (ppm)	206Pb 204Pb	U/Th	206Pb* 207Pb*	± (%)	207Pb* 235U*	± (%)	206Pb* 238U	± (%)	error corr.	206Pb* 238U*	± (Ma)	207Pb* 235U	± (Ma)	206Pb* 207Pb*	± (Ma)	Best age (Ma)	± (Ma)
18BEG10																		
-SAMPLE 1 Spot 10	89	6278	2.8	23.7681	5.6	0.0134	5.9	0.0023	2.0	0.34	14.9	0.3	13.5	0.8	NA	NA	14.9	0.3
-SAMPLE 1 Spot 16	112	942	2.6	27.4976	22.6	0.0116	22.6	0.0023	1.7	0.07	14.9	0.2	11.7	2.6	NA	NA	14.9	0.2
-SAMPLE 1 Spot 17	72	1552	2.5	23.7877	10.0	0.0137	10.2	0.0024	2.0	0.19	15.2	0.3	13.8	1.4	NA	NA	15.2	0.3
-SAMPLE 1 Spot 28	61	507	2.8	46.1981	71.4	0.0071	71.5	0.0024	2.5	0.03	15.3	0.4	7.2	5.1	NA	NA	15.3	0.4
-SAMPLE 1 Spot 3	239	3631	1.9	22.8027	3.3	0.0143	3.5	0.0024	1.3	0.36	15.3	0.2	14.5	0.5	NA	NA	15.3	0.2
-SAMPLE 1 Spot 8	80	1276	2.6	26.1039	16.3	0.0125	16.4	0.0024	2.1	0.13	15.3	0.3	12.7	2.1	NA	NA	15.3	0.3
-SAMPLE 1 Spot 26	53	1161	3.0	21.0278	6.9	0.0157	7.6	0.0024	3.1	0.41	15.4	0.5	15.8	1.2	76.2	163.6	15.4	0.5
-SAMPLE 1 Spot 2	106	1617	2.8	20.9886	5.6	0.0158	6.0	0.0024	2.1	0.35	15.5	0.3	15.9	0.9	80.6	133.1	15.5	0.3
-SAMPLE 1 Spot 1	72	1508	2.6	20.0532	9.2	0.0166	9.4	0.0024	2.0	0.21	15.6	0.3	16.7	1.6	187.8	215.1	15.6	0.3
-SAMPLE 1 Spot 19	69	593	2.7	36.3245	19.1	0.0092	19.2	0.0024	1.9	0.10	15.6	0.3	9.3	1.8	NA	NA	15.6	0.3
-SAMPLE 1 Spot 16	62	3142	2.6	21.5027	6.0	0.0156	6.3	0.0024	2.1	0.33	15.7	0.3	15.7	1.0	22.9	143.4	15.7	0.3
-SAMPLE 1 Spot 24	53	1266	2.8	24.8331	6.5	0.0136	6.9	0.0025	2.3	0.33	15.8	0.4	13.8	0.9	NA	NA	15.8	0.4
-SAMPLE 1 Spot 7	70	1574	2.5	20.3083	5.9	0.0168	6.2	0.0025	2.0	0.32	15.9	0.3	16.9	1.0	158.3	137.5	15.9	0.3
-SAMPLE 1 Spot 4	45	4702	2.8	17.6698	6.8	0.0196	7.2	0.0025	2.5	0.35	16.2	0.4	19.7	1.4	474.8	149.7	16.2	0.4
-SAMPLE 1 Spot 9	47	5211	2.9	15.3225	8.1	0.0227	8.4	0.0025	2.1	0.25	16.2	0.3	22.8	1.9	781.9	170.2	16.2	0.3
-SAMPLE 1 Spot 25	69	5529	2.6	17.7457	5.7	0.0196	6.2	0.0025	2.4	0.39	16.2	0.4	19.7	1.2	465.3	126.8	16.2	0.4
-SAMPLE 1 Spot 5	104	1434	2.5	12.4200	11.3	0.0282	11.5	0.0025	1.9	0.17	16.4	0.3	28.2	3.2	1208.8	223.8	16.4	0.3
-SAMPLE 1 Spot 27	160	12877	2.7	20.3389	4.7	0.0176	5.1	0.0026	1.9	0.37	16.7	0.3	17.7	0.9	154.7	111.0	16.7	0.3
-SAMPLE 1 Spot 20	50	1250	3.2	6.3205	20.6	0.0614	20.9	0.0028	3.7	0.18	18.1	0.7	60.5	12.3	2435.9	352.3	18.1	0.7
-SAMPLE 1 Spot 18	40	1602	2.9	6.4786	23.3	0.0612	23.9	0.0029	5.5	0.23	18.5	1.0	60.4	14.0	2394.0	401.6	18.5	1.0
18BMG07																		
-Sample 2 Spot 42	159	1349	3.8	26.1735	4.1	0.0129	4.4	0.0024	1.6	0.37	15.8	0.3	13.0	0.6	NA	NA	15.8	0.3
-Sample 2 Spot 52	189	3200	4.6	23.0814	3.3	0.0025	3.6	0.0025	1.5	0.42	15.8	0.2	14.8	0.5	NA	NA	15.8	0.2
-Sample 2 Spot 45	250	4815	3.4	22.9629	2.8	0.0148	3.2	0.0025	1.6	0.49	15.9	0.3	14.9	0.5	NA	NA	15.9	0.3
-Sample 2 Spot 64	274	8290	3.9	21.6559	2.9	0.0157	3.2	0.0025	1.3	0.40	15.9	0.2	15.8	0.5	5.8	70.3	15.9	0.2
-Sample 2 Spot 37	1529	93723	2.3	20.7072	1.5	0.0165	1.9	0.0025	1.2	0.63	16.0	0.2	16.7	0.3	112.6	35.2	16.0	0.2
-Sample 2 Spot 39	106	1075	3.6	24.4085	17.7	0.0140	17.8	0.0025	1.6	0.09	16.0	0.2	14.2	2.5	NA	NA	16.0	0.2
-Sample 2 Spot 55	408	3359	2.6	22.4222	3.5	0.0153	3.7	0.0025	1.3	0.36	16.1	0.2	15.4	0.6	NA	NA	16.1	0.2
-Sample 2 Spot 43	332	18777	3.3	21.0176	2.8	0.0164	3.1	0.0025	1.4	0.44	16.1	0.2	16.5	0.5	77.3	66.5	16.1	0.2
-Sample 2 Spot 62	156	2549	3.2	22.9138	3.4	0.0151	3.9	0.0025	1.8	0.46	16.1	0.3	15.2	0.6	NA	NA	16.1	0.3
-Sample 2 Spot 38	205	7549	3.9	21.9850	3.4	0.0157	3.7	0.0025	1.5	0.41	16.1	0.2	15.8	0.6	NA	NA	16.1	0.2
-Sample 2 Spot 51	204	1373	4.5	26.0371	14.8	0.0133	14.9	0.0025	1.8	0.12	16.2	0.3	13.4	2.0	NA	NA	16.2	0.3
-Sample 2 Spot 61	570	9208	1.9	20.8821	2.3	0.0167	2.6	0.0025	1.2	0.45	16.3	0.2	16.8	0.4	92.7	55.1	16.3	0.2
-Sample 2 Spot 41	361	24879	3.6	20.8176	2.8	0.0167	3.2	0.0025	1.5	0.47	16.3	0.2	16.8	0.5	100.0	66.5	16.3	0.2
-Sample 2 Spot 63	1128	8614	2.8	21.8978	1.5	0.0160	2.0	0.0025	1.4	0.69	16.3	0.2	16.1	0.3	NA	NA	16.3	0.2
-Sample 2 Spot 65	99	1100	4.1	32.7633	19.3	0.0107	19.5	0.0025	2.1	0.11	16.3	0.3	10.8	2.1	NA	NA	16.3	0.3
-Sample 2 Spot 53	375	5502	3.1	21.0827	2.8	0.0166	3.2	0.0025	1.4	0.44	16.4	0.2	16.7	0.5	70.0	67.6	16.4	0.2
-Sample 2 Spot 54	1089	23108	2.4	20.7933	2.0	0.0170	2.5	0.0026	1.4	0.58	16.5	0.2	17.2	0.4	102.8	47.6	16.5	0.2
-Sample 2 Spot 44	86	364653	2.8	18.6477	4.9	0.0195	5.3	0.0026	2.1	0.40	17.0	0.4	19.6	1.0	354.4	110.0	17.0	0.4
-Sample 2 Spot 36	347	14579	2.1	20.5803	2.5	0.0258	2.8	0.0039	1.3	0.47	24.8	0.3	25.9	0.7	127.1	58.0	24.8	0.3
-Sample 2 Spot 40	239	70937	2.0	10.8188	6.2	0.0514	6.4	0.0040	1.3	0.21	26.0	0.3	50.9	3.2	1475.4	118.5	26.0	0.3
18BMG25																		
-SAMPLE 3 Spot 4	93	640	2.7	34.8818	42.4	0.0086	42.5	0.0022	1.9	0.05	14.1	0.3	8.7	3.7	NA	NA	14.1	0.3
-SAMPLE 3 Spot 32	43	568	2.4	129.0411	180.3	0.0024	180.3	0.0022	2.1	0.01	14.2	0.3	2.4	4.3	NA	NA	14.2	0.3
-SAMPLE 3 Spot 1	53	882	2.3	29.9108	6.7	0.0103	7.2	0.0022	2.7	0.38	14.5	0.4	10.4	0.7	NA	NA	14.5	0.4
-SAMPLE 3 Spot 23	55	8376	2.2	16.8136	6.0	0.0185	6.4	0.0023	2.3	0.35	14.5	0.3	18.6	1.2	583.6	130.9	14.5	0.3
-SAMPLE 3 Spot 35	63	3245	2.4	23.4588	6.1	0.0134	6.7	0.0023	2.7	0.41	14.6	0.4	13.5	0.9	NA	NA	14.6	0.4
-SAMPLE 3 Spot 14	60	1128	2.4	23.2423	8.1	0.0135	8.5	0.0023	2.4	0.29	14.6	0.4	13.6	1.1	NA	NA	14.6	0.4
-SAMPLE 3 Spot 33	91	1389	2.2	22.9812	13.1	0.0137	13.1	0.0023	1.6	0.12	14.8	0.2	13.9	1.8	NA	NA	14.8	0.2
-SAMPLE 3 Spot 34	80	13930	2.5	20.1674	4.5	0.0157	5.0	0.0023	2.1	0.42	14.8	0.3	15.8	0.8	174.5	105.3	14.8	0.3
-SAMPLE 3 Spot 31	84	271797	2.3	19.3045	5.1	0.0164	5.6	0.0023	2.4	0.43	14.8	0.4	16.5	0.9	275.6	115.9	14.8	0.4
-SAMPLE 3 Spot 13	103	5424	2.2	22.9557	4.1	0.0140	4.4	0.0023	1.5	0.34	14.9	0.2	14.1	0.6	NA	NA	14.9	0.2
-SAMPLE 3 Spot 3	64	22534	2.4	19.3970	6.4	0.0166	7.1	0.0023	2.9	0.41	15.0	0.4	16.7	1.2	264.7	147.7	15.0	0.4

-SAMPLE 3 Spd 12	27	596	2.1	20.0054	9.4	0.0162	10.4	0.0024	4.3	0.41	15.2	0.7	16.4	1.7	193.4	219.7	15.2	0.7
-SAMPLE 3 Spd 30	52	1640	2.3	13.7208	9.1	0.0239	9.4	0.0024	2.6	0.28	15.3	0.4	24.0	2.2	1009.8	184.4	15.3	0.4
-SAMPLE 3 Spd 5	24	475	2.3	118.3134	117.1	0.0028	117.1	0.0024	2.6	0.02	15.4	0.4	2.8	3.3	NA	NA	15.4	0.4
-SAMPLE 3 Spd 22	48	958	2.3	22.8194	8.6	0.0145	9.0	0.0024	2.5	0.28	15.5	0.4	14.6	1.3	NA	NA	15.5	0.4
-SAMPLE 3 Spd 21	27	1181	2.6	16.1623	11.3	0.0209	11.8	0.0025	3.4	0.29	15.8	0.5	21.0	2.5	668.7	242.6	15.8	0.5
-SAMPLE 3 Spd 29	59	4131	2.5	7.7068	16.5	0.0441	16.7	0.0025	2.3	0.14	15.9	0.4	43.8	7.2	2093.9	292.9	15.9	0.4

Appendix 2. ¹⁸¹BmG01 Derivat Zircon U-Pb geochronologic analyses

Analysis	U (ppm)	²⁰⁶ Pb ²⁰⁴ Pb	U/Th	Isotope ratios				Apparent ages (Ma)				± (Ma)	Best age (Ma)	± (Ma)
				± (%)	²⁰⁷ Pb* 235U*	± (%)	206Pb* 238U*	± (%)	error corr.	206Pb* 238U*	± (Ma)	207Pb* 235U	± (Ma)	206Pb* 207Pb*
-181BmG01 Spot 7	722	2006	8.1											
-181BmG01 run2 Spot 115	61	70	2.3	20.5	0.0256	22.9	0.0014	10.2	0.45	9.1	0.9	25.6	5.8	2123.3
-181BmG01 run2 Spot 139	69	70	2.6	13.6	0.0301	13.8	0.0018	2.1	0.15	11.4	0.2	30.1	4.1	1997.4
-181BmG01 run2 Spot 98	85	342	2.0	6.0	0.0616	6.3	0.0018	1.9	0.30	11.9	0.2	60.7	3.7	3130.6
-181BmG01 run2 Spot 99	100	1929	2.0	75.2	0.0024	75.3	0.0022	2.4	0.03	14.3	0.3	2.5	1.9	NA
-181BmG01 Spot 13	100	1929	2.0	10.0	0.0159	10.6	0.0022	3.2	0.31	14.3	0.5	16.1	1.7	280.3
-181BmG01 run2 Spot 92	105	444	2.0	44.9087	0.0070	17.6	0.0023	2.6	0.15	14.7	0.4	7.1	1.2	NA
-181BmG01 run2 Spot 101	107	754	1.9	37.6015	0.0084	8.1	0.0023	2.0	0.25	14.8	0.3	8.5	0.7	NA
-181BmG01 run2 Spot 19	59	405	2.8	49.5689	0.0064	28.4	0.0023	2.3	0.08	14.8	0.3	6.5	1.8	NA
-181BmG01 run2 Spot 3	90	563	2.4	45.0548	0.0070	9.3	0.0023	2.7	0.28	14.8	0.4	7.1	0.7	NA
-181BmG01 Spot 46	96	1983	2.4	18.8379	0.0169	10.1	0.0023	3.4	0.33	14.9	0.5	17.0	1.7	331.4
-181BmG01 run2 Spot 17	93	343	2.3	882.0369	0.0004	880.9	0.0023	2.4	0.00	15.0	0.4	0.4	3.2	NA
-181BmG01 run2 Spot 145	80	585	2.2	33.0234	0.0097	17.0	0.0023	2.7	0.16	15.0	0.4	9.8	1.7	NA
-181BmG01 run2 Spot 53	92	1578	2.2	22.0007	0.0146	12.2	0.0023	2.0	0.17	15.0	0.3	14.7	1.8	NA
-181BmG01 run2 Spot 0	97	602	2.2	60.0464	0.0054	12.2	0.0023	2.4	0.20	15.0	0.4	5.4	0.7	NA
-181BmG01 run2 Spot 68	70	596	2.5	30.0084	0.0105	9.8	0.0023	2.4	0.24	15.0	0.4	10.6	1.0	NA
-181BmG01 run2 Spot 31	108	394	1.8	114.1502	0.0028	132.2	0.0023	2.4	0.02	15.1	0.4	2.9	3.8	NA
-181BmG01 run2 Spot 129	81	531	2.4	33.9053	0.0095	8.0	0.0023	2.4	0.30	15.1	0.4	9.6	0.8	NA
-181BmG01 run2 Spot 128	84	431	2.3	36.7281	0.0088	8.0	0.0023	2.2	0.28	15.1	0.3	8.9	0.7	NA
-181BmG01 run2 Spot 103	95	4585	2.2	18.3612	0.0078	4.6	0.0023	2.0	0.43	15.1	0.3	17.7	0.8	389.2
-181BmG01 run2 Spot 131	91	1303	2.3	21.8607	0.0148	13.5	0.0023	2.2	0.16	15.1	0.3	14.9	2.0	NA
-181BmG01 run2 Spot 24	107	426	1.9	54.8403	0.0059	6.6	0.0023	2.4	0.36	15.1	0.4	6.0	0.4	NA
-181BmG01 run2 Spot 38	103	1623	2.2	28.3370	0.0114	14.2	0.0024	1.9	0.13	15.1	0.3	11.5	1.6	NA
-181BmG01 run2 Spot 86	89	1480	2.5	26.0958	0.0124	7.0	0.0024	2.6	0.37	15.2	0.4	12.5	0.9	NA
-181BmG01 run2 Spot 132	189	686	1.5	26.2760	0.0124	17.3	0.0024	2.1	0.12	15.2	0.3	12.5	2.1	NA
-181BmG01 Spot 32	394	3249	1.6	17.9410	0.0181	7.1	0.0024	3.3	0.47	15.2	0.5	18.2	1.3	441.0
-181BmG01 run2 Spot 42	77	686	2.6	23.9826	0.0136	16.0	0.0024	3.0	0.19	15.2	0.5	13.7	2.2	NA
-181BmG01 run2 Spot 136	78	3323	2.6	21.0156	0.0155	6.8	0.0024	3.2	0.47	15.2	0.5	15.6	1.1	77.6
-181BmG01 run2 Spot 82	89	2287	2.3	18.1433	0.0180	7.6	0.0024	2.1	0.27	15.2	0.3	18.1	1.4	416.0
-181BmG01 run2 Spot 32	86	360	2.0	1816.7655	0.0002	194.1	0.0024	2.3	0.01	15.3	0.4	0.2	0.4	NA
-181BmG01 run2 Spot 18	191	1420	2.2	36.3712	0.0090	20.0	0.0024	1.5	0.08	15.3	0.2	9.1	1.8	NA
-181BmG01 run2 Spot 40	89	1071	2.3	23.3814	0.0140	6.3	0.0024	2.0	0.32	15.3	0.3	14.1	0.9	NA
-181BmG01 Spot 52	1315	118173	1.6	20.8276	0.0157	3.9	0.0024	2.3	0.59	15.3	0.4	15.9	0.6	96.9
-181BmG01 run2 Spot 13	96	12788	1.9	20.5155	0.0160	5.9	0.0024	2.5	0.43	15.3	0.4	16.1	0.9	134.5
-181BmG01 run2 Spot 104	253	1070	1.9	28.1241	0.0117	20.4	0.0024	1.5	0.08	15.3	0.2	11.8	2.4	NA
-181BmG01 run2 Spot 64	647	18073	1.4	20.5245	0.0160	2.8	0.0024	1.7	0.63	15.4	0.3	16.2	0.4	133.4
-181BmG01 run2 Spot 22	121	1742	1.8	24.0685	0.0137	5.7	0.0024	1.8	0.32	15.4	0.3	13.8	0.8	NA
-181BmG01 run2 Spot 27	151	3218	2.3	19.3209	0.0171	5.6	0.0024	2.1	0.38	15.4	0.3	17.2	1.0	273.7
-181BmG01 run2 Spot 140	93	1942	1.5	24.0666	0.0135	6.0	0.0024	1.8	0.30	15.4	0.3	13.7	0.8	NA
-181BmG01 run2 Spot 39	81	867	2.2	26.9395	0.0123	8.9	0.0024	2.1	0.24	15.4	0.3	12.4	1.1	NA
-181BmG01 run2 Spot 113	100	1286	2.0	26.3430	0.0126	13.4	0.0024	2.1	0.16	15.5	0.3	12.7	1.7	NA
-181BmG01 run2 Spot 110	198	801	1.8	26.3718	0.0126	5.7	0.0024	1.8	0.32	15.5	0.3	12.7	0.7	NA
-181BmG01 run2 Spot 55	131	1582	1.7	24.8316	0.0133	4.8	0.0024	1.8	0.37	15.5	0.3	13.5	0.6	NA
-181BmG01 Spot 5	157	15295	2.0	21.4750	0.0154	6.1	0.0024	2.4	0.39	15.5	0.4	15.6	0.9	26.0
-181BmG01 run2 Spot 118	68	2611	2.6	21.3066	0.0156	6.9	0.0024	2.4	0.35	15.5	0.4	15.7	1.1	44.9
-181BmG01 Spot 37	98	5612	2.1	10.1211	0.0328	2.8	0.0024	2.8	1.00	15.5	0.4	32.8	0.9	1600.8
-181BmG01 run2 Spot 149	95	1985	2.3	19.9559	0.0166	6.0	0.0024	2.2	0.36	15.5	0.3	16.8	1.0	199.1
-181BmG01 run2 Spot 34	112	500	2.0	55.1448	0.0060	4.6	0.0024	2.3	0.50	15.6	0.4	6.1	0.3	NA
-181BmG01 run2 Spot 46	74	855	2.3	22.9122	0.0145	9.1	0.0024	1.9	0.20	15.6	0.3	14.7	1.3	NA
-181BmG01 run2 Spot 121	621	6884	1.6	21.8118	0.0153	3.9	0.0024	1.9	0.48	15.6	0.3	15.4	0.6	NA
-181BmG01 run2 Spot 76	101	2983	1.9	19.0894	0.0175	6.3	0.0024	2.6	0.41	15.6	0.4	17.6	1.1	301.3
-181BmG01 run2 Spot 119	54	563	2.9	37.5841	0.0089	15.5	0.0024	2.7	0.18	15.6	0.4	9.0	1.4	NA
-181BmG01 run2 Spot 20	86	888	2.2	28.9276	0.0116	8.7	0.0024	2.1	0.24	15.7	0.3	11.7	1.0	NA
-181BmG01 Spot 31	109	6067	1.5	12.5976	0.0266	11.2	0.0024	3.3	0.30	15.7	0.5	26.7	2.9	1180.8
-181BmG01 run2 Spot 43	91	1654	2.2	25.2184	0.0132	5.5	0.0024	2.5	0.45	15.7	0.4	13.4	0.7	NA
-181BmG01 run2 Spot 87	220	67344	1.8	20.7300	0.0153	3.7	0.0024	1.3	0.36	15.7	0.2	16.3	0.6	110.0

-181BMG01 run2 Spot 73	166	3645	2.3	13.5109	8.4	0.0249	8.6	0.0024	1.8	0.21	15.7	0.3	25.0	2.1	1041.0	169.6	15.7	0.3
-181BMG01 Spot 39	118	11858	2.1	14.8522	9.0	0.0227	9.6	0.0024	3.1	0.32	15.7	0.5	22.8	2.2	847.1	188.3	15.7	0.5
-181BMG01 run2 Spot 8	111	1086	1.9	20.3623	8.3	0.0166	8.5	0.0025	2.1	0.24	15.8	0.3	16.7	1.4	152.1	194.0	15.8	0.3
-181BMG01 run2 Spot 76	107	1791	2.2	13.8933	7.6	0.0247	7.9	0.0025	2.2	0.28	15.8	0.4	24.8	1.9	1013.8	154.6	15.8	0.4
-181BMG01 run2 Spot 123	83	16062	2.3	20.8282	4.9	0.0162	5.4	0.0025	2.4	0.162	15.8	0.4	16.4	0.9	98.8	114.9	15.8	0.4
-181BMG01 run2 Spot 60	80	1469	2.6	13.4892	9.3	0.0251	9.6	0.0025	2.3	0.24	15.8	0.4	25.2	2.4	1044.2	188.2	15.8	0.4
-181BMG01 Spot 9	228	3741	1.5	20.9661	5.4	0.0162	8.1	0.0025	6.0	0.174	15.8	0.9	16.3	1.3	83.2	129.1	15.8	0.9
-181BMG01 run2 Spot 148	125	1688	1.9	18.0773	7.5	0.0188	7.9	0.0025	2.5	0.31	15.9	0.4	18.9	1.5	424.1	188.6	15.9	0.4
-181BMG01 run2 Spot 47	120	783	1.8	15.037	12.6	0.0223	12.7	0.0025	1.9	0.15	15.9	0.3	22.4	2.8	798.2	264.6	15.9	0.3
-181BMG01 run2 Spot 21	102	3492	1.8	22.6387	5.0	0.0150	5.4	0.0025	2.1	0.38	15.9	0.3	15.1	0.8	NA	NA	15.9	0.3
-181BMG01 run2 Spot 98	135	2256	0.8	21.8804	4.9	0.0156	5.3	0.0025	2.0	0.38	15.9	0.3	15.7	0.8	NA	NA	15.9	0.3
-181BMG01 run2 Spot 54	94	2929	2.2	22.9278	6.3	0.0149	6.9	0.0025	2.8	0.41	15.9	0.4	15.0	1.0	NA	NA	15.9	0.4
-181BMG01 run2 Spot 109	163	995	2.2	29.6281	11.7	0.0115	11.8	0.0025	1.4	0.112	15.9	0.2	11.6	1.4	NA	NA	15.9	0.2
-181BMG01 run2 Spot 94	127	614	1.8	17.9839	23.1	0.0190	23.2	0.0025	2.6	0.11	15.9	0.4	19.1	4.4	435.7	520.5	15.9	0.4
-181BMG01 run2 Spot 130	87	11139	2.3	18.9693	5.1	0.0180	5.7	0.0025	2.5	0.44	16.0	0.4	18.1	1.0	315.6	116.3	16.0	0.4
-181BMG01 run2 Spot 85	232	9432	0.8	20.0232	1.9	0.0171	2.2	0.0025	1.3	0.56	16.0	0.2	17.2	0.4	191.3	43.3	16.0	0.2
-181BMG01 run2 Spot 90	105	3032	2.4	15.1444	8.9	0.0218	9.1	0.0025	2.0	0.22	16.0	0.3	21.9	2.0	728.7	188.6	16.0	0.3
-181BMG01 run2 Spot 83	83	2560	2.2	17.6152	8.3	0.0195	8.5	0.0025	2.0	0.195	16.0	0.3	19.6	1.7	481.6	183.1	16.0	0.3
-181BMG01 run2 Spot 122	97	21966	1.8	22.4702	5.5	0.0153	5.9	0.0025	2.1	0.35	16.0	0.3	15.4	0.9	NA	NA	16.0	0.3
-181BMG01 run2 Spot 11	77	1421	2.4	22.2385	8.0	0.0155	8.4	0.0025	2.7	0.32	16.1	0.4	15.6	1.3	NA	NA	16.1	0.4
-181BMG01 run2 Spot 89	73	1629	2.4	22.4515	8.6	0.0153	8.8	0.0025	1.8	0.20	16.1	0.3	15.5	1.3	NA	NA	16.1	0.3
-181BMG01 run2 Spot 66	70	1267	2.6	21.8217	7.3	0.0158	7.6	0.0025	2.0	0.26	16.1	0.3	15.9	1.2	NA	NA	16.1	0.3
-181BMG01 run2 Spot 23	217	1596	2.0	26.4003	3.7	0.0131	3.9	0.0025	1.3	0.34	16.1	0.2	13.2	0.5	NA	NA	16.1	0.2
-181BMG01 run2 Spot 144	78	1021	2.4	27.0521	7.8	0.0128	8.2	0.0025	2.4	0.29	16.2	0.4	12.9	1.1	NA	NA	16.2	0.4
-181BMG01 run2 Spot 77	87	1153	2.2	12.5140	11.8	0.0277	12.0	0.0025	2.2	0.19	16.2	0.4	27.7	3.3	1193.9	233.7	16.2	0.4
-181BMG01 run2 Spot 35	292	5354	0.9	11.3466	2.1	0.0307	2.7	0.0025	1.6	0.59	16.3	0.3	30.7	0.8	1394.5	41.1	16.3	0.3
-181BMG01 Spot 10	96	873	2.4	9.3758	16.8	0.0372	17.1	0.0025	3.1	0.18	16.3	0.5	37.1	6.2	1742.2	310.6	16.3	0.5
-181BMG01 run2 Spot 49	163	613	0.8	13.0586	19.8	0.0269	19.9	0.0025	1.5	0.08	16.4	0.3	27.0	5.3	1109.3	400.0	16.4	0.3
-181BMG01 run2 Spot 46	78	1182	2.5	15.1534	8.8	0.0233	9.3	0.0026	2.8	0.30	16.5	0.5	23.4	2.1	805.2	185.6	16.5	0.5
-181BMG01 run2 Spot 117	118	25313	2.3	8.6905	10.4	0.0410	10.5	0.0026	1.6	0.15	16.7	0.3	40.8	4.2	1880.2	188.0	16.7	0.3
-181BMG01 run2 Spot 133	89	309	2.2	7.9194	14.9	0.0450	15.1	0.0026	2.7	0.18	16.7	0.4	44.7	6.6	2045.9	284.1	16.7	0.4
-181BMG01 run2 Spot 97	98	1724	2.0	9.3639	12.4	0.0382	12.7	0.0026	2.6	0.21	16.7	0.4	38.1	4.7	1744.6	228.1	16.7	0.4
-181BMG01 Spot 34	104	1836	1.9	6.9683	24.3	0.0515	24.5	0.0026	3.2	0.13	16.7	0.5	51.0	12.2	2271.7	425.1	16.7	0.5
-181BMG01 run2 Spot 44	674	25057	1.0	20.1486	2.0	0.0178	2.5	0.0026	1.6	0.63	16.8	0.3	18.0	0.5	176.7	45.7	16.8	0.3
-181BMG01 run2 Spot 30	104	1515	2.1	8.3077	15.2	0.0443	15.4	0.0027	2.2	0.15	17.2	0.4	44.0	6.6	1960.9	273.2	17.2	0.4
-181BMG01 Spot 53	89	717	2.3	6.4476	21.3	0.0572	21.8	0.0027	4.8	0.22	17.2	0.8	56.5	12.0	2402.1	386.2	17.2	0.8
-181BMG01 run2 Spot 5	103	1164	2.1	7.7865	22.3	0.0476	22.5	0.0027	2.5	0.11	17.3	0.4	47.2	10.4	2075.8	398.6	17.3	0.4
-181BMG01 run2 Spot 111	76	1281	2.5	10.3579	15.9	0.0358	16.1	0.0027	2.5	0.16	17.3	0.4	35.7	5.6	1557.6	300.0	17.3	0.4
-181BMG01 run2 Spot 127	101	888	1.9	6.6898	20.0	0.0565	20.1	0.0027	2.3	0.11	17.6	0.4	55.8	10.9	2339.3	345.8	17.6	0.4
-181BMG01 run2 Spot 96	520	1672	1.6	7.3565	13.6	0.0527	13.7	0.0028	1.7	0.13	18.1	0.3	52.2	7.0	2175.3	238.7	18.1	0.3
-181BMG01 run2 Spot 93	85	17864	2.0	5.4217	33.7	0.0717	33.9	0.0028	4.0	0.12	18.2	0.7	70.3	23.0	2692.5	575.0	18.2	0.7
-181BMG01 Spot 54	347	7577	2.5	19.3403	4.8	0.0202	5.6	0.0028	2.9	0.51	18.3	0.5	20.4	1.1	271.4	109.6	18.3	0.5
-181BMG01 run2 Spot 14	359	2933	2.6	21.5456	3.1	0.0193	3.5	0.0029	1.6	0.45	18.4	0.3	18.4	0.6	18.1	74.1	18.4	0.3
-181BMG01 run2 Spot 15	1976	36106	1.4	20.8552	1.8	0.0190	2.4	0.0029	1.5	0.195	18.5	0.3	19.1	0.5	95.8	43.7	18.5	0.3
-181BMG01 run2 Spot 29	686	7677	1.6	20.6835	2.4	0.0192	3.0	0.0029	1.8	0.80	18.5	0.3	19.3	0.6	115.3	57.2	18.5	0.3
-181BMG01 run2 Spot 45	198	1260	3.3	25.3390	14.6	0.0157	14.6	0.0029	1.4	0.10	18.6	0.3	15.8	2.3	NA	NA	18.6	0.3
-181BMG01 run2 Spot 67	510	31056	3.1	20.7653	2.2	0.0192	2.7	0.0029	1.5	0.192	18.6	0.3	19.3	0.5	105.9	51.2	18.6	0.3
-181BMG01 run2 Spot 141	535	25835	3.3	20.6139	2.8	0.0194	3.4	0.0029	1.9	0.57	18.7	0.4	19.5	0.7	123.2	65.4	18.7	0.4
-181BMG01 run2 Spot 143	1221	20686	1.6	20.9036	1.7	0.0191	2.1	0.0029	1.2	0.59	18.7	0.2	19.2	0.4	90.3	39.9	18.7	0.2
-181BMG01 Spot 33	206	11444	2.6	18.9392	5.6	0.0213	6.6	0.0029	3.5	0.54	18.7	0.7	21.4	1.4	331.3	126.4	18.7	0.7
-181BMG01 run2 Spot 102	46	3025	1.3	7.6931	7.6	0.0522	8.0	0.0029	2.6	0.33	18.8	0.5	51.7	4.0	2097.0	133.3	18.8	0.5
-181BMG01 run2 Spot 105	179	928	1.3	6.1875	4.1	0.0650	4.5	0.0029	1.9	0.43	18.8	0.4	64.0	2.8	2471.9	68.5	18.8	0.4
-181BMG01 run2 Spot 12	582	4401	2.2	22.7734	1.9	0.0177	2.6	0.0029	1.7	0.65	18.8	0.3	17.8	0.5	NA	NA	18.8	0.3
-181BMG01 run2 Spot 91	1037	5119	1.3	22.6074	3.5	0.0178	3.8	0.0029	1.6	0.42	18.8	0.3	17.9	0.7	NA	NA	18.8	0.3
-181BMG01 run2 Spot 10	599	8449	2.8	22.1686	3.4	0.0192	3.9	0.0029	1.9	0.49	18.9	0.4	18.3	0.7	NA	NA	18.9	0.4
-181BMG01 run2 Spot 96	606	10561	2.3	18.1202	3.0	0.0223	3.3	0.0029	1.3	0.39	18.9	0.2	22.4	0.7	418.8	67.8	18.9	0.2
-181BMG01 run2 Spot 107	608	3684	2.6	23.4096	3.8	0.0173	4.1	0.0029	1.6	0.38	18.9	0.3	17.4	0.7	NA	NA	18.9	0.3
-181BMG01 run2 Spot 69	273	33596	2.1	22.1349	3.3	0.0163	3.6	0.0029	1.6	0.44	18.9	0.3	18.4	0.7	NA	NA	18.9	0.3
-181BMG01 run2 Spot 7	264	21206	3.1	19.5718	3.9	0.0208	4.3	0.0030	1.8	0.41	19.0	0.3	20.9	0.9	244.1	90.9	19.0	0.3
-181BMG01 run2 Spot 61	245	9112	2.6	21.7439	3.3	0.0187	3.7	0.0030	1.6	0.44	19.0	0.3	18.8	0.7	NA	NA	19.0	0.3

-181BMG01 run2 Spot 120	246	1205	3.5	28.2546	3.6	0.0144	4.1	0.0030	1.8	0.45	19.0	0.3	14.5	0.6	NA	NA	19.0	0.3
-181BMG01 run2 Spot 33	230	1320	3.4	28.6703	3.6	0.0142	4.0	0.0030	1.9	0.46	19.1	0.4	14.4	0.6	NA	NA	19.1	0.4
-181BMG01 run2 Spot 126	332	1234	1.2	26.4028	4.2	0.0155	4.4	0.0030	1.4	0.32	19.1	0.3	15.6	0.7	NA	NA	19.1	0.3
-181BMG01 run2 Spot 142	409	5829	2.2	21.9351	3.0	0.0186	3.4	0.0030	1.6	0.47	19.1	0.3	18.8	0.6	NA	NA	19.1	0.3
-181BMG01 run2 Spot 16	378	1825	2.3	23.1089	4.6	0.0177	4.9	0.0030	1.8	0.36	19.1	0.3	17.8	0.9	NA	NA	19.1	0.3
-181BMG01 run2 Spot 72	191	41317	1.8	21.2199	3.5	0.0194	3.9	0.0030	1.7	0.44	19.2	0.3	19.5	0.8	54.6	84.2	19.2	0.3
-181BMG01 run2 Spot 50	700	3222	0.6	24.2310	3.2	0.0170	6.7	0.0030	5.9	0.88	19.2	1.1	17.1	1.1	NA	NA	19.2	1.1
-181BMG01 run2 Spot 114	310	5743	1.8	22.3170	4.4	0.0185	4.9	0.0030	2.2	0.44	19.3	0.4	18.6	0.9	NA	NA	19.3	0.4
-181BMG01 run2 Spot 146	194	2426	1.9	23.9969	3.0	0.0175	3.6	0.0030	2.1	0.57	19.3	0.4	17.6	0.6	NA	NA	19.3	0.4
-181BMG01 run2 Spot 59	210	2698	3.3	23.2385	3.5	0.0179	3.9	0.0030	1.7	0.43	19.4	0.3	18.0	0.7	NA	NA	19.4	0.3
-181BMG01 run2 Spot 74	249	2922	3.0	26.2077	5.9	0.0159	6.0	0.0030	1.3	0.22	19.4	0.3	16.0	1.0	NA	NA	19.4	0.3
-181BMG01 run2 Spot 81	140	5350	2.6	18.7509	4.2	0.0222	4.6	0.0030	1.7	0.38	19.4	0.3	22.3	1.0	341.9	95.5	19.4	0.3
-181BMG01 run2 Spot 63	112	2352	2.2	23.6607	7.1	0.0176	7.4	0.0030	2.3	0.30	19.4	0.4	17.7	1.3	NA	NA	19.4	0.4
-181BMG01 run2 Spot 137	337	14654	3.5	21.5032	3.0	0.0194	3.5	0.0030	1.8	0.51	19.4	0.3	19.5	0.7	22.8	71.3	19.4	0.3
-181BMG01 run2 Spot 28	663	21389	2.3	20.5782	2.0	0.0203	2.4	0.0030	1.3	0.54	19.5	0.2	20.4	0.5	127.3	47.3	19.5	0.2
-181BMG01 run2 Spot 26	225	2030	2.7	22.8440	3.7	0.0183	4.0	0.0030	1.4	0.36	19.5	0.3	18.4	0.7	NA	NA	19.5	0.3
-181BMG01 run2 Spot 112	87	407	2.0	4.6412	45.3	0.0905	45.4	0.0030	3.0	0.07	19.6	0.6	87.9	38.3	2946.3	779.8	19.6	0.6
-181BMG01 Spot 12	88	251	2.5	3.6968	50.3	0.1137	51.0	0.0030	8.3	0.16	19.6	1.6	109.3	52.9	3308.2	NA	19.6	1.6
-181BMG01 run2 Spot 36	412	4796	1.9	23.4215	4.4	0.0180	4.8	0.0031	1.9	0.40	19.7	0.4	18.1	0.9	NA	NA	19.7	0.4
-181BMG01 Spot 48	428	9513	1.4	13.8541	8.8	0.0304	10.4	0.0031	5.4	0.52	19.7	1.1	30.4	3.1	990.1	180.2	19.7	1.1
-181BMG01 Spot 30	110	2213	1.5	4.8368	39.1	0.0873	39.3	0.0031	3.6	0.09	19.7	0.7	85.0	32.0	2879.5	685.4	19.7	0.7
-181BMG01 run2 Spot 41	110	3887	2.2	4.3649	30.6	0.0973	30.7	0.0031	2.8	0.09	19.8	0.5	94.3	27.7	3045.1	503.6	19.8	0.5
-181BMG01 run2 Spot 106	588	17958	1.9	10.9031	8.6	0.0395	8.7	0.0031	1.3	0.15	19.9	0.3	39.4	3.4	1478.2	163.4	19.9	0.3
-181BMG01 Spot 8	107	2407	1.8	3.9752	39.7	0.1077	39.9	0.0031	3.9	0.10	20.0	0.8	103.9	39.4	3193.9	659.2	20.0	0.8
-181BMG01 run2 Spot 147	97	4045	1.2	4.8904	5.5	0.0877	5.8	0.0031	1.9	0.32	20.0	0.4	85.4	4.8	2861.6	89.8	20.0	0.4
-181BMG01 run2 Spot 86	71	706	2.7	4.9785	27.4	0.0863	27.5	0.0031	2.2	0.08	20.1	0.4	84.0	22.2	2832.5	456.4	20.1	0.4
-181BMG01 run2 Spot 108	948	7135	1.3	22.3905	21.1	0.0193	2.8	0.0031	1.8	0.65	20.2	0.4	19.4	0.5	NA	NA	20.2	0.4
-181BMG01 Spot 38	564	5045	1.9	14.8068	7.7	0.0284	8.2	0.0032	2.9	0.35	20.3	0.6	29.4	2.4	853.5	160.1	20.3	0.6
-181BMG01 Spot 14	117	1309	1.9	3.9310	37.9	0.1128	38.0	0.0032	2.3	0.06	20.7	0.5	108.5	39.1	3211.6	625.7	20.7	0.5
-181BMG01 Spot 11	1288	31936	2.2	21.1936	2.3	0.0241	3.3	0.0032	2.4	0.72	20.9	0.5	21.2	0.7	57.5	55.1	20.9	0.5
-181BMG01 run2 Spot 100	68	4942	1.5	4.2597	7.0	0.1049	7.5	0.0032	2.9	0.38	20.9	0.6	101.3	7.3	3084.1	111.5	20.9	0.6
-181BMG01 run2 Spot 50	3733	40701	1.5	19.9691	0.9	0.0226	1.6	0.0033	1.3	0.81	21.1	0.3	22.7	0.4	197.6	22.0	21.1	0.3
-181BMG01 Spot 51	81	700	2.3	2.8865	48.7	0.1751	49.3	0.0037	7.5	0.15	23.7	1.8	164.7	75.0	3690.7	1536.0	23.7	1.8
-181BMG01 run2 Spot 4	98	1538	2.8	3.2426	45.5	0.1587	45.7	0.0037	3.8	0.08	24.0	0.9	149.6	63.6	3512.2	1459.9	24.0	0.9
-181BMG01 run2 Spot 57	1358	15296	2.6	21.5512	1.5	0.0252	2.1	0.0039	1.5	0.70	25.3	0.4	25.2	0.5	17.4	36.4	25.3	0.4
-181BMG01 Spot 6	439	118449	2.5	21.1539	3.2	0.0292	3.7	0.0045	2.0	0.52	28.8	0.6	28.2	1.1	62.0	76.1	28.8	0.6
-181BMG01 run2 Spot 37	674	5007	3.5	21.9235	1.9	0.0285	2.6	0.0045	1.8	0.67	29.1	0.5	29.5	0.7	NA	NA	29.1	0.5
-181BMG01 Spot 49	826	22858	1.7	21.9382	2.9	0.0286	3.7	0.0045	2.3	0.63	29.3	0.7	28.6	1.0	NA	NA	29.3	0.7
-181BMG01 Spot 45	925	9592	1.8	21.7344	2.6	0.0289	3.9	0.0046	2.9	0.75	29.3	0.9	28.9	1.1	NA	NA	29.3	0.9
-181BMG01 run2 Spot 1	387	4877	2.7	22.6269	4.3	0.0278	4.6	0.0046	1.5	0.34	29.4	0.5	27.9	1.3	NA	NA	29.4	0.5
-181BMG01 run2 Spot 75	442	2233	1.5	12.0075	3.7	0.0529	3.9	0.0046	1.4	0.36	29.6	0.4	52.3	2.0	1275.0	71.8	29.6	0.4
-181BMG01 run2 Spot 6	546	6451	3.2	22.2856	2.4	0.0286	3.1	0.0046	2.1	0.66	29.7	0.6	28.6	0.9	NA	NA	29.7	0.6
-181BMG01 run2 Spot 71	62	329	2.8	2.3886	50.0	0.2669	50.3	0.0046	5.9	0.12	29.8	1.7	240.2	108.1	3976.8	NA	29.8	1.7
-181BMG01 run2 Spot 80	60	1349	1.4	2.2320	7.2	0.0289	8.3	0.0046	4.2	0.50	29.8	1.2	255.3	18.8	4078.1	107.7	29.8	1.2
-181BMG01 run2 Spot 134	500	6206	3.2	22.0677	2.1	0.0293	2.6	0.0047	1.6	0.61	30.2	0.5	29.3	0.7	NA	NA	30.2	0.5
-181BMG01 run2 Spot 116	418	3035	2.8	14.7838	6.9	0.0439	7.2	0.0047	2.1	0.29	30.3	0.6	43.6	3.1	856.7	142.6	30.3	0.6
-181BMG01 run2 Spot 9	373	8606	3.1	21.8467	2.6	0.0297	3.1	0.0047	1.8	0.57	30.3	0.5	29.7	0.9	NA	NA	30.3	0.5
-181BMG01 run2 Spot 62	186	1112	2.1	26.9619	16.9	0.0241	17.0	0.0047	1.7	0.10	30.3	0.5	24.2	4.1	NA	NA	30.3	0.5
-181BMG01 run2 Spot 124	793	11661	2.5	21.5863	2.4	0.0303	2.8	0.0047	1.6	0.55	30.5	0.5	30.3	0.8	13.6	56.6	30.5	0.5
-181BMG01 Spot 47	637	54088	3.0	21.0175	2.5	0.0312	3.2	0.0048	2.0	0.62	30.6	0.6	31.2	1.0	77.3	59.9	30.6	0.6
-181BMG01 run2 Spot 52	906	13909	3.5	20.9850	1.7	0.0313	2.3	0.0048	1.6	0.70	30.7	0.5	31.3	0.7	81.0	40.0	30.7	0.5
-181BMG01 run2 Spot 125	586	8015	2.2	21.3220	2.0	0.0310	2.3	0.0048	1.2	0.51	30.9	0.4	31.0	0.7	43.1	47.1	30.9	0.4
-181BMG01 run2 Spot 135	461	7592	2.3	22.0369	2.2	0.0301	2.9	0.0048	1.8	0.63	30.9	0.6	30.1	0.9	NA	NA	30.9	0.6
-181BMG01 run2 Spot 138	747	22849	4.6	21.1079	1.5	0.0317	2.2	0.0048	1.5	0.71	31.2	0.5	31.6	0.7	67.1	36.9	31.2	0.5
-181BMG01 run2 Spot 66	1183	7870	3.4	20.3587	1.5	0.0343	2.2	0.0051	1.6	0.74	32.6	0.5	34.2	0.7	152.5	34.7	32.6	0.5
-181BMG01 run2 Spot 25	225	1035	1.5	3.8552	44.1	0.2376	44.1	0.0068	2.2	0.05	42.7	0.9	216.4	86.2	3242.3	738.7	42.7	0.9
-181BMG01 Spot 36	506	21517	2.0	21.2787	3.0	0.0441	4.0	0.0068	2.8	0.68	43.8	1.2	43.8	1.7	47.9	70.5	43.8	1.2
-181BMG01 run2 Spot 79	91	501	1.6	1.6889	6.4	0.9939	7.1	0.0073	3.2	0.45	47.0	1.5	473.4	27.0	NA	NA	47.0	1.5
-181BMG01 run2 Spot 58	411	87544	3.0	14.2539	6.5	0.1264	6.8	0.0131	2.1	0.31	83.7	1.8	120.8	7.7	932.0	132.9	83.7	1.8
-181BMG01 run2 Spot 70	1658	109156	2.0	21.1347	0.9	0.0866	1.6	0.0133	1.3	0.84	85.0	1.1	84.3	1.3	64.2	20.9	85.0	1.1

-18BMG01 Spot 35	951	164458	4.1	20.7311	1.4	0.0892	2.3	0.0134	1.8	0.78	85.9	1.5	86.8	1.9	109.9	33.8	85.9	1.5
-18BMG01 run2 Spot 51	62	331	2.4	1.5172	50.0	1.2942	50.2	0.0142	4.3	0.09	91.2	3.9	843.1	295.5	NA	NA	91.2	3.9

Appendix 3. ¹⁸¹BEG03 Detrital Zircon U-Pb geochronologic analyses

Analysis	U (ppm)	²⁰⁶ Pb ²⁰⁴ Pb	U/Th	Isotope ratios				Apparent ages (Ma)				± (Ma)	Best age (Ma)	± (Ma)
				±	207Pb* 235U*	±	206Pb* 238U*	±	206Pb* 238U*	±	207Pb* 235U*	±	206Pb* 207Pb*	±
-181BEG03 run2Spot 90	229	3514	1.2	4.4	0.0147	4.9	0.0023	2.1	0.44	0.3	14.8	0.7	43.7	104.3
-181BEG03 Spot 4	211	5006	1.8	6.1	0.0162	6.8	0.0024	3.2	0.46	0.5	16.3	1.1	170.9	141.9
-181BEG03 run2Spot 159	149	1181	1.9	29.6242	4.2	0.0113	4.5	0.0024	1.6	0.36	11.4	0.5	NA	NA
-181BEG03 run2Spot 5	405	59406	1.0	20.3942	3.4	0.0164	3.7	0.0024	1.4	0.39	16.6	0.6	148.4	79.3
-181BEG03 run2Spot 36	87	1295	2.1	26.3451	14.9	0.0127	15.0	0.0024	1.8	0.12	12.9	1.9	NA	NA
-181BEG03 run2Spot 51	105	2188	2.2	33.7381	4.5	0.0100	5.0	0.0024	2.2	0.44	10.1	0.5	NA	NA
-181BEG03 run2Spot 64	81	1686	2.3	19.7589	9.4	0.0171	9.7	0.0025	2.5	0.26	17.2	1.7	222.1	217.7
-181BEG03 run2Spot 125	376	8340	1.9	20.7658	3.6	0.0163	4.1	0.0025	1.9	0.46	16.4	0.7	105.9	85.4
-181BEG03 run2Spot 116	369	21750	1.5	22.1914	2.4	0.0153	3.0	0.0025	1.8	0.80	15.4	0.5	NA	NA
-181BEG03 run2Spot 74	1322	16484	2.4	22.0013	1.8	0.0154	2.4	0.0025	1.5	0.64	15.6	0.4	NA	NA
-181BEG03 run2Spot 28	179	2091	1.6	24.7395	6.3	0.0138	6.7	0.0025	2.2	0.33	13.9	0.9	NA	NA
-181BEG03 run2Spot 6	48	405	3.6	35.4444	8.4	0.0096	8.9	0.0025	2.9	0.33	9.7	0.9	NA	NA
-181BEG03 run2Spot 58	1969	30512	1.1	15.5545	8.0	0.0219	8.8	0.0025	3.7	0.42	22.0	1.9	736.7	168.6
-181BEG03 run2Spot 21	136	960	2.4	27.2898	13.1	0.0125	13.3	0.0025	1.9	0.14	12.7	1.7	NA	NA
-181BEG03 run2Spot 39	368	2823	1.3	22.9548	4.1	0.0149	4.4	0.0025	1.6	0.35	15.0	0.7	NA	NA
-181BEG03 run2Spot 122	273	2986	2.4	22.0060	5.9	0.0156	6.3	0.0025	2.2	0.35	15.7	1.0	NA	NA
-181BEG03 run2Spot 82	757	10173	1.2	23.6117	2.9	0.0145	3.1	0.0025	1.3	0.42	14.6	0.5	NA	NA
-181BEG03 run2Spot 156	293	3069	2.0	23.0166	6.3	0.0149	6.5	0.0025	1.6	0.25	15.0	1.0	NA	NA
-181BEG03 run2Spot 32	196	6386	1.8	21.9308	3.6	0.0157	3.9	0.0025	1.5	0.38	15.8	0.6	NA	NA
-181BEG03 run2Spot 26	592	1682	1.4	25.1814	2.7	0.0136	3.4	0.0025	1.9	0.58	16.1	0.3	NA	NA
-181BEG03 run2Spot 151	384	4869	2.1	22.3635	4.1	0.0154	4.3	0.0025	1.3	0.30	15.5	0.7	NA	NA
-181BEG03 Spot 26	245	61450	1.8	19.9389	5.5	0.0173	6.0	0.0025	2.4	0.40	17.4	1.0	201.0	127.0
-181BEG03 run2Spot 35	461	13676	2.1	21.5180	2.9	0.0160	3.2	0.0025	1.4	0.43	16.1	0.5	21.2	69.3
-181BEG03 run2Spot 24	225	11960	1.4	19.2319	4.1	0.0180	4.6	0.0025	2.1	0.46	16.1	0.8	284.3	94.1
-181BEG03 run2Spot 70	365	9396	2.1	22.2591	3.2	0.0155	3.7	0.0025	1.8	0.155	16.1	0.3	NA	NA
-181BEG03 run2Spot 130	436	22712	2.2	21.3350	2.5	0.0162	3.4	0.0025	2.3	0.67	16.2	0.4	41.6	61.0
-181BEG03 run2Spot 102	548	13426	1.7	21.1778	2.9	0.0164	3.7	0.0025	2.2	0.61	16.2	0.4	59.3	69.9
-181BEG03 run2Spot 118	112	1031	1.8	24.6087	6.0	0.0141	6.5	0.0025	2.4	0.37	14.2	0.9	NA	NA
-181BEG03 Spot 18	392	4719	2.4	20.2785	4.3	0.0171	4.8	0.0025	2.2	0.45	17.2	0.8	161.7	101.0
-181BEG03 run2Spot 164	104	20456	2.1	19.2973	5.6	0.0140	6.0	0.0025	2.2	0.36	18.1	1.1	276.5	127.6
-181BEG03 run2Spot 110	673	7863	1.5	23.2077	3.7	0.0149	4.2	0.0025	2.0	0.47	15.1	0.6	NA	NA
-181BEG03 run2Spot 10	391	4652	1.8	17.6614	4.2	0.0197	4.4	0.0025	1.4	0.33	19.8	0.9	475.8	92.0
-181BEG03 run2Spot 30	1642	65368	2.9	20.7164	2.0	0.0167	2.5	0.0025	1.5	0.60	16.2	0.2	104.5	46.4
-181BEG03 run2Spot 114	200	1702	2.4	23.7677	5.1	0.0146	5.5	0.0025	2.1	0.37	14.7	0.8	NA	NA
-181BEG03 run2Spot 134	115	1316	1.9	33.9149	7.3	0.0102	7.8	0.0025	2.5	0.32	10.3	0.8	NA	NA
-181BEG03 run2Spot 103	1023	28089	1.3	17.3449	4.8	0.0201	5.1	0.0025	1.5	0.29	20.2	1.0	515.7	106.6
-181BEG03 run2Spot 111	425	1570	2.3	23.2706	3.6	0.0150	4.0	0.0025	1.8	0.44	15.1	0.6	NA	NA
-181BEG03 run2Spot 68	117	1076	2.1	35.5464	5.7	0.0098	6.1	0.0025	2.3	0.37	9.9	0.6	NA	NA
-181BEG03 run2Spot 11	218	2561	2.1	23.4844	4.5	0.0149	4.9	0.0025	2.0	0.41	15.0	0.7	NA	NA
-181BEG03 run2Spot 124	481	21534	2.6	22.4342	3.0	0.0156	3.5	0.0025	1.7	0.49	16.3	0.3	NA	NA
-181BEG03 run2Spot 42	611	26029	1.5	21.5172	2.9	0.0163	3.3	0.0025	1.5	0.46	16.4	0.5	21.3	69.5
-181BEG03 run2Spot 43	286	1640	2.1	28.2304	6.8	0.0124	6.9	0.0025	1.5	0.22	12.5	0.9	NA	NA
-181BEG03 run2Spot 73	148	8482	2.2	24.2827	3.5	0.0145	4.0	0.0026	2.0	0.36	14.6	0.6	NA	NA
-181BEG03 run2Spot 1	346	2075	1.4	23.3096	3.5	0.0151	3.7	0.0026	1.3	0.36	15.2	0.6	NA	NA
-181BEG03 Spot 13	250	11911	2.5	20.1943	4.4	0.0176	5.3	0.0026	2.9	0.56	17.7	0.9	171.4	102.3
-181BEG03 run2Spot 140	92	12797	2.1	19.9459	5.3	0.0179	5.8	0.0026	2.4	0.41	18.0	1.0	211.9	122.8
-181BEG03 run2Spot 2	108	998	1.5	22.6140	7.1	0.0157	7.4	0.0026	2.1	0.29	15.8	1.2	NA	NA
-181BEG03 run2Spot 143	399	2937	2.4	24.7136	4.3	0.0144	4.6	0.0026	1.6	0.35	14.5	0.7	NA	NA
-181BEG03 run2Spot 15	132	3621	2.8	22.2124	4.8	0.0161	5.0	0.0026	1.3	0.27	16.2	0.8	NA	NA
-181BEG03 run2Spot 12	629	6103	1.9	8.8936	8.3	0.0402	8.5	0.0026	1.9	0.22	40.0	3.3	1838.4	150.5
-181BEG03 Spot 22	1632	16048	1.7	21.0761	2.2	0.0169	3.4	0.0026	2.6	0.76	17.1	0.6	70.8	51.9
-181BEG03 run2Spot 117	270	3496	2.5	22.3982	3.5	0.0159	3.8	0.0026	1.5	0.38	16.1	0.6	NA	NA
-181BEG03 run2Spot 52	271	25590	2.1	21.3072	2.6	0.0168	3.1	0.0026	1.7	0.54	16.7	0.3	44.7	62.9
-181BEG03 run2Spot 148	145	1795	1.7	21.2554	5.3	0.0169	5.6	0.0026	1.9	0.33	17.0	0.9	50.6	125.6

-18BEG03 run2Spot 112	122	821	3.5	13.9753	11.1	0.0257	11.3	0.0026	2.2	0.20	16.8	0.4	25.7	2.9	972.4	226.1	16.8	0.4
-18BEG03 run2Spot 163	107	3818	2.6	21.2881	4.7	0.0169	5.3	0.0026	2.5	0.47	16.8	0.4	17.1	0.9	46.8	112.0	16.8	0.4
-18BEG03 run2Spot 71	365	7143	2.2	22.8160	3.2	0.0158	3.6	0.0026	1.7	0.47	16.8	0.3	15.9	0.6	NA	NA	16.8	0.3
-18BEG03 run2Spot 113	254	2491	2.3	24.5973	8.2	0.0144	8.4	0.0026	1.7	0.20	16.9	0.3	14.6	1.2	NA	NA	16.9	0.3
-18BEG03 run2Spot 87	266	1705	2.4	27.4036	12.5	0.0132	12.6	0.0026	1.8	0.14	16.9	0.3	13.3	1.7	NA	NA	16.9	0.3
-18BEG03 run2Spot 136	678	11211	1.8	21.5983	3.0	0.0168	3.4	0.0026	1.5	0.43	16.9	0.2	16.9	0.6	12.2	73.3	16.9	0.2
-18BEG03 run2Spot 158	83	23492	2.2	20.8887	5.6	0.0174	5.9	0.0026	1.9	0.32	16.9	0.3	17.5	1.0	92.0	133.6	16.9	0.3
-18BEG03 run2Spot 145	249	1600	2.3	25.1047	5.5	0.0145	5.8	0.0026	1.7	0.30	17.0	0.3	14.7	0.8	NA	NA	17.0	0.3
-18BEG03 Spot 8	376	2928	2.0	21.8076	5.5	0.0178	6.4	0.0028	3.3	0.52	18.1	0.6	17.9	1.1	NA	NA	18.1	0.6
-18BEG03 run2Spot 69	452	8198	2.9	19.9806	2.2	0.0195	3.3	0.0028	2.5	0.75	18.2	0.4	19.6	0.6	198.6	50.5	18.2	0.4
-18BEG03 Spot 17	261	2019	2.2	18.3701	10.2	0.0213	11.5	0.0028	5.4	0.47	18.3	1.0	21.4	2.4	388.1	228.4	18.3	1.0
-18BEG03 run2Spot 99	984	11434	1.2	22.1004	2.0	0.0178	2.8	0.0028	1.9	0.70	18.3	0.4	17.9	0.5	NA	NA	18.3	0.4
-18BEG03 run2Spot 27	191	1405	1.8	26.6800	5.1	0.0147	5.5	0.0029	2.0	0.36	18.4	0.4	14.9	0.8	NA	NA	18.4	0.4
-18BEG03 run2Spot 63	608	5718	1.2	22.3433	2.6	0.0176	3.2	0.0029	2.0	0.61	18.4	0.4	17.7	0.6	NA	NA	18.4	0.4
-18BEG03 run2Spot 79	716	112286	2.0	19.8157	2.7	0.0189	3.2	0.0029	1.6	0.52	18.4	0.3	20.0	0.6	215.5	63.5	18.4	0.3
-18BEG03 run2Spot 97	111	578	3.2	124.6405	3.1	0.0032	4.0	0.0029	2.5	0.63	18.4	0.5	3.2	0.1	NA	NA	18.4	0.5
-18BEG03 run2Spot 18	331	2622	2.2	22.4769	3.5	0.0176	3.7	0.0029	1.1	0.31	18.5	0.2	17.7	0.6	NA	NA	18.5	0.2
-18BEG03 run2Spot 138	270	5295	2.9	21.6610	3.6	0.0183	4.1	0.0029	1.9	0.46	18.5	0.4	18.4	0.7	5.2	87.4	18.5	0.4
-18BEG03 run2Spot 8	794	101077	1.7	21.3235	2.0	0.0187	2.8	0.0029	1.9	0.70	18.5	0.4	18.8	0.5	53.1	46.9	18.5	0.4
-18BEG03 run2Spot 78	140	761	1.9	28.1553	4.4	0.0141	4.9	0.0029	2.2	0.45	18.5	0.4	14.2	0.7	NA	NA	18.5	0.4
-18BEG03 run2Spot 19	300	1377	2.4	26.1062	8.4	0.0152	8.5	0.0029	1.3	0.15	18.6	0.2	15.3	1.3	NA	NA	18.6	0.2
-18BEG03 run2Spot 0	348	21110	2.1	21.6931	3.3	0.0183	3.6	0.0029	1.3	0.36	18.6	0.2	18.5	0.7	1.7	80.1	18.6	0.2
-18BEG03 run2Spot 93	457	4743	2.3	22.7889	4.2	0.0175	4.5	0.0029	1.7	0.38	18.6	0.3	17.6	0.8	NA	NA	18.6	0.3
-18BEG03 run2Spot 100	775	22418	1.3	21.3394	2.2	0.0188	3.0	0.0029	2.1	0.69	18.6	0.4	18.9	0.6	52.4	52.1	18.6	0.4
-18BEG03 run2Spot 38	959	6278	1.5	21.4836	1.9	0.0186	2.3	0.0029	1.3	0.57	18.7	0.2	18.7	0.4	25.0	44.7	18.7	0.2
-18BEG03 run2Spot 88	518	4623	1.5	22.0213	2.3	0.0181	3.0	0.0029	1.9	0.181	18.7	0.4	18.2	0.5	NA	NA	18.7	0.4
-18BEG03 Spot 21	639	8099	1.8	20.2348	3.6	0.0198	5.9	0.0029	4.6	0.79	18.7	0.9	19.9	1.2	166.8	84.7	18.7	0.9
-18BEG03 run2Spot 53	557	4167	2.7	22.1686	3.0	0.0180	3.4	0.0029	1.5	0.44	18.7	0.3	18.2	0.6	NA	NA	18.7	0.3
-18BEG03 run2Spot 139	333	6560	2.1	21.3243	3.9	0.0188	4.4	0.0029	2.2	0.49	18.7	0.4	18.9	0.8	42.8	92.8	18.7	0.4
-18BEG03 run2Spot 96	397	3659	2.0	22.8851	3.1	0.0175	3.8	0.0029	2.1	0.56	18.7	0.4	17.6	0.7	NA	NA	18.7	0.4
-18BEG03 run2Spot 13	461	3939	2.2	22.2691	2.8	0.0181	3.0	0.0029	1.3	0.42	18.8	0.2	18.2	0.5	NA	NA	18.8	0.2
-18BEG03 Spot 1	335	12266	2.7	17.9223	7.4	0.0224	8.2	0.0029	3.7	0.45	18.8	0.7	22.5	1.8	443.3	164.3	18.8	0.7
-18BEG03 Spot 10	170	10750	2.2	18.7711	6.2	0.0214	6.6	0.0029	2.2	0.34	18.8	0.4	21.5	1.4	339.5	139.6	18.8	0.4
-18BEG03 run2Spot 80	386	1999	2.2	24.2570	6.5	0.0166	6.8	0.0029	1.9	0.28	18.8	0.4	16.7	1.1	NA	NA	18.8	0.4
-18BEG03 Spot 14	232	2121	2.3	23.4016	6.0	0.0172	6.8	0.0029	3.3	0.48	18.8	0.6	17.3	1.2	NA	NA	18.8	0.6
-18BEG03 run2Spot 133	532	16975	2.1	21.2628	2.6	0.0190	3.5	0.0029	2.3	0.66	18.8	0.4	19.1	0.7	49.8	62.4	18.8	0.4
-18BEG03 run2Spot 84	511	8555	1.8	22.1951	2.9	0.0182	3.3	0.0029	1.7	0.50	18.8	0.3	18.3	0.6	NA	NA	18.8	0.3
-18BEG03 run2Spot 160	1237	118200	1.4	21.7127	1.9	0.0186	2.6	0.0029	1.7	0.66	18.8	0.3	18.7	0.5	NA	NA	18.8	0.3
-18BEG03 run2Spot 54	678	4176	2.1	19.8022	2.7	0.0204	3.3	0.0029	1.8	0.57	18.8	0.3	20.5	0.7	217.0	62.3	18.8	0.3
-18BEG03 run2Spot 91	642	13742	2.1	20.2247	2.0	0.0200	2.5	0.0029	1.5	0.61	18.9	0.3	20.1	0.5	167.9	47.0	18.9	0.3
-18BEG03 Spot 25	698	28882	2.1	18.5585	5.1	0.0218	6.5	0.0029	4.0	0.62	18.9	0.8	21.9	1.4	365.1	115.2	18.9	0.8
-18BEG03 run2Spot 40	278	1413	1.9	24.7531	13.7	0.0153	13.8	0.0029	1.7	0.12	18.9	0.3	16.5	2.2	NA	NA	18.9	0.3
-18BEG03 run2Spot 115	833	21476	1.9	21.3054	2.1	0.0190	3.2	0.0029	2.4	0.75	18.9	0.4	19.1	0.6	44.9	50.8	18.9	0.4
-18BEG03 run2Spot 106	314	2969	3.0	23.2166	7.0	0.0175	7.2	0.0029	1.6	0.22	18.9	0.3	17.6	1.3	NA	NA	18.9	0.3
-18BEG03 run2Spot 132	289	12233	2.3	21.0193	3.6	0.0193	4.1	0.0029	1.8	0.45	18.9	0.3	19.4	0.8	77.1	85.8	18.9	0.3
-18BEG03 run2Spot 29	715	19377	1.7	21.5180	2.2	0.0189	2.9	0.0029	2.0	0.67	19.0	0.4	19.0	0.5	21.2	51.8	19.0	0.4
-18BEG03 run2Spot 49	135	1027	2.3	32.1365	4.8	0.0126	5.1	0.0029	1.7	0.32	19.0	0.3	12.8	0.6	NA	NA	19.0	0.3
-18BEG03 run2Spot 34	1978	23936	2.0	20.7972	1.4	0.0195	2.2	0.0029	1.7	0.76	19.0	0.3	19.7	0.4	102.3	34.0	19.0	0.3
-18BEG03 run2Spot 37	207	3768	2.7	23.2105	3.7	0.0175	4.1	0.0030	1.8	0.44	19.0	0.3	17.6	0.7	NA	NA	19.0	0.3
-18BEG03 run2Spot 14	408	2352	1.6	25.5596	2.7	0.0160	3.1	0.0030	1.4	0.46	19.0	0.3	16.1	0.5	NA	NA	19.0	0.3
-18BEG03 run2Spot 50	184	2150	3.0	26.4225	4.1	0.0154	4.4	0.0030	1.4	0.33	19.0	0.3	15.5	0.7	NA	NA	19.0	0.3
-18BEG03 run2Spot 147	188	4526	1.9	21.1004	3.9	0.0193	4.2	0.0030	1.5	0.37	19.1	0.3	19.4	0.8	68.0	92.1	19.1	0.3
-18BEG03 run2Spot 123	376	81507	2.0	19.6677	3.1	0.0209	3.3	0.0030	1.3	0.40	19.1	0.3	21.0	0.7	244.6	70.4	19.1	0.3
-18BEG03 run2Spot 141	334	7835	2.2	22.4284	3.0	0.0182	3.5	0.0030	1.8	0.50	19.1	0.3	18.3	0.6	NA	NA	19.1	0.3
-18BEG03 run2Spot 89	419	7355	2.7	21.6111	3.8	0.0189	4.3	0.0030	2.0	0.46	19.1	0.4	19.0	0.8	10.8	90.8	19.1	0.4
-18BEG03 run2Spot 107	449	4145	1.2	23.6617	2.3	0.0173	2.9	0.0030	1.7	0.60	19.1	0.3	17.4	0.5	NA	NA	19.1	0.3
-18BEG03 run2Spot 23	323	3042	2.5	25.2620	3.6	0.0162	4.0	0.0030	1.6	0.162	19.1	0.3	16.3	0.6	NA	NA	19.1	0.3
-18BEG03 run2Spot 45	486	6411	1.5	21.3430	2.8	0.0192	3.3	0.0030	1.8	0.54	19.1	0.3	19.3	0.6	40.8	66.1	19.1	0.3
-18BEG03 run2Spot 72	543	10457	1.5	22.3005	1.9	0.0184	2.7	0.0030	1.9	0.72	19.1	0.4	18.5	0.5	NA	NA	19.1	0.4
-18BEG03 run2Spot 85	671	102589	2.4	20.7865	2.6	0.0198	3.3	0.0030	2.1	0.61	19.2	0.4	19.9	0.7	112.4	62.3	19.2	0.4

-18BEG03 run2Spot 7	450	6889	2.0	22.2899	3.4	0.0194	3.9	0.0030	1.8	0.47	192	0.4	18.5	0.7	NA	NA	19.2	0.4
-18BEG03 run2Spot 67	221	13144	2.5	20.8641	4.2	0.0187	4.6	0.0030	1.8	0.40	192	0.4	19.8	0.9	94.7	99.2	19.2	0.4
-18BEG03 run2Spot 105	235	4043	2.7	16.0925	5.8	0.0256	5.9	0.0030	1.4	0.23	192	0.3	25.6	1.5	678.0	123.1	19.2	0.3
-18BEG03 Spot 2	201	16678	2.3	16.8976	5.9	0.0244	6.9	0.0030	3.7	0.53	192	0.7	24.5	1.7	572.8	127.5	19.2	0.7
-18BEG03 Spot 29	220	3178	2.9	23.4863	7.0	0.0175	7.7	0.0030	3.2	0.42	192	0.6	17.7	1.3	NA	NA	19.2	0.6
-18BEG03 run2Spot 55	2076	24449	1.2	21.6840	1.2	0.0190	2.0	0.0030	1.5	0.78	193	0.3	19.1	0.4	2.7	29.8	19.3	0.3
-18BEG03 run2Spot 77	451	48270	1.7	21.8822	2.9	0.0189	3.3	0.0030	1.6	0.48	193	0.3	19.0	0.6	NA	NA	19.3	0.3
-18BEG03 run2Spot 162	529	10149	2.1	21.4034	2.3	0.0193	3.0	0.0030	2.0	0.86	193	0.4	19.5	0.6	34.0	54.9	19.3	0.4
-18BEG03 run2Spot 47	195	2958	2.1	23.9833	6.2	0.0173	6.5	0.0030	2.0	0.30	193	0.4	17.4	1.1	NA	NA	19.3	0.4
-18BEG03 run2Spot 94	307	5327	1.9	21.8745	3.2	0.0189	3.6	0.0030	1.6	0.45	193	0.3	19.0	0.7	NA	NA	19.3	0.3
-18BEG03 run2Spot 20	95	742	2.2	37.9487	6.9	0.0109	7.1	0.0030	1.4	0.20	194	0.3	11.0	0.8	NA	NA	19.4	0.3
-18BEG03 run2Spot 4	611	3379	2.4	23.2325	2.4	0.0178	2.8	0.0030	1.4	0.51	194	0.3	17.9	0.5	NA	NA	19.4	0.3
-18BEG03 run2Spot 119	307	31864	2.0	21.4459	3.1	0.0194	3.3	0.0030	1.1	0.194	194	0.2	19.5	0.6	29.2	73.7	19.4	0.2
-18BEG03 run2Spot 98	699	7695	1.9	9.9864	13.4	0.0416	13.7	0.0030	2.7	0.20	194	0.5	41.4	5.5	1625.8	250.2	19.4	0.5
-18BEG03 run2Spot 153	220	3445	2.3	23.6280	5.7	0.0176	5.9	0.0030	1.5	0.25	194	0.3	17.7	1.0	NA	NA	19.4	0.3
-18BEG03 Spot 0	115	3719	2.1	21.4324	5.8	0.0194	6.4	0.0030	2.9	0.45	195	0.6	19.5	1.2	30.7	137.9	19.5	0.6
-18BEG03 Spot 27	176	994	2.7	29.7460	6.3	0.0140	6.9	0.0030	3.0	0.43	195	0.6	14.1	1.0	NA	NA	19.5	0.6
-18BEG03 run2Spot 41	168	840969	2.6	20.8273	4.0	0.0200	4.3	0.0030	1.4	0.32	195	0.3	20.1	0.9	96.9	95.8	19.5	0.3
-18BEG03 run2Spot 152	821	30222	1.9	20.7930	2.6	0.0201	3.1	0.0030	1.6	0.51	195	0.3	20.2	0.6	102.8	62.4	19.5	0.3
-18BEG03 run2Spot 127	435	37019	2.6	22.0592	3.0	0.0189	3.5	0.0030	1.8	0.52	195	0.4	19.0	0.7	NA	NA	19.5	0.4
-18BEG03 run2Spot 149	192	2102	2.9	22.6173	4.0	0.0185	4.4	0.0030	1.7	0.40	195	0.3	18.6	0.8	NA	NA	19.5	0.3
-18BEG03 run2Spot 57	264	17319	2.2	22.3368	3.2	0.0186	3.6	0.0030	1.6	0.45	195	0.3	18.7	0.7	NA	NA	19.5	0.3
-18BEG03 run2Spot 56	207	3005	2.4	18.6323	5.0	0.0224	5.2	0.0030	1.4	0.27	195	0.3	22.5	1.2	356.2	113.3	19.5	0.3
-18BEG03 Spot 3	289	6927	2.3	21.2836	5.3	0.0196	5.7	0.0030	2.3	0.40	195	0.4	19.7	1.1	47.4	125.7	19.5	0.4
-18BEG03 run2Spot 60	162	2342	2.0	25.2395	8.0	0.0166	8.2	0.0030	1.9	0.23	195	0.4	16.7	1.4	NA	NA	19.5	0.4
-18BEG03 Spot 11	375	3040	2.2	16.0315	6.3	0.0261	6.7	0.0030	2.1	0.32	195	0.4	26.2	1.7	886.2	135.5	19.5	0.4
-18BEG03 Spot 23	737	13272	1.8	20.9490	3.0	0.0200	6.9	0.0030	6.2	0.90	196	1.2	20.1	1.4	85.1	70.7	19.6	1.2
-18BEG03 Spot 5	229	3388	2.2	20.5465	6.0	0.0204	6.8	0.0030	3.2	0.48	196	0.6	20.6	1.4	130.9	140.6	19.6	0.6
-18BEG03 Spot 7	696	19591	1.2	16.4142	4.9	0.0256	6.8	0.0031	4.7	0.69	196	0.9	25.7	1.7	635.6	105.3	19.6	0.9
-18BEG03 run2Spot 25	205	3644	2.3	22.7662	3.8	0.0185	4.1	0.0031	1.5	0.37	197	0.3	18.6	0.8	NA	NA	19.7	0.3
-18BEG03 run2Spot 168	1362	33188	0.9	16.7848	3.7	0.0252	4.2	0.0031	1.9	0.46	198	0.4	25.3	1.0	587.3	81.0	19.8	0.4
-18BEG03 run2Spot 146	185	1505	2.1	19.6423	7.1	0.0216	7.4	0.0031	2.0	0.27	198	0.4	21.7	1.6	235.8	164.0	19.8	0.4
-18BEG03 run2Spot 16	193	2602	2.1	19.3707	5.4	0.0219	5.6	0.0031	1.7	0.31	198	0.3	22.0	1.2	267.8	122.8	19.8	0.3
-18BEG03 run2Spot 83	542	2825	1.8	24.2386	3.1	0.0175	3.9	0.0031	2.3	0.59	198	0.5	17.6	0.7	NA	NA	19.8	0.5
-18BEG03 run2Spot 167	137	2048	2.4	23.4492	4.7	0.0182	5.2	0.0031	2.2	0.43	199	0.4	18.3	0.9	NA	NA	19.9	0.4
-18BEG03 run2Spot 166	339	68957	2.0	15.0030	6.8	0.0284	7.0	0.0031	1.6	0.22	199	0.3	28.4	2.0	826.1	143.1	19.9	0.3
-18BEG03 Spot 20	267	1723	2.4	7.8790	13.2	0.0542	13.5	0.0031	2.9	0.22	200	0.6	53.6	7.0	2055.0	233.6	20.0	0.6
-18BEG03 run2Spot 126	418	13688	2.0	21.3143	2.6	0.0201	3.2	0.0031	1.8	0.57	200	0.4	20.2	0.6	43.9	62.6	20.0	0.4
-18BEG03 run2Spot 9	648	161207	2.2	22.2763	1.9	0.0193	2.5	0.0031	1.7	0.88	201	0.3	19.4	0.5	NA	NA	20.1	0.3
-18BEG03 run2Spot 131	165	10395	2.2	17.7363	5.6	0.0243	5.9	0.0031	1.9	0.33	201	0.4	24.3	1.4	466.1	123.2	20.1	0.4
-18BEG03 run2Spot 62	276	2097	2.0	23.6347	3.5	0.0181	3.7	0.0031	1.3	0.34	201	0.3	18.2	0.7	NA	NA	20.1	0.3
-18BEG03 run2Spot 86	371	5588	1.6	21.4354	2.9	0.0202	3.5	0.0031	1.8	0.52	202	0.4	20.3	0.7	30.4	70.7	20.2	0.4
-18BEG03 run2Spot 155	671	29212	1.2	22.0216	2.3	0.0197	2.8	0.0032	1.7	0.61	203	0.3	19.8	0.6	NA	NA	20.3	0.3
-18BEG03 run2Spot 101	239	2795	1.5	16.7312	5.6	0.0260	5.8	0.0032	1.5	0.26	203	0.3	26.1	1.5	594.3	121.6	20.3	0.3
-18BEG03 run2Spot 65	216	3167	1.9	16.9363	6.2	0.0258	6.3	0.0032	1.1	0.18	204	0.2	25.8	1.6	567.8	135.3	20.4	0.2
-18BEG03 run2Spot 106	299	19644	2.2	21.0588	3.0	0.0208	3.4	0.0032	1.5	0.44	204	0.3	20.9	0.7	72.7	72.3	20.4	0.3
-18BEG03 run2Spot 3	198	4139	1.8	10.7411	12.8	0.0407	13.1	0.0032	2.9	0.22	204	0.6	40.5	5.2	1489.1	243.4	20.4	0.6
-18BEG03 run2Spot 144	725	6606	1.5	21.0860	3.4	0.0208	4.1	0.0032	2.2	0.54	205	0.5	20.9	0.8	69.7	81.2	20.5	0.5
-18BEG03 Spot 6	149	7749	2.4	13.3981	9.3	0.0329	9.6	0.0032	2.6	0.27	206	0.5	32.9	3.1	1057.7	187.4	20.6	0.5
-18BEG03 run2Spot 31	718	13894	0.9	21.4447	2.5	0.0206	2.8	0.0032	1.3	0.46	207	0.3	20.7	0.6	29.4	58.9	20.7	0.3
-18BEG03 run2Spot 128	198	9255	2.8	10.2636	13.6	0.0432	13.7	0.0032	1.8	0.13	207	0.4	42.9	5.7	1574.7	254.9	20.7	0.4
-18BEG03 Spot 16	107	1777	1.2	15.6357	10.6	0.0285	13.8	0.0032	8.8	0.64	208	1.8	28.6	3.9	739.2	225.4	20.8	1.8
-18BEG03 run2Spot 59	356	5935	1.2	22.1231	3.7	0.0203	4.2	0.0033	1.8	0.43	209	0.4	20.4	0.6	NA	NA	20.9	0.4
-18BEG03 run2Spot 165	434	5428	1.3	10.2451	11.9	0.0461	12.0	0.0034	1.8	0.15	220	0.3	45.7	5.4	1578.1	223.4	22.0	0.4
-18BEG03 run2Spot 150	609	8301	2.6	21.9849	2.5	0.0217	2.9	0.0035	1.4	0.49	223	0.3	21.8	0.6	NA	NA	22.3	0.3
-18BEG03 run2Spot 135	154	3455	1.7	21.3153	4.2	0.0246	4.7	0.0038	2.1	0.45	244	0.5	24.6	1.2	43.8	100.9	24.4	0.5
-18BEG03 run2Spot 95	442	12270	1.8	21.1088	2.2	0.0254	2.7	0.0039	1.7	0.61	250	0.4	25.0	0.7	67.0	51.9	25.0	0.4
-18BEG03 run2Spot 121	320	3410	3.2	23.797	2.2	0.0235	2.6	0.0039	1.4	0.54	254	0.4	23.6	0.6	NA	NA	25.4	0.4
-18BEG03 Spot 9	192	3624	3.0	23.2595	5.4	0.0274	5.8	0.0046	2.2	0.38	297	0.7	27.4	1.6	NA	NA	29.7	0.7
-18BEG03 run2Spot 22	1067	25058	1.7	21.6399	1.4	0.0296	2.2	0.0046	1.6	0.75	299	0.5	29.6	0.6	7.9	34.7	29.9	0.5

-18BEG03 run2Spot 46	461	10093	2.5	22.0416	2.1	0.0295	2.6	0.0047	1.6	0.61	30.3	0.5	29.5	0.8	NA	NA	30.3	0.5
-18BEG03 run2Spot 81	281	25860	3.2	13.6261	2.6	0.0453	3.0	0.0048	1.7	0.54	30.7	0.5	47.9	1.4	1023.8	51.8	30.7	0.5
-18BEG03 run2Spot 44	240	4585	1.6	21.9782	5.0	0.0305	5.3	0.0049	1.6	0.31	31.3	0.5	30.6	1.6	NA	NA	31.3	0.5
-18BEG03 run2Spot 66	580	51714	0.8	18.1549	2.1	0.0884	2.7	0.0117	1.7	0.63	74.7	1.2	86.1	2.2	414.5	46.3	74.7	1.2
-18BEG03 run2Spot 75	2377	208866	2.5	20.3483	0.6	0.0873	1.3	0.0132	1.2	0.89	84.6	1.0	85.0	1.1	96.5	14.3	84.6	1.0
-18BEG03 run2Spot 92	1010	23004	2.4	21.2932	0.9	0.0869	1.7	0.0134	1.5	0.85	85.9	1.3	84.6	1.4	46.3	22.2	85.9	1.3
-18BEG03 run2Spot 157	1094	54060	3.4	21.1424	0.9	0.0884	2.0	0.0136	1.8	0.89	86.9	1.5	86.1	1.6	63.3	21.4	86.9	1.5
-18BEG03 run2Spot 109	408	84210	3.8	21.0078	1.8	0.0895	2.5	0.0136	1.7	0.89	87.4	1.5	87.1	2.1	78.5	42.7	87.4	1.5
-18BEG03 run2Spot 120	1728	192114	2.5	20.2302	1.3	0.0951	2.4	0.0140	2.0	0.85	89.3	1.8	92.2	2.1	167.3	30.1	89.3	1.8
-18BEG03 run2Spot 104	577	15487	2.0	21.2960	1.3	0.0918	1.8	0.0142	1.3	0.73	90.8	1.2	89.2	1.6	46.0	30.1	90.8	1.2
-18BEG03 Spot 19	720	87110	2.1	21.0082	1.5	0.0932	3.2	0.0142	2.9	0.89	91.0	2.6	90.5	2.8	78.4	34.7	91.0	2.6
-18BEG03 run2Spot 76	980	87945	3.6	20.8486	1.3	0.0940	2.4	0.0142	2.0	0.84	91.0	1.8	91.2	2.1	96.5	30.3	91.0	1.8
-18BEG03 Spot 24	841	53894	2.6	19.9811	1.7	0.0988	3.7	0.0143	3.2	0.88	91.7	2.9	95.7	3.3	196.2	39.9	91.7	2.9
-18BEG03 run2Spot 61	1053	139383	2.2	20.7126	1.1	0.0954	1.7	0.0143	1.3	0.75	91.8	1.2	92.5	1.5	112.0	26.5	91.8	1.2
-18BEG03 run2Spot 169	1453	577294	2.1	21.0326	1.3	0.0945	2.5	0.0144	2.1	0.86	92.3	2.0	91.7	2.2	75.6	30.5	92.3	2.0
-18BEG03 Spot 28	883	107713	2.2	20.6962	1.7	0.0976	2.8	0.0147	2.2	0.78	93.8	2.0	94.6	2.5	113.9	40.4	93.8	2.0
-18BEG03 run2Spot 48	1020	24344	1.6	18.9954	3.1	0.1065	3.3	0.0147	1.3	0.39	94.0	1.2	102.8	3.3	312.5	69.8	94.0	1.2
-18BEG03 run2Spot 17	240	23420	3.0	20.3387	1.2	0.1005	1.8	0.0148	1.3	0.74	94.9	1.3	97.2	1.7	154.7	28.1	94.9	1.3
-18BEG03 run2Spot 129	185	41894	2.7	20.9109	1.7	0.1010	2.1	0.0153	1.2	0.57	98.0	1.2	97.7	1.9	88.5	40.6	98.0	1.2
-18BEG03 run2Spot 137	205	109534	1.5	20.5218	1.7	0.1330	2.5	0.0188	1.8	0.73	126.4	2.3	126.8	3.0	133.8	39.8	126.4	2.3
-18BEG03 run2Spot 142	227	16725	1.3	20.3035	1.7	0.1711	2.6	0.0252	1.9	0.75	160.5	3.1	160.4	3.8	158.9	39.9	160.5	3.1
-18BEG03 run2Spot 161	2195	575455	1.3	20.3155	1.0	0.1758	1.8	0.0259	1.6	0.85	164.9	2.5	164.5	2.8	157.5	23.0	164.9	2.5

Appendix 4. 18IBMG01 Trace and Rare Earth Element Data

Sample: 18IBMG01	Al (ppm)	Si (ppm)	P (ppm)	Sc (ppm)	Ti (ppm)	Y (ppm)
18IBMG01 Spot 5	18	153,230	249	330	13	1,624
18IBMG01 Spot 6	50	153,230	170	400	7	1,729
18IBMG01 Spot 7	25	153,230	174	349	10	1,129
18IBMG01 Spot 8	1,241	153,230	249	337	18	1,569
18IBMG01 Spot 9	14	153,230	197	313	10	1,607
18IBMG01 Spot 10	46	153,230	198	339	14	961
18IBMG01 Spot 11	36	153,230	349	399	3	1,983
18IBMG01 Spot 12	569	153,230	184	325	16	825
18IBMG01 Spot 13	1,167	153,230	201	329	15	1,346
18IBMG01 Spot 14	420	153,230	208	313	15	1,361
18IBMG01 Spot 30	115	153,230	243	314	14	1,691
18IBMG01 Spot 31	2,472	153,230	687	324	19	1,045
18IBMG01 Spot 32	13	153,230	369	311	12	4,161
18IBMG01 Spot 33	10	153,230	227	401	9	1,278
18IBMG01 Spot 34	5	153,230	910	306	14	1,527
18IBMG01 Spot 35	25	153,230	45	410	2	416
18IBMG01 Spot 36	0	153,230	208	378	7	984
18IBMG01 Spot 37	17	153,230	201	321	15	1,054
18IBMG01 Spot 38	16	153,230	405	339	4	757
18IBMG01 Spot 39	21	153,230	221	316	14	1,122
18IBMG01 Spot 45	10	153,230	239	398	5	1,265
18IBMG01 Spot 46	31	153,230	189	322	14	859
18IBMG01 Spot 47	9	153,230	113	386	4	1,443
18IBMG01 Spot 48	7	153,230	178	350	6	1,168
18IBMG01 Spot 49	35	153,230	261	463	6	2,057
18IBMG01 Spot 50	35	153,230	356	362	11	2,337
18IBMG01 Spot 51	1,715	153,230	194	311	32	857
18IBMG01 Spot 52	31	153,230	234	401	4	1,247
18IBMG01 Spot 53	687	153,230	1,627	376	15	1,128
18IBMG01 Spot 54	1,310	153,230	171	387	13	1,402

Nb (ppm)	La (ppm)	Ce (ppm)	Pr (ppm)	Nd (ppm)	Sm (ppm)	Eu (ppm)
9	0	11	0	5	9	1
3	0	10	0	6	10	2
5	0	16	0	2	4	1
5	2	11	1	7	10	1
9	0	12	0	5	9	0
6	0	7	0	2	4	0
30	0	52	0	1	4	1
6	0	7	0	1	3	0
6	0	8	0	5	8	1
6	0	8	0	5	8	1
5	0	9	1	8	11	1
6	15	40	7	27	9	1
24	0	22	1	13	22	1
3	1	11	0	4	6	1
6	15	47	8	34	15	1
1	0	17	0	1	1	1
6	0	33	0	2	4	1
6	0	8	0	2	5	0
7	4	39	1	5	3	1
7	0	8	0	3	5	1
5	0	17	0	2	4	1
7	0	8	0	1	3	0
2	0	7	0	6	9	2
6	0	30	0	2	4	1
11	0	62	0	4	8	2
10	0	92	0	6	13	5
7	1	9	0	3	3	0
7	0	52	0	2	4	1
7	260	674	129	468	97	5
5	0	14	0	4	7	2

Gd (ppm)	Tb (ppm)	Dy (ppm)	Ho (ppm)	Er (ppm)	Tm (ppm)	Yb (ppm)
37	14	152	56	226	46	420
42	15	162	57	251	55	488
19	7	89	35	164	37	383
39	13	146	53	215	44	385
37	14	158	56	232	47	423
18	7	83	31	131	30	281
25	11	150	61	288	69	643
15	6	72	27	123	26	251
32	12	132	46	189	38	368
33	12	132	45	189	39	358
47	16	167	63	249	50	432
26	9	103	37	149	32	296
101	36	403	150	579	115	931
27	10	105	40	166	37	359
44	14	150	52	208	42	380
6	2	26	11	56	16	222
17	6	82	32	142	36	374
21	9	95	35	150	30	279
11	5	60	24	116	28	308
26	9	104	39	157	34	324
21	8	100	41	183	44	436
18	7	74	30	128	27	272
36	12	129	48	200	44	420
21	8	97	36	162	37	360
34	13	163	67	305	71	610
55	20	209	77	333	71	593
17	7	75	28	123	26	256
21	8	100	38	179	42	459
100	18	133	40	145	27	268
29	11	118	45	210	43	411

					Best age	±
Lu (ppm)	Hf (ppm)	Ta (ppm)	Th (ppm)	U (ppm)	(Ma)	(Ma)
68	8,150	2	90	143	15.5	0.4
89	7,861	1	223	410	28.8	0.6
72	7,704	1	111	239	9.1	0.9
69	7,504	1	64	94	20.0	0.8
68	8,262	2	94	156	15.8	0.9
46	8,006	2	45	85	16.3	0.5
128	10,318	6	647	1,137	20.9	0.5
42	8,221	1	42	82	19.6	1.6
58	8,004	1	55	92	14.3	0.5
58	7,489	2	62	99	20.7	0.5
72	7,699	1	77	109	19.7	0.7
51	7,949	2	58	90	15.7	0.5
154	7,606	4	354	545	15.2	0.5
63	7,712	1	105	195	18.7	0.7
63	7,478	2	64	97	16.7	0.5
48	9,816	0	218	688	85.9	1.5
73	8,053	2	206	322	43.8	1.2
48	7,928	2	48	86	15.5	0.4
57	9,522	2	301	475	20.3	0.6
52	7,514	2	59	102	15.7	0.5
85	7,577	1	477	753	29.3	0.9
45	8,005	2	44	86	14.9	0.5
74	7,643	1	226	505	30.6	0.6
66	7,161	1	414	443	19.7	1.1
132	7,616	2	481	698	29.3	0.7
124	6,778	2	966	527	19.2	1.1
43	7,622	1	40	78	23.7	1.8
91	10,125	2	896	1,100	15.3	0.4
45	8,018	2	50	88	17.2	0.8
76	6,914	1	161	296	18.3	0.5

Appendix 5. 18IBEG03 Trace and Rare Earth Element Data

Sample: 18IBEG03	Al (ppm)	Si (ppm)	P (ppm)	Sc (ppm)	Ti (ppm)	Y (ppm)
18IBEG03 Spot 0	5	153,230	90	15	6	440
18IBEG03 Spot 1	473	153,230	587	14	5	658
18IBEG03 Spot 2	8	153,230	552	14	5	741
18IBEG03 Spot 3	3	153,230	94	13	7	534
18IBEG03 Spot 4	6	153,230	88	15	8	936
18IBEG03 Spot 5	4	153,230	99	14	3	429
18IBEG03 Spot 6	1	153,230	481	14	7	510
18IBEG03 Spot 7	126	153,230	1,586	15	4	932
18IBEG03 Spot 8	7	153,230	114	14	3	542
18IBEG03 Spot 9	16	153,230	85	16	6	538
18IBEG03 Spot 10	6	153,230	97	13	5	446
18IBEG03 Spot 11	2	153,230	888	14	3	588
18IBEG03 Spot 12	828	153,230	760	14	13	631
18IBEG03 Spot 13	13	153,230	71	14	4	356
18IBEG03 Spot 14	0	153,230	90	14	6	618
18IBEG03 Spot 15	103	153,230	90	13	3	529
18IBEG03 Spot 16	14	153,230	89	15	4	410
18IBEG03 Spot 17	5	153,230	93	14	3	645
18IBEG03 Spot 18	20	153,230	101	14	2	353
18IBEG03 Spot 19	4	153,230	41	15	1	294
18IBEG03 Spot 20	347	153,230	193	14	5	603
18IBEG03 Spot 21	4	153,230	103	14	2	769
18IBEG03 Spot 22	6	153,230	217	16	2	1,508
18IBEG03 Spot 23	5	153,230	199	14	2	1,002
18IBEG03 Spot 24	11	153,230	92	13	2	358
18IBEG03 Spot 25	48	153,230	511	15	2	822
18IBEG03 Spot 26	8	153,230	67	15	3	615
18IBEG03 Spot 27	1	153,230	83	14	7	635
18IBEG03 Spot 28	9	153,230	81	16	2	827
18IBEG03 Spot 29	16	153,230	86	14	6	641

Nb (ppm)	La (ppm)	Ce (ppm)	Pr (ppm)	Nd (ppm)	Sm (ppm)	Eu (ppm)
4	0	20	0	1	2	1
5	116	228	36	84	19	2
6	28	78	7	19	6	1
3	0	12	0	2	3	1
2	0	14	0	4	7	2
6	2	34	1	2	2	1
3	22	50	7	19	6	1
16	73	204	20	44	10	3
7	4	45	1	3	3	1
2	0	11	0	1	3	2
4	0	26	0	1	2	1
8	98	202	27	64	12	2
6	421	272	104	257	47	9
3	0	13	0	1	1	1
4	0	17	0	2	3	1
5	1	41	0	2	3	1
2	0	13	0	1	1	1
7	0	39	0	1	2	1
3	1	22	0	1	1	1
3	0	33	0	1	2	1
5	6	36	2	6	4	1
12	2	54	1	2	3	1
22	0	59	0	2	5	1
17	8	79	2	8	5	1
4	2	38	1	2	1	1
12	118	236	31	73	14	2
2	0	14	0	2	3	2
4	0	13	0	2	3	1
7	0	58	0	1	3	2
5	0	18	0	1	3	1

Gd (ppm)	Tb (ppm)	Dy (ppm)	Ho (ppm)	Er (ppm)	Tm (ppm)	Yb (ppm)
6	5	37	24	69	26	188
18	10	57	37	95	33	213
13	9	55	39	113	41	285
9	7	45	30	81	29	198
18	14	83	53	135	47	296
6	5	35	24	67	26	193
10	7	43	28	80	28	188
15	11	71	46	129	47	311
7	6	41	28	84	32	232
8	6	40	28	81	31	217
7	6	39	26	73	26	197
12	7	47	31	87	34	245
33	14	61	36	89	32	209
4	3	23	18	55	23	185
11	8	51	33	88	33	209
8	6	43	29	86	31	234
5	4	31	22	68	28	225
8	6	46	33	89	34	244
4	4	27	19	56	22	177
5	3	22	14	41	16	144
10	8	48	33	88	30	214
10	8	56	39	110	41	297
17	16	116	77	219	81	470
14	11	80	53	140	52	333
5	4	26	18	54	23	193
17	9	64	42	119	45	304
9	7	46	32	87	35	260
10	8	51	33	94	34	229
12	9	64	42	118	43	307
9	7	49	34	96	36	242

					Best age	±
Lu (ppm)	Hf (ppm)	Ta (ppm)	Th (ppm)	U (ppm)	(Ma)	(Ma)
51	6,238	1	66	159	19.5	0.6
56	6,109	1	146	395	18.8	0.7
76	6,881	2	140	296	19.2	0.7
53	5,337	1	136	353	19.5	0.4
78	6,769	0	143	263	15.3	0.5
54	6,089	1	137	300	19.6	0.6
52	5,321	1	56	192	20.6	0.5
89	6,451	3	712	971	19.6	0.9
61	6,540	2	270	558	18.1	0.6
63	5,003	1	75	250	29.7	0.7
51	6,387	1	101	235	18.8	0.4
66	7,341	2	219	507	19.5	0.4
54	6,233	1	154	331	X	X
59	6,611	1	123	312	16.6	0.5
55	5,509	1	126	299	18.8	0.6
66	6,446	1	372	605	X	X
67	6,281	1	139	312	20.8	1.8
67	6,538	2	306	585	18.3	1.0
51	6,984	1	217	553	16.2	0.4
42	7,917	0	487	1,084	91.0	2.6
55	6,707	1	156	363	20.0	0.6
80	6,513	3	420	812	18.7	0.9
143	7,855	5	1,023	2,104	16.7	0.4
90	6,575	3	488	1,069	19.6	1.2
56	7,327	1	411	1,130	91.7	2.9
85	6,513	3	450	982	18.9	0.8
76	6,744	1	177	314	16.1	0.4
60	5,092	1	85	240	19.5	0.6
88	7,196	2	602	1,277	93.8	2.0
67	6,027	1	88	265	19.2	0.6