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Application of Detrital Zircon Geochronology to Determine the Sedimentary Provenance of the Middle Bloyd Sandstone, Arkoma Shelf, Northern Arkansas

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ABSTRACT

The sedimentary provenance of the middle Bloyd sandstone and subsequent sediment transport and dispersal patterns of the Early Pennsylvanian were interpreted by utilizing U-Pb detrital zircon geochronology. Eight middle Bloyd sandstone samples were analyzed. A total of 855 concordant analyses resulted. Peaks occurred at 350-500 Ma, 950-1200 Ma, 1300-1500 Ma, 1800-2300 Ma, and >2500 Ma. These peaks were determined to represent crystalline source rocks on the Laurentian craton from Acadian-Taconic, Grenville, Midcontinent Granite-Rhyolite, Yavapai-Mazatzal, Paleoproterozoic, and Archean Superior Provinces respectively. Grenville age zircons were the most common zircons identified in the middle Bloyd sandstone samples. The Appalachian Mountain region is determined to be the primary source of sediment in the middle Bloyd sandstone as evidenced by the high percentage of grains attributed to the Acadian-Taconic and Grenville age terranes. The moderate presence of Midcontinent Granite-Rhyolite and Yavapai-Mazatzal age zircons in the middle Bloyd sandstone indicates that a secondary source of sediment for the sandstone unit likely originated from north and west of the study area. Sediments were likely transported from both north-northwestern and eastern source regions into a common drainage basin that allowed movement of sediments southward by a substantial fluvial system onto the Arkoma Shelf in northern Arkansas where the deposition of the middle Bloyd sandstone occurred as part of a large scale braided stream system near the Pennsylvanian-Morrowan coast.

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I. INTRODUCTION

A. PROJECT PURPOSE AND SCOPE

Detrital zircon geochronology is a valuable tool in determining sedimentary provenance (Thomas, 2011a). Although speculations have been made on sediment provenance for the middle Bloyd sandstone, no previous work utilized detrital zircon geochronology to help identify the provenance of the sandstone unit. The principal focus of previous middle Bloyd studies has been lithostratigraphy and depositional dynamics of the sandstone unit, particularly petrographic study as well as measured paleocurrent data to determine a source direction and region. The scope of the present study is to utilize ages of extracted detrital zircons in conjunction with previous data in an effort to more accurately identify source terrains that were contributors to the sediment that comprises the middle Bloyd sandstone unit. The ultimate goal of this study has been to construct a model for the unit that incorporated the major source areas, the major sediment dispersal pathways, and the depositional environment in which the middle Bloyd sandstone unit was finally deposited.

B. PREVIOUS STUDIES

Several previous investigations of the middle Bloyd sandstone have been conducted in the past by students of the University of Arkansas, Department of Geosciences. These previous studies have looked at various aspects of the sandstone unit, and they have utilized numerous methods to describe the sandstone. Particularly, past research has focused on topics such as lithostratigraphy, petrography, paleocurrent analysis, and attempts to establish surface to subsurface correlation as it passes into the Arkoma Basin. These interpretations will be synthesized with the addition of geochronology data to attempt to establish the provenance of the middle Bloyd sandstone.

Prior to the early 1970's, the middle Bloyd sandstone unit was thought to be the Atokan Greenland Sandstone Member, Winslow Formation (Henbest, 1953). Study by Glenn (1973), under the direction of Dr. Doy L. Zachry, was the earliest to suggest that the middle Bloyd sandstone represented a separate Morrowan lithostratigraphic entity. He utilized stratigraphic and petrographic techniques in his research. Glenn concluded through his research that the middle Bloyd sandstone was not continuous with the Greenland sandstone, and that the unit was deposited within broad braided stream systems during the Morrowan (Glenn, 1973).

Zachry and Haley (1975) was the earliest regional investigation of the middle Bloyd sandstone. Their focus was predominantly on providing a description of the depositional environment in which the sandstone unit was emplaced. The research included a detailed investigation of the sedimentary structures found within the middle Bloyd sandstone genetic sequence. Their mapping of the middle Bloyd sandstone at Cannon Creek demonstrated that the sandstone unit was below the Kessler Limestone, confirming that the middle Bloyd sandstone was Morrowan rather than Atokan in age. Further investigation of paleocurrent data and sedimentary structure determined that the middle Bloyd sandstone was emplaced by a south-flowing braided stream system on a near-strand coastal plain (Zachry, 1979).

Several previous studies have been conducted on the middle Bloyd sandstone (Glenn, 1973; Zachry, 1975; Berry, 1978; Crowder, 1982; Antia-Barrero, 2006; Pontiff, 2007; Allen, 2008; Dupont, 2008; Lonigro, 2008; Porter 2009). Berry (1978) conducted research on the middle Bloyd sandstone in order to provide further insight into the middle Bloyd sandstone.

During his research, he collected information about the middle Bloyd sandstone's thickness trends, succession of sedimentary structures, paleocurrent data, grain size, and conducted a petrographic analysis in order to determine the depositional environment of the middle Bloyd sandstone. His study was conducted in southeastern Madison County, Arkansas. His petrographic analysis indicated the presence of metamorphic rock fragments (MRFs). The nature of the MRFs in the middle Bloyd sandstone indicated that a portion of the sediment in the middle Bloyd sandstone had to have been sourced from a metamorphic terrane (Berry, 1978). He also noted the common presence of monocrystalline quartz in the samples. Evidence he gathered from his investigation of the middle Bloyd sandstone unit led him to conclude that the middle Bloyd sandstone was quite possibly a continuation of dispersal trends identified in the Morrowan sandstones of the Illinois Basin. In addition, he suggested that the Nemaha Ridge may have input sediment identified in the middle Bloyd sandstone, but that the sediment contributed from this region was likely minor. His final conclusion was that the middle Bloyd sandstone was deposited within a braided fluvial system in a near marine environment, consistent with earlier interpretations of the deposition of the unit.

Research conducted by Crowder (1982) set about subdividing the middle Bloyd sandstone (Gaither Sandstone) into three lithofacies in order to construct a depositional model for the middle Bloyd sandstone. He accomplished this by describing lithologies that were observed during field work, paleocurrent measurements, examination of sedimentary structures, and analysis of thin sections created from samples taken from 20 middle Bloyd outcrops in Washington, Madison, Newton, Searcy, Boone, and Carroll Counties, Arkansas. Three distinct lithofacies are present in the sandstone unit: channel-fill dominated facies in the east; channel and, dominantly, planar-tabular bedform migration in the north-central portion, and well-sorted calcareous sandstone and bioclastic limestone in the westernmost exposures (Crowder, 1982). Crowder (1982) concluded from his study of the facies present in the sandstone unit, that the middle Bloyd was deposited in a coastal, fluvio-marine setting. In addition, Crowder (1982) also concluded that the Morrowan shoreline had undergone two changes in position in the Morrowan during the deposition of the Bloyd Formation, as evidenced by the middle Bloyd sandstone and its bounding strata.

Research conducted by Antia-Barrero (2006) expanded the knowledge of the unit southward into the northern portions of the Arkoma Basin. This research included a detailed analysis and description of several middle Bloyd sandstone outcrops in Johnson and Pope Counties, Arkansas, further south than any of the previous research on the unit. He provided a detailed analysis of depositional facies, stratigraphy, and paleocurrent measurements of the middle Bloyd Sandstone.

The research of Pontiff (2007) sought to provide an improved surface to subsurface understanding of the middle Bloyd sandstone in the north-central portion of the Arkoma Basin. She studied Morrowan outcrops at the surface, located north of the basin, and used well logs within the northern Arkoma Basin. Through his research, Porter (2009) provided additional understanding to the stratigraphic framework of the Morrowan section in the subsurface. He also related surface outcrops on the southern Ozark shelf to wireline logs in the northern portions of the Arkoma Basin.

The research by Dupont (2008) and Lonigro (2008) focused on a detailed description of specific outcrop locations of middle Bloyd sandstone. Dupont's (2008) research focused on a reconstruction of the depositional facies of the sandstone unit near Sam's Throne in southeast

Newton County, Arkansas. Lonigro's (2008) research focused on describing depositional facies within several middle Bloyd sandstone outcrops within the Sand Gap Quadrangle, Pope County, Arkansas.

Allen (2008) conducted a petrographic analysis of the middle Bloyd sandstone to determine the porosity of the sandstone unit that might apply to the subsurface equivalents in the Arkoma Basin. He also conducted modal analysis of nine middle Bloyd sandstone thin sections to document its composition. He characterized the sandstone as a medium-grained sublitharenite. Monocrystalline quartz represented the main constituent of the sandstone. Metamorphic rock fragments and polycrystalline quartz were also common in his samples (Allen, 2008). Allen also speculated on the provenance of the unit based upon his analysis of the grain constituents. He noted that metamorphic rock fragments (MRFs) were present in the middle Bloyd sandstone, an anomaly in the lower Pennsylvanian section of northern Arkansas. He concluded that the Appalachians must have been a source for the MRF-bearing sediment, due to the lack of a metamorphic source terrane in the midcontinent. This sediment was sourced by depositional connectivity to the Eastern Illinois Basin during the Morrowan (Allen, 2008). In addition, he also concluded that a large river system must have been present to transport this sediment to northern Arkansas as suggested by Archer and Greb (1995).

Early Pennsylvanian Sediment Transport of the Central U.S. (Archer and Greb, 1995)

Archer and Greb (1995) set about the task of comparing Morrowan age conglomeratic sandstones in the central North American craton in an effort to explain a regional sediment transportation system and to identify the factors that affected the system. The authors noted the presence of conglomeratic sandstones in the Central Appalachian Basin, the Illinois Basin (Eastern Interior Basin) with downdip contemporaneous deposition of such sandstones in northern Arkansas, and the Hugoton Embayment. The Illinois Basin was depositionally connected to northern Arkansas during the early Pennsylvanian, although they are now structurally isolated (Archer and Greb, 1995). The large-scale river system they describe in their study is an important factor in relating how the sediment identified in the middle Bloyd sandstone was transported from potential source areas to northern Arkansas (Figure 1). The authors also note that the coarse grain sizes identified in the sandstones are indicative of deposition in large-scale river systems during a lowstand system tract in the Morrowan time, also consistent with the system during which the middle Bloyd sandstone was deposited.

The Illinois Basin contains several incised paleovalleys which commonly exhibit valley-fill sequences that are dominated by crossbedded orthoquartzites and quartz-pebble conglomerates and record south-southwest paleocurrents in a fluvial system (Archer and Greb, 1995). The composition of the valley-fill sequences in the Illinois Basin is similar to the composition of the middle Bloyd sandstone.

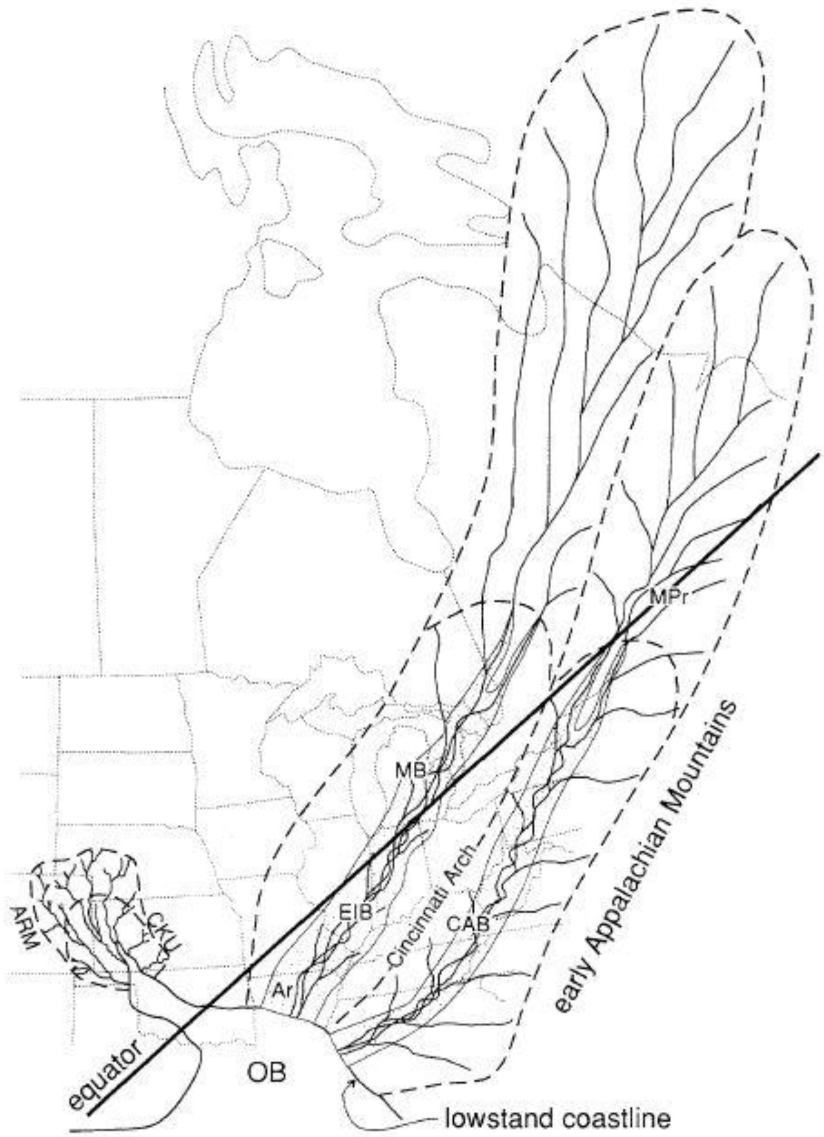


Figure 1. Large-scale sediment transport system of the Morrowan sandstones. Ar-Bloyd sandstone, ARM-Ancestral Rocky Mountains, CAB-Central Appalachian Basin, CKU-Central Kansas Uplift, EIB- Eastern Interior Basin (Illinois Basin), MB-Michigan Basin, MPr-Maritime Provinces of Canada, and OB-Ouachita Basin (Archer and Greb, 1995).

Paleogeographic constraint was one of the factors that were considered by Archer and Greb (1995), when trying to identify the drainage basins of the large river systems. The areas they studied were all situated near the equator during the Morrowan. This makes the climate a possible important factor in the nature of the river system. Archer and Greb (1995) constructed paleodrainage basins for the river systems based upon the paleogeography during the Morrowan. They then compared the estimated basins to the drainage basins of several modern analogs such as the Amazon, Ganges, and the Orinoco rivers. Several modern rivers exhibited a relationship that was roughly linear in nature, allowing the authors to estimate the discharge of the ancient system by comparison to the modern analogs.

Several factors were explored as controls on sedimentation in the large fluvial system. They included eustatic changes, tectonic activity, and climatic factors. After exploring these factors, Archer and Greb (1995) concluded that the conglomeritic sandstones were deposited in large, tropical rivers during lowstand conditions. The largest rivers flowing through the basins were similar in scale to the modern Ganges, Orinoco, and Amazon rivers (Archer and Greb, 1995). There is a strong similarity of the nature of the sandstones identified in the Illinois Basin and the middle Bloyd sandstone. Paleocurrent data suggests a south-southwest flow, and depositional connectivity between the Illinois Basin and northern Arkansas during the Early Pennsylvanian is determined to have existed. These aspects combine to indicate that the large-scale river system of the Early Pennsylvanian, as presented by Archer and Greb (1995), was important for the transportation of at least a portion of the middle Bloyd sandstone's sediment. Archer and Greb's (1995) proposal of a connected large scale river system is likely an important contribution to understanding the sedimentary provenance of the middle Bloyd sandstone.

C. GEOLOGIC SETTING

Regional Geology

Arkansas can be divided into five geologic provinces: the Ozark Dome, the Arkoma Basin, the Ouachita Mountains, the Mississippi Embayment, and the Gulf Coastal Plain (Manger, Zachry, Garrigan, 1988; Figure 2). The study area for this project is situated upon the Northern Arkansas Structural Platform, which includes the Ozark Dome, the Springfield Plateau, and the Boston Mountains Plateau. This region forms the southernmost portion of the Ozark Dome. This geologic province of Arkansas is characterized by successions of nearly flat-lying strata that range from Cambrian to Pennsylvanian in age. The sedimentary rocks that comprise the succession of strata within this geologic region remain largely undeformed. Continuing south into the Arkoma Basin, deformation and thickness of strata both increase greatly.

The Late Mississippian, Chesterian series of the southern mid-continent region is marked by widespread seas (Johnson, *et al*., 1989). The southern margin of the North American craton at this time was characterized by the broad, gently sloping Arkoma Shelf. During this time, carbonates dominate the Mississippian section with siliciclastics present as confined to maximum flooding and lowstand conditions that persisted as a result of high-order transgression and regression.

The Morrowan Series, Pennsylvanian System, within the southern Ozark region is characterized by two third-order cycles. A regional unconformity marks the base of the Morrowan at the Mississippian-Pennsylvanian boundary. Another unconformity exists at the base of the Dye Shale Member, Bloyd Formation, with a third unconformity found at the top of the Bloyd Formation at the base of the Atoka Formation. Between each of these unconformities, a pattern can be observed which includes a transgressive systems tract, a maximum flooding interval resulting in the deposition of shales, and limestone deposited during highstand and regression. Sea level rise marked the beginning of the Morrowan sequence.

Siliciclastic input onto the tidal shelf at the beginning of the Morrowan is reflected by the Cane Hill Member, Hale Formation. Sea level continued to rise resulting in the deposition of a shoreface sandstone, the Prairie Grove Member, Hale Formation (Manger and Zachry, 2006). Transgression of Pennsylvanian seas across the Arkoma Shelf continued through the deposition of the Brentwood limestone where it reached maximum flooding. A regression of seas occurred, exposing the Brentwood to weathering, and deposition of terrestrial units began as the Woolsey Shale and coeval-homotaxial middle Bloyd sandstone were deposited on the Arkoma Shelf.

The middle Bloyd sandstone lies unconformably on the Brentwood limestone with up to six feet of erosional relief noted in some locations, but its eastern lateral equivalent, the Woolsey Shale Member of the Bloyd Formation, lies conformably above the Brentwood limestone Member (Zachry, 1979). The Woolsey Member is a terrestrial shale unit with a sporadically developed Baldwin Coal. The middle Bloyd sandstone replaces the Woolsey shale towards the east of Washington County, Arkansas. This sandstone unit was emplaced by a large braided stream system on a coastal plain. Following the deposition of these terrestrial units, the Arkoma Shelf is once again subjected to a marine transgression.

The Woolsey and middle Bloyd sandstone are succeeded by a calcareous conglomerate that marks a return to a marine deposition on the Arkoma Shelf (Allen, 2008). This unit is recognized as the “caprock” of the Dye Member, Bloyd Formation. Above the “caprock” of the Dye Member, the unit is composed of black marine shales (Zachry, 1979). Deposition of shallow carbonates comprises the Kessler Limestone that follows the Dye Shale Member. As seas fell once again, carbonate deposition ended, and the top of the Morrowan section is marked by an unconformity, followed by the Atoka Formation.

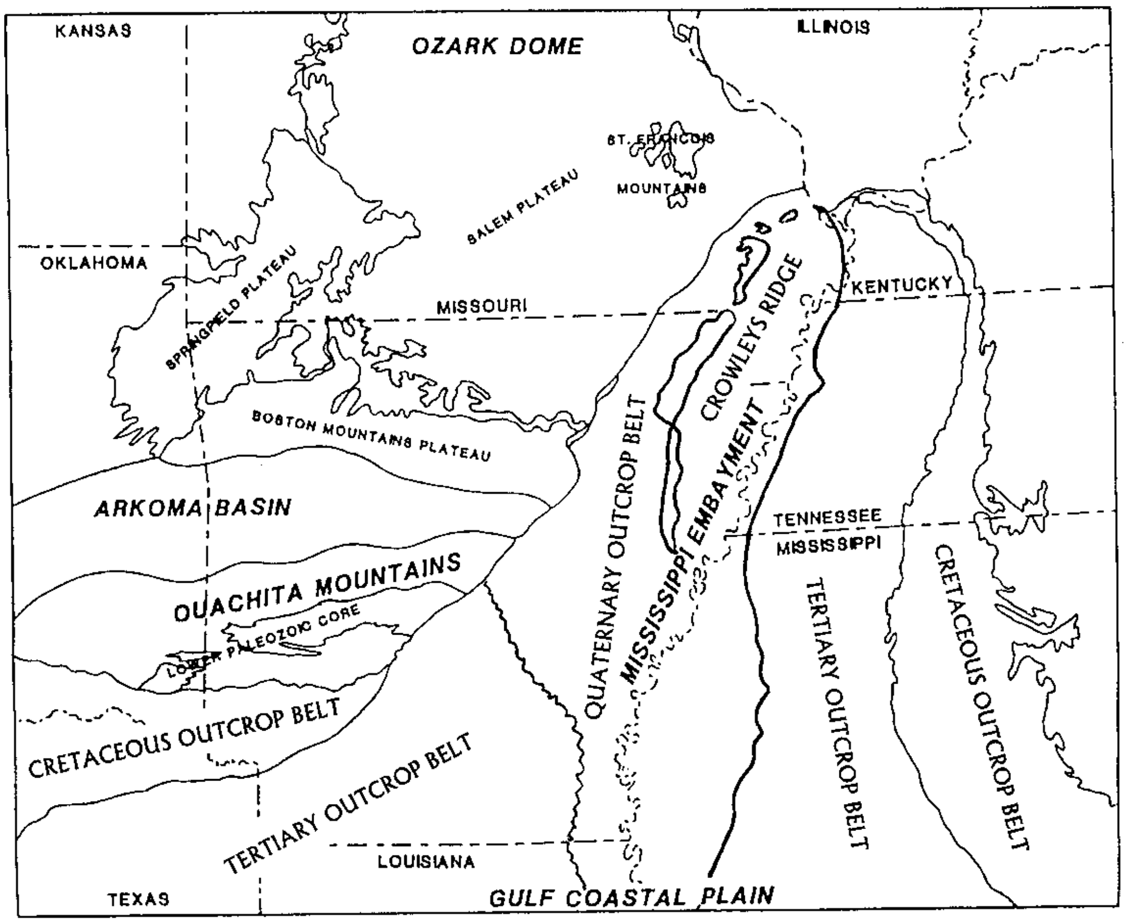


Figure 2. Arkansas structural provinces. (Manger, Zachry, Garrigan, 1988).

A shift from a fluvial dominated system to a tidally dominated system can be noted in the unit as it is traced from north to south. This shift is evidenced by the presence of trough cross-stratification that commonly displays bidirectional forsets to the south within its genetic intervals (Antia-Barrero, 2006). In the subsurface, the middle Bloyd sandstone has been observed as overlying the Brentwood limestone in many locations, just as it is observed at the surface in outcrops (Lonigro, 2008). The unit passes into the subsurface along the northern margin of the Arkoma Basin within the Cass and Mulberry Fault Zones (Zachry, 1979). It is known by drillers in the basin as the Cannon Sand (Pontiff, 2007).The Cannon sand has been recognized in the White Oak gas field in the northwestern portion of the Central Arkoma Basin (Pontiff, 2007).

Study Area

The middle Bloyd sandstone is a major bluff-forming unit that crops out for approximately 100 kilometers, east to west across north-central Arkansas (Dupont, 2008). Its bluffs range from approximately 3 meters up to 35 meters thick (Lonigro, 2008). Figure 3 depicts the middle Bloyd sandstone outcrop belt across northern Arkansas. The study area of focus for this project includes the southern portion of the Ozark Plateau and extends southward into the extreme northern portion of the Arkoma Basin.

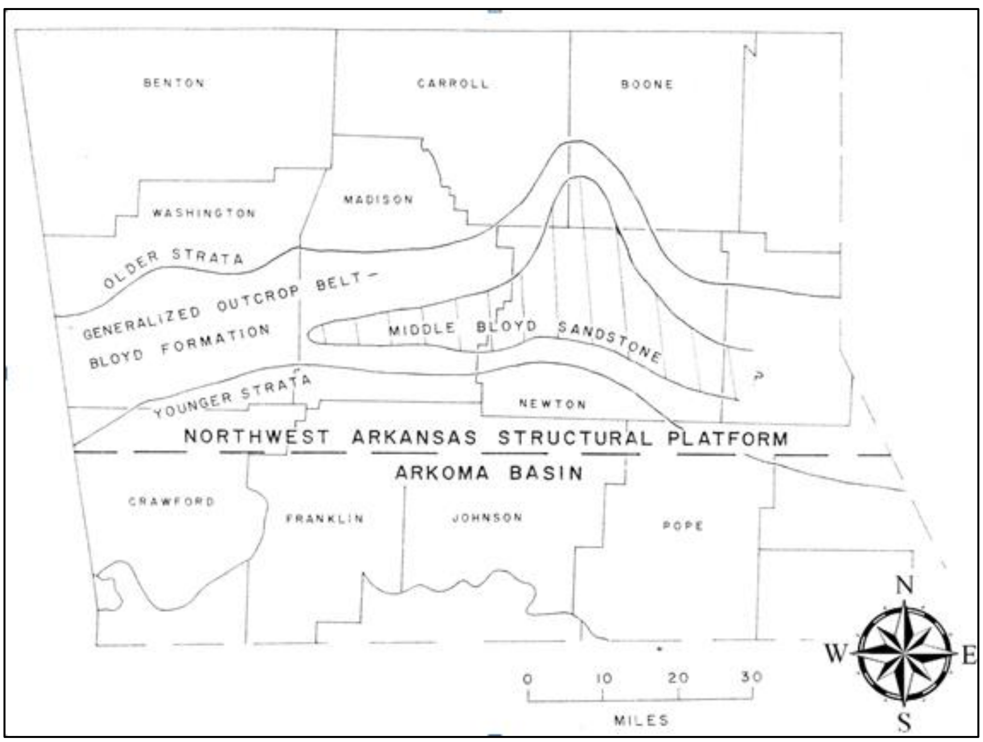


Figure 3. Middle Bloyd Sandstone outcrop extent. (Zachry, 1979).

D. LITHOSTRATIGRAPHY AND DEPOSITIONAL ENVIRONMENT

The Bloyd Formation in northern Arkansas contains four formally named members: the Brentwood Limestone, the Woolsey Shale (the western lateral equivalent of the informal middle Bloyd sandstone), the Dye Shale, and the Kessler Limestone (Figure 4). The Brentwood Limestone Member of the lower Bloyd Formation was deposited during a maximum flooding interval in the early Morrowan. This unit is composed of interbedded limestone, sandstone, siltstone, and shale (Lonigro, 2008). As a regression of seas occurred, both the Woolsey Shale, a terrestrial shale, and its lateral equivalent, the middle Bloyd sandstone were deposited. The Woolsey Shale conformably overlies the Brentwood Limestone to the west. Meanwhile, the middle Bloyd sandstone overlies the Brentwood Limestone to the east where they are separated by an unconformable boundary. A subsequent transgression returned marine conditions, and subsequently the deposition of the Dye Shale Member, a black marine shale (Zachry, 1979). The Kessler Limestone, the final interval prior to the Atoka Formation, was deposited above the Dye Shale Member and concluded the Bloyd and Morrowan deposition.

The middle Bloyd sandstone commonly displays a succession of bedforms that are indicative of deposition within a braided stream system (Zachry, 1979). The succession of bedforms suggests repeated periods of reduction in current competency, each separated at the base by an erosional surface. A genetic succession of bedforms is commonly repeated several times within a single vertical section of the middle Bloyd sandstone, and they commonly range from to 3 to 15 feet (Zachry, 1979; Figure 5). An erosional surface with up to a foot of erosional relief bounds the first bedform recognized within the middle Bloyd sandstone succession. Moving upward, a quartz-pebble conglomerate is the first depositional feature to be encountered in the section. Tabular cross-strata follow next in succession. Single or multiple sets of cross-strata may be present. Some locations exhibit forsets that have been overturned (Zachry, 1979). The overturned forsets are likely due to a competent current, carrying a considerable sediment load (Dupont, 2008). Tabular cross-strata are found to be replaced in the genetic sequence by large-scale trough cross-strata in some locations, but this bedform is not as commonly found in the sequence as tabular cross-strata. Small-scale trough cross-stratification overlies trough cross-stratified beds in the succession with ripple-laminated zones on their top surface. Ripple laminations indicate low flow and low current competency within the system (Dupont, 2008). These shale intervals are draped over rippled bedforms. This thin shale interval was deposited during a time of low flow. Often, the shale interval has been truncated by an erosional surface that begins a repetition of the succession of the previously described bedforms.

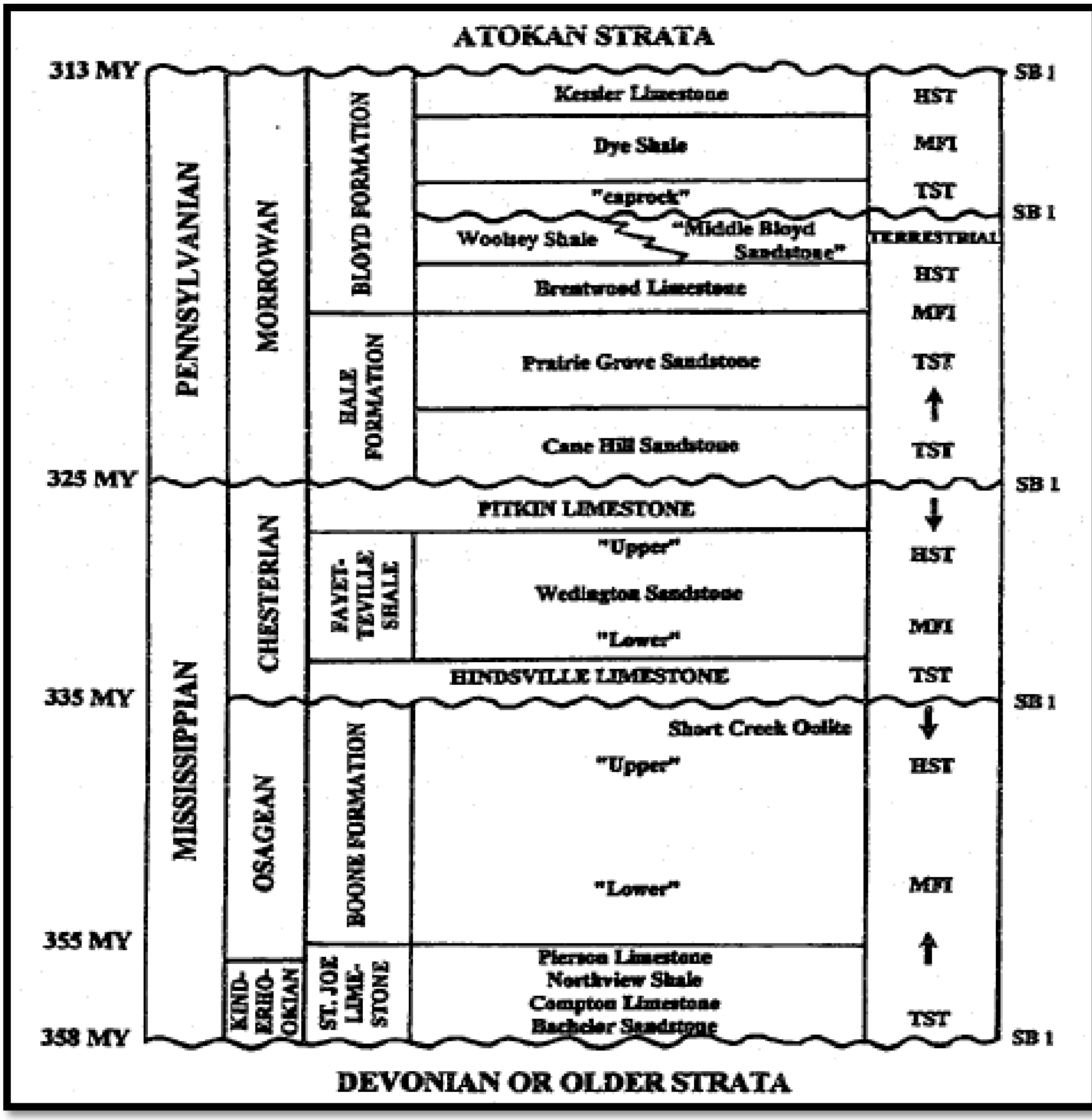


Figure 4. Lithostratigraphy and sequence stratigraphy of the Mississippian and Pennsylvanian strata of Northwest Arkansas. (Manger and Zachry, 1998)

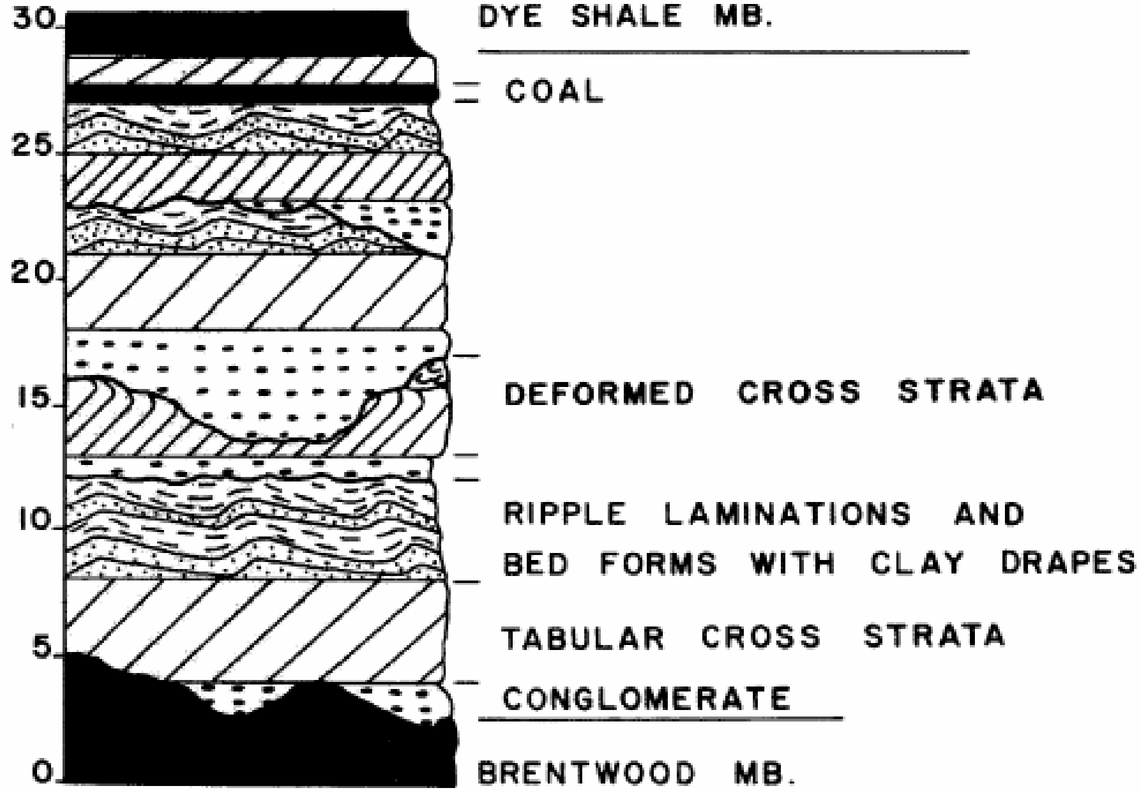


Figure 5. Genetic sequence of bedforms within the middle Bloyd sandstone from (Zachry, 1979).

Several previous studies of the middle Bloyd sandstone have measured and recorded abundant paleocurrent data from various outcrop locations across northern Arkansas. They are in agreement that the sandstone unit was deposited as part of a southwesterly-flowing system (Glenn, 1973; Berry, 1978; Zachry, 1979; Crowder, 1982; Antia-Barrero; 2006). Berry (1978) conducted paleocurrent measurements of several outcrop locations of the sandstone unit. His analysis of 255 measurements resulted in a vector mean of 211.8° with a vector magnitude of 63.5%. Crowder (1982) also conducted a paleocurrent analysis. His analysis utilized data gathered from outcrops in Washington, Madison, Newton, Searcy, Boone, and Carroll Counties, Arkansas. More than 80% of the vector means calculated by Crowder (1982) are oriented towards the southwest (Figure 6). The pattern of repeated sequences in conjunction with paleocurrent data shows a low dispersal pattern. This suggests that the middle Bloyd sandstone was deposited within a braided stream system on a near-strand coastal plain (Zachry, 1979).

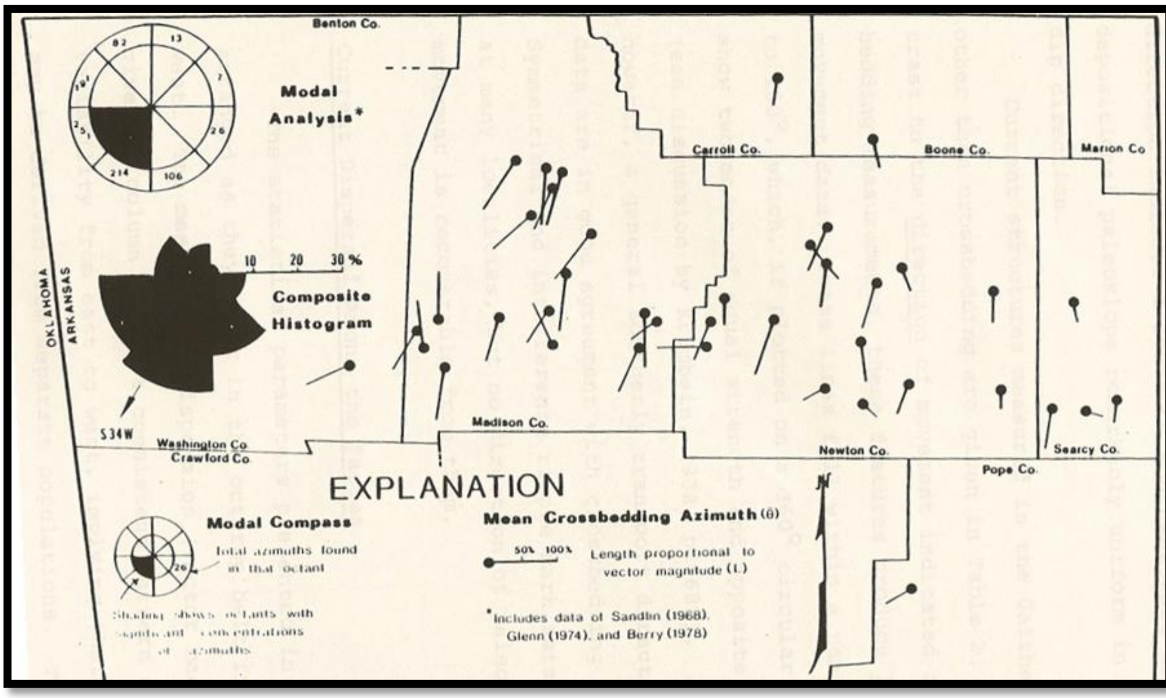


Figure 6. Paleocurrent measurements along the middle Bloyd sandstone outcrop belt in Washington, Madison, Newton, Searcy, Boone, and Carroll Counties, Arkansas. Map includes data from Sandlin, 1968, Glenn, 1973, and Berry, 1978. (Crowder, 1982).

II. PROJECT APPROACH AND METHODS

A. U-PB DETRITAL ZIRCON GEOCHRONOLOGY

Detrital zircon geochronology has become a common tool in the determination of sandstone provenance (Thomas, 2011a). Although petrography and the subsequent use of ternary diagrams are useful tools in provenance studies, zircon geochronology has added precision to the study of sandstone provenance. Zircons are highly resistant to weathering, so they are commonly subjected to multiple cycles of erosion and deposition throughout their history between their points of origin and their final site of deposition. Due to the longevity of zircons, many different ages may be represented within a sampling of zircon grains. The representation of all ages of grains within the sampling is important to fully characterize the provenance of the unit. Laser-ablation-inductively-coupled-mass-spectrometry (LA-ICP-MS), which is the analytical method used in this project, is a method that has allowed large numbers of grains to be analyzed from a sample with relative ease. This method utilizes large numbers of grains from a single sample analyzed to obtain the ages of grains represented within a sample. Caution must be taken while conducting the analyses as metamorphism may create growth rims on the grains of a younger age than the zircon grain core. U-Pb analysis was the particular method used for the determination of ages for this project. This allows the ages of grains obtained by LA-ICP-MS to be matched to the ages of crystallization of source terrains. This, in conjunction with paleogeography, paleocurrent data, stratigraphy, and potential transport pathways, allows for the determination of potential provenance of a sandstone unit (Thomas, 2011a).

B. SAMPLE LOCATION AND COLLECTION

Eight samples of the middle Bloyd sandstone unit were taken from various locations along the outcrop belt. The locations of the eight samples included in this study are depicted in Figure 7, and the coordinates of the outcrops from which samples were taken are given in Table 1. The samples included one outcrop location each in Carroll County and Boone Counties, five in Newton County, and one sample from extreme northern Pope County, Arkansas. Samples were obtained from these locations with the assistance of Dr. Walter Manger, Dr. Xiangyang Xie, and Dr. Doy Zachry, Department of Geosciences, University of Arkansas. Several of these locations were the same as those outcrops that were the focus of middle Bloyd sandstone stratigraphic and petrographic work in past research of the unit (e.g. Antia-Barrero, 2006).

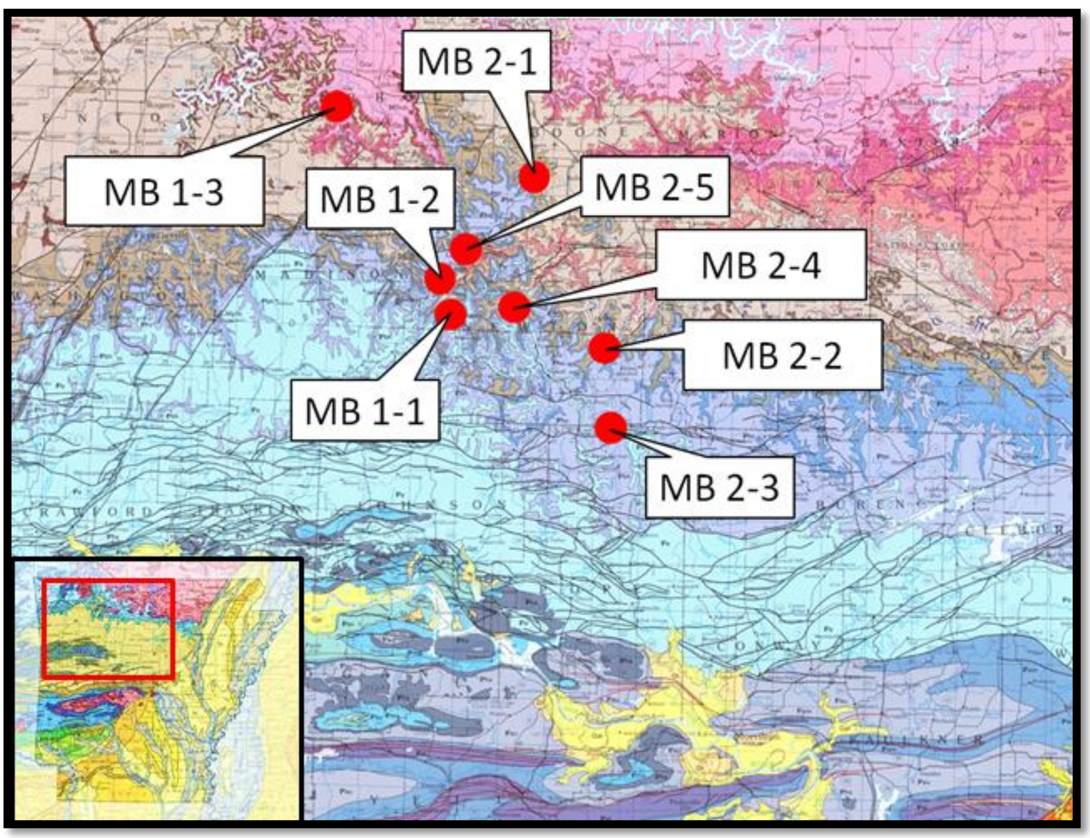


Figure 7: Middle Bloyd sandstone sample locations for this thesis. Modified from Geology of Arkansas map (Haley, *et al.*, 1993).

Sample	Location
MB1-3	N 36°02´0.2´´, W 093°40´20.6´´
MB2-4	N 35°56´28.0´´, W 093°15´20.8´´
MB2-2	N 35°52´31.3´´, W 093°02´44.6´´
MB2-3	N 35°43´26.5´´, W 093°01´29.6´´
MB2-5	N 36°03´17.0´´, W 093°21´31.7´´
MB2-1	N 36°10´40.2´´, W 093°12´25.7´´
MB1-2	N 35°59´49.1´´, W 093°25´15.8´´
MB1-1	N 35°55´41.9´´, W 093°23´23.6´´

Table 1: Coordinate locations of middle Bloyd sandstone outcrop samples

C. SAMPLE PREPARATION

The eight collected middle Bloyd sandstone samples were brought back to the University of Arkansas at Fayetteville, where they were prepared for analysis. Zircon grains had to be separated from the sandstone samples. This process began with crushing the samples by using a disc mill. Crushed samples were then taken to the University of Arkansas at Little Rock for further mineral separation. Crushed samples were then processed further on a Wilfley Table to separate the denser minerals, including zircon grains, from less dense minerals. The sediment collected from the Wilfley Table was then dried. The dried sediment was passed through a Frantz-LB-1 magnetic separator. This allowed the removal of magnetic minerals that were separated with zircons on the Wilfley Table as well as metallic shavings from crushing in the disc mill. Heavy liquid, Methylene Iodide ($\rho > 3.3 g/cm^3$), was then used to separate zircons and other dense minerals from the remaining sediment. The resulting sediment was then transported back to the University of Arkansas at Fayetteville, where the final stage of separation was performed. Zircon grains were picked by hand from the remaining sediment in alcohol under a binocular microscope. Zircon grains were selected without bias for their physical properties (e.g.

size, shape, roundness, or color) in order to avoid the exclusion of any of the multiple age populations of grains that may be represented in each of the samples.

The zircon grains that had been separated under microscope were removed from their petri dishes and placed in sealable containers. They were then allowed to dry prior to transport. The zircon grains were then taken to the Geoanalytical Laboratory at Washington State University, Pullman, for the grain analysis. The grains from each sample were mounted in epoxy within one inch diameter plastic rings, a *puck*. Space was left within each puck for epoxy rods containing standard samples to be inserted for each analysis. After the epoxy cured, the surface containing the zircon grains was polished to prepare it for analysis.

The pucks were taken to the University of Idaho, Moscow Idaho, for imaging. Each of the pucks was coated with carbon so that they could be imaged using Cathodoluminescence. Images of all the grains were made in order to have a map of the grain locations on each of the pucks. In addition, the images allowed examination of the internal structure of each of the grains. This allowed selection of the spot on each grain for analysis to avoid growth rims and concentrate on the core of the grains. Examples of mounted zircon grains are given in Figure 8 as a Cathodoluminescence Image. The pucks were polished again before the analyses to remove the carbon film from the imaging process.

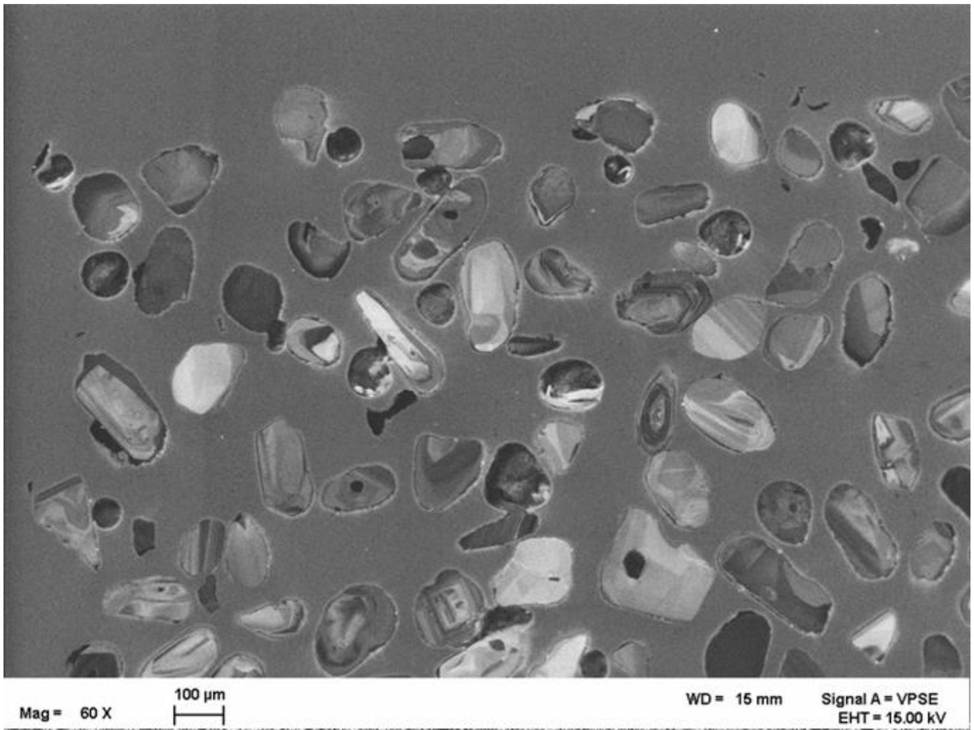


Figure 8. Cathodoluminescence Image of mounted middle Bloyd sandstone zircon grains.

D. Sample Analysis

Analysis of the zircon grains was conducted at the Geoanalytical Laboratory at Washington State University. Washington State University's New Wave^{TM} UP-213 Laser Ablation System coupled with the Thermo Finnigan Element 2^{TM} single collector double focusing magnetic sector inductively coupled mass spectrometer were used to perform laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) on the zircon grains.

Prior to analysis of the detrital zircon grains, PEIXE and FC-1 standards were analyzed to assure that the LA-ICP-MS had been calibrated and would provide consistent results. Standards were also run between every 10-15 zircon grains to assure that the sampling remained consistent as well as to provide necessary values to calculate fractionation factors for data reduction. Standards, known as FC1 and Peixe, were analyzed in order to ensure that the variability in

$^{206}Pb/^{238}U$ and $^{207}Pb/^{206}Pb$ ratio remained near ±2% throughout the analyses (Xie and Heller, 2013). In order to provide greater assurance of consistent results, the machines were run constantly, and the analysis of all zircon grains was conducted constantly until all were completed. A minimum of 125 grains were analyzed for each middle Bloyd sandstone sample. The total number of grains analyzed was 1070. At the very least, 59 zircon grains must be analyzed to reduce the probability of missing an age population within a sample to <5% (Fedo *et al*., 2003). According to Vermeesch (2004), at least 117 grains must be analyzed from each sample to have a 95% confidence that all grain age populations representing >5% of the total grains would be included in the analysis (Vermeesch, 2004).

E. Data Reduction

Data reduction began by removing all outliers beyond a 98% confidence interval (Chang *et al*., 2006). Once data from the analysis of each grain was cleaned, fractionation factors calculated from the standards were applied for the 10-15 zircon grains that they were analyzed between the standard samples. The grain ages with the fractionation factors applied were transported to Excel for further analysis. Once in Excel, diagrams were produced using the Isoplot V3.0 program from Ludwig (2003). The analyses were plotted using standard Concordia diagrams as well as Tera-Wasserburg Concordia diagrams (Appendix B). Grains with ages that exhibited >10% discordance were removed to be exclude from the final interpretation. Grains with ages greater than 1000 Ma utilized the $^{207}Pb/^{206}Pb$ calculated age. Grains with ages less than 1000 Ma utilized the $^{206}Pb/^{238}U$ calculated ages for the final interpretation (Appendix A). Probability-density plots of each sample were created utilizing the Isoplot 3.0 program from Ludwig (2003), as well as programs provided by the Arizona Laserchron Center at the University of Arizona (http://www.laserchron.com) (Appendix C).

III. RESULTS AND INTERPRETATIONS

A total of 1070 zircon grains were analyzed from eight outcrops of middle Bloyd sandstone in northern Arkansas. Analyses that exhibited greater than ten percent discordance were culled. This resulted in 855 zircon analyses to be used in the determination of middle Bloyd sandstone provenance. The sandstone samples used for zircon analysis were taken near the base of the unit at each location. This ensured that the sand was emplaced in a fluvial environment without any effect from marine processes that may be present in the upper section of the middle Bloyd sandstone during the return of a transgressive system tract. Samples were analyzed using LA-ICP-MS, and the data were plotted in probability density plots using Ludwig's IsoPlot 3.0, allowing the data to be interpreted (Ludwig, 2003). Probability density plotting software from Arizona LaserChron center was also used. The resulting graph is shown in Figure 14. Individual sample results are discussed below.

A. SAMPLE MB 1-1

This sample was collected from a middle Bloyd sandstone outcrop in Newton County, Arkansas (N 35°55´41.9´´, W 093°23´23.6´´) along Highway 21, south of the Buffalo River (Figure 9). A total number of 135 zircon grains were analyzed for this sample. After cleaning this sample and removing grains with approximately >10% discordance, a total number of 111 grains from this sample were selected for the final interpretation. Sample MB 1-1 exhibited a minimum age of 396.5 Ma and a maximum age of 3034.8 Ma. Approximately 6.3% of grains fall in the 350-500 Ma range, 0.9% in the 501-700 Ma range, 56.8% within the 900-1200 Ma range, 10.8% within the 1300-1500 Ma range, 9.0% within the 1600-1800 Ma range, 3.6% within the 1800-

2300 Ma range, and 12.6% >2500 Ma. Results for this sample, as well as the following samples can be seen in Table 2.

Figure 9. Roadcut along Highway 21, south of the Buffalo River showing Outcrop MB 1-1. Lower contact with underlying Brentwood Limestone is shown. Photograph by Greg Buratowski, February 14, 2014.

B. SAMPLE MB 1-2

This sample was collected from a middle Bloyd sandstone outcrop in Newton County, Arkansas (N 35°59´49.1´´, W 093°25´15.8´´) along Highway 21, south of Kingston, Arkansas (Figure 10). A total number of 135 grains were analyzed for this sample. After cleaning this sample and removing grains with approximately >10% discordance, a total number of 107 grains from this sample were selected for the final interpretation. Sample MB 1-2 exhibited a minimum grain age of 434.4 Ma and a maximum age of 2874.3 Ma. Approximately 3.7% of grains fall in the 350-500 Ma range, no grains fall within the 501-700 Ma range, 51.4% within the 900-1200 Ma range, 19.6% within the 1300-1500 Ma range, 12.1% within the 1600-1800 Ma range, 5.6% within the 1800-2300 Ma range, and 7.5% >2500 Ma (Table 2).

Figure 10. Roadcut along Highway 21, south of the Kingston, Arkansas, showing Outcrop MB 1-2. Lower contact with underlying Brentwood Limestone can be seen. Photograph by Greg Buratowski, February 14, 2014.

C. SAMPLE MB 1-3

This sample was collected from a middle Bloyd Sandstone outcrop in Carroll County, Arkansas (N 36°02´0.2´´, W 093°40´20.6´´), south of Huntsville Arkansas. A total number of 125 grains were analyzed from this sample. After cleaning this sample and removing grains with approximately >10% discordance, a total number of 112 grains from this sample were selected for the final interpretation. Sample MB 1-3 exhibited a minimum grain age of 421.9 Ma and a maximum age of 2886.6 Ma. Approximately 2.7% of grains fall in the 350-500 Ma range, 2.7% within the 501-700 Ma range, 48.2% within the 900-1200 Ma range, 14.3% within the 1300-1500 Ma range, 15.2% within the 1600-1800 Ma range, 4.5% within the 1800-2300 Ma range, and 12.5% >2500 Ma (Table 2).

D. SAMPLE MB 2-1

This sample was collected from a middle Bloyd sandstone outcrop in Boone County, Arkansas at Gaither Mountain (N 36°10´40.2´´, W 093°12´25.7´´). This bluff (Figure 11) is an exposure of the full thickness of the middle Bloyd sandstone. A distinct change in bedding characteristics at this location is indicative of a change from terrestrial low stand to a transgressive systems tract at the top of the unit during the deposition of the sandstone body. A total number of 135 grains were analyzed from this sample. After cleaning this sample and removing grains with approximately >10% discordance, a total number of 109 grains from this sample were selected for the final interpretation. Sample MB 2-1 exhibited a minimum grain age of 373.9 Ma and a maximum age of 2789.7 Ma. Approximately 4.6% of grains fall in the 350-500 Ma range, 0.9% within the 501-700 Ma range, 55.0% within the 900-1200 Ma range, 22.0% within the 1300-1500 Ma range, 11.9% within the 1600-1800 Ma range, 0.9% within the 1800-2300 Ma range, and 4.6% >2500 Ma (Table 2).

Figure 11. Roadcut at Gaither Mountain from which outcrop MB 2-1 samples were taken. The full thickness of the middle Bloyd sandstone is exposed here. Photograph by Greg Buratowski, February 14, 2014.

E. SAMPLE MB 2-2

This sample was collected from a middle Bloyd sandstone outcrop in Newton County, Arkansas at Mount Judea (N 35°52´31.3´´, W 093°02´44.6´´) (Figure 12). A total number of 130 zircon grains were analyzed for this sample. After cleaning this sample and removing grains with approximately >10% discordance, a total number of 99 grains from this sample were selected for the final interpretation. Sample MB 2-2 exhibited a minimum age of 393.9 Ma and a maximum age of 3145.6 Ma. Approximately 2.0% of grains fall in the 350-500 Ma range, 1.0% in the 501-700 Ma range, 54.5% within the 900-1200 Ma range, 11.0% within the 1300-1500 Ma range, 17.2% within the 1600-1800 Ma range, 4.0% within the 1800-2300 Ma range, and 10.1% >2500 Ma (Table 2).

Figure 12. Bluff (in the distance) formed by middle Bloyd sandstone along Highway 123, south of Mount Judea, Arkansas. MB 2-2 outcrop samples were taken from this location. Photograph by Greg Buratowski, February 14, 2014.

F. SAMPLE MB 2-3

This sample was collected from a middle Bloyd sandstone outcrop in Newton County, Arkansas at Kings Bluff (N 35°43´26.5´´, W 093°01´29.6´´). A total number of 135 zircon grains were analyzed for this sample. After cleaning this sample and removing grains with approximately >10% discordance, a total number of 101 grains from this sample were selected for the final interpretation. Sample MB 2-3 exhibited a minimum age of 360.1Ma and a maximum age of 2996.4 Ma. Approximately 5.9% of grains fall in the 350-500 Ma range, no grains within the 501-700 Ma range, 38.6% within the 900-1200 Ma range, 16.8% within the 1300-1500 Ma range, 18.8% within the 1600-1800 Ma range, 8.9% within the 1800-2300 Ma range, and 9.4% >2500 Ma (Table 2).

G. SAMPLE MB 2-4

This sample was collected from a middle Bloyd sandstone outcrop in Newton County, Arkansas at Parthenon (N 35°56´28.0´´, W 093°15´20.8´´) (Figure 13). A total number of 130 zircon grains were analyzed for this sample. After cleaning this sample and removing grains with approximately >10% discordance, a total number of 106 grains from this sample were selected for the final interpretation. Sample MB 2-4 exhibited a minimum age of 428.1Ma and a maximum age of 2856.1Ma. Approximately 4.7% of grains fall in the 350-500 Ma range, 0.9% in the 501-700 Ma range, 50.9% within the 900-1200 Ma range, 15.1% within the 1300-1500 Ma range, 13.2% within the 1600-1800 Ma range, 5.7% within the 1800-2300 Ma range, and 9.4% >2500 Ma (Table 2).

Figure 13. Roadcut along Highway 387, south of Parthenon, Arkansas. MB 2-4 outcrop samples were taken from the outcrop shown above. Photograph by Greg Buratowski, February 14, 2014.

H. SAMPLE MB 2-5

This sample was collected from a middle Bloyd sandstone outcrop in Newton County, Arkansas at Ponca (N 36°03´17.0´´, W 093°21´31.7´´). A total number of 145 zircon grains were analyzed for this sample. After cleaning this sample and removing grains with approximately >10% discordance, a total number of 110 grains from this sample were selected for the final interpretation. Sample MB 2-5 exhibited a minimum age of 384.1 Ma and a maximum age of 2807.5 Ma. Approximately 4.7% of grains fall in the 350-500 Ma range, 1.9% in the 501-700 Ma range, 51.9% within the 900-1200 Ma range, 12.3% within the 1300-1500 Ma range, 17.9% within the 1600-1800 Ma range, 3.8% within the 1800-2300 Ma range, and 11.3% >2500 Ma (Table 2).

Number of Grains								
		Acadian-Taconic	Iapetan Synrift	Grenville	Midcontinent	Yavapai-Mazatzal	Paleoproterozoic	Archean
Sample	Total #	350 - 500	(500-760)	(900-1200)	(1300-1500)	1600-1800	1.8-2.3 Ga	>2.5 Ga
MB 1-1	111	7	1	63	12	10	4	14
MB 1-2	107	4	0	55	21	13	6	8
MB 1-3	112	3	3	54	16	17	5	14
MB 2-1	109	5	1	60	24	13	1	5
MB 2-2	99	2	1	54	11	17	4	10
MB 2-3	101	6	0	39	17	19	9	11
MB 2-4	106	5	1	54	16	14	6	10
MB 2-5	110	5	2	55	13	19	4	12
Percentage								
		Acadian-Taconic	Iapetan Synrift	Grenville	Midcontinent	Yavapai-Mazatzal	Paleoproterozoic	Archean
Sample	Total #	350 - 500	(500-760)	(900-1200)	(1300-1500)	1600-1800	1.8-2.3 Ga	>2.5 Ga
MB 1-1	111	6.3	0.9	56.8	10.8	9.0	3.6	12.6
MB 1-2	107	3.7	0.0	51.4	19.6	12.1	5.6	7.5
MB 1-3	112	2.7	2.7	48.2	14.3	15.2	4.5	12.5
MB 2-1	109	4.6	0.9	55.0	22.0	11.9	0.9	4.6
MB 2-2	99	2.0	1.0	54.5	11.1	17.2	4.0	10.1
MB 2-3	101	5.9	0.0	38.6	16.8	18.8	8.9	10.9
MB 2-4	106	4.7	0.9	50.9	15.1	13.2	5.7	9.4
MB 2-5	110	4.5	1.8	50.0	11.8	17.3	3.6	10.9

Table 2. Middle Bloyd sandstone zircon grain age distribution. Number of grains per sample and percentage of grains per sample for associated terrain ages.

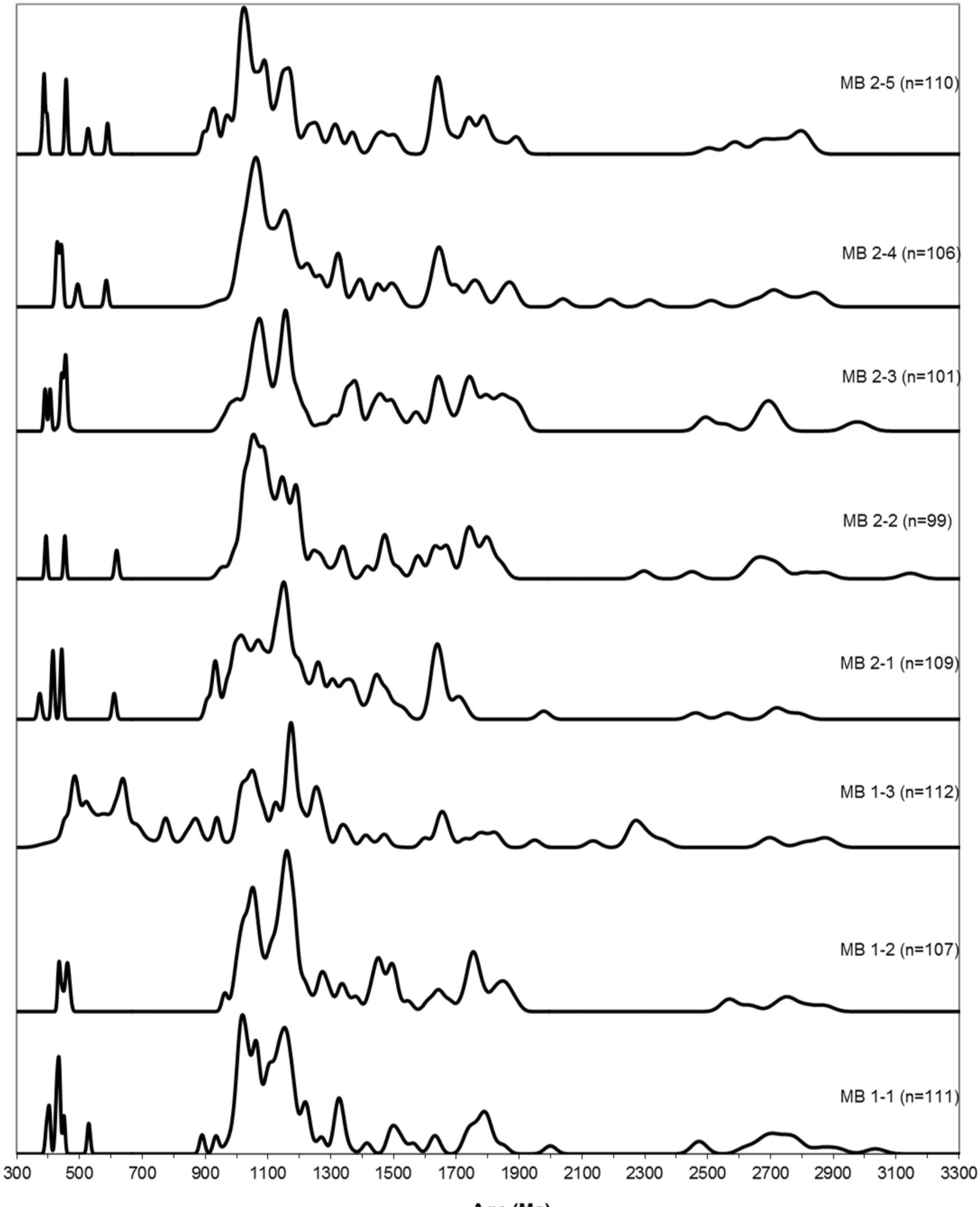


Figure 14. Probability density plots for detrital zircons analyzed for each middle Bloyd sandstone sample. Plot constructed using software available from the Arizona Laserchron Center Website (http://www.laserchron.org).

IV. POTENTIAL SOURCE TERRANES

The North American Craton has been assembled over billions of years. This process began with the assembly of the core of the North American in the Paleoproterozoic (2.0-1.8 Ga), when the Archean subcontinents of Slave and Rae-Hearne, and later the Superior subcontinent, collided and became a single continental mass (Whitmeyer and Karlstrom, 2007). Juvenile arc terranes and continental masses continued to collide with the North American craton over the next several hundred million years. Major episodes of collision in the southern to eastern portion of Laurentia included the Mojave Province, Yavapai Province, Mazatzal Province, Midcontinent Granite-Rhyolite Province, Grenville Orogeny, and the assembly of Rodinia which included the Acadian and Taconic Orogenies. The result is a mosaic of accreted terrains composed of Archean crustal provinces, juvenile volcanic arcs, and oceanic terranes. All the while, intracratonic magmatism was ongoing in the interior of the craton, adding additional crustal material (Whitmeyer and Karlstrom, 2007). All of the terranes found within the crustal mosaic of the North American craton contain rocks within a specific age range. Through the analysis of detrital zircon grains, an absolute age was found for each grain. This allows for the comparison of the ages found through analysis with the known and well-documented ages of potential source terranes on the North American craton. Linking the detrital zircon ages with the ages of potential source terranes allows a provenance for the middle Bloyd sandstone to be determined. Although it is possible that sediment was sourced from another continent during collision, paleocurrent data measured by previous researchers suggests that sediment originated from the north and northeast (Zachry, 1979; Antia-Barrero, 2006).

A. ARCHEAN CRUSTAL ROCKS (>2.5 GA)

All middle Bloyd sandstone samples analyzed contained detrital zircon grains that had ages over 2500 Ma. Most samples contained approximately 10% grains that were >2.5 Ga with only one sample containing less than 7.5% (contained 4.6%) grains with age >2.5 Ga and one sample composed of 12.6% of those grains. Rocks of an age >2.5 Ga appear to be a substantial source for sediment that composes the middle Bloyd sandstone. Archean basement rocks appear to be the most likely source of sediment >2.5 Ga. These rocks compose the basement rock of the Canadian Shield province. The Canadian Shield was assembled in the Paleoproterozoic between ca. 1.96 to 1.80 Ga by the continental-continental collision of Archean cratonic blocks (Whitmeyer and Karlstrom, 2007). The southernmost portions of the Superior and Wyoming provinces of the Canadian Shield represent the closest source of sediment greater than 2.5 Ga. The southern margins of the Superior and Wyoming provinces are covered by the miogeoclinal packages of the Huronian and Snowy Pass Supergroups that range in age from 2.0-2.5 Ga (Whitmeyer and Karlstrom, 2007).

B. PALEOPROTEROZOIC SOURCE TERRANES (1.8-2.3 GA)

All middle Bloyd sandstone samples analyzed contained grains that fell within the ages of 1.8-2.3 Ga. The number of grains within this age ranged from one grain in sample MB 2-1 to nine grains in sample MB 2-3. Grains of this age are not a major constituent in the middle Bloyd sandstone samples, although, they are represented in all of the samples analyzed. Two entities arise as candidates of possible sediment sources for grains of ages 1.8-2.3 Ga. The Trans-Hudson orogen represents one of these two entities. The Trans-Hudson orogen characterizes the collision and suturing of the Hearne, Wyoming, and Superior cratons with Laurentia ca. 1.8-1.9 Ga.

Associated with the collision were the emplacement of juvenile volcanic arc rocks of the same age that were then amalgamated to the craton (Whitmeyer and Karlstrom, 2007). During the collision, a small fragment of Archean craton, the Sask block, was sandwiched between the Hearne and Superior cratons. The Trans-Hudson orogenic event is analogous to the India-Asia Himalayan collision (Whitmeyer and Karlstrom, 2007). The collision created plentiful uplifted terrane. The uplift created conditions that allowed for abundant sediment to be eroded from the uplifted terranes. Rocks of the Trans-Hudson Orogen were exposed during the Middle to Late Ordovician, allowing erosion to create available sediment (Workman, 2012). In addition to the Trans-Hudson orogen, the Penokean orogen also is a likely source of Paleoproterozoic sediment found in the middle Bloyd sandstone. The Trans-Hudson and the Penokean orogenies are approximately contemporaneous (Whitmeyer and Karlstrom, 2007). The Penokean orogenic belt, which contains Archean and Paleoproterozoic igneous and metasedimentary rocks, extends from central Minnesota northeastward through northern Michigan until it terminates at the Grenville deformation front in northern Ontario, Canada. Rocks within the Penokean orogenic belt show a consistent age of approximately 2.1 Ga. (Whitmeyer and Karlstrom, 2007). Likewise with the Trans-Hudson orogen, the terrane would have experienced uplift associated with the collision of the Penokean orogen.

C. YAVAPAI-MAZATZAL PROVINCES (1.6-1.8 Ga.)

Zircon grains with ages between 1.6-1.8 Ga were a substantial contributor to the total population of grains analyzed for the middle Bloyd sandstone. Grains within this age range contributed between 9.0-18.8% of the grain population of each of the sandstone samples analyzed. The accretion of major island arc terranes occurred between 1.8-1.6 Ga and accounts for the addition of more than 1000 km of juvenile crust to the Wyoming craton during that time period (Shaw and Karlstrom, 1999). Rocks that were accreted to the southern margin of Laurentia during this time period are characterized by two main orogenic events, the Yavapai and the Mazatzal orogenies. The broad zone of accreted crust extends from northern Arizona towards the northeast, where it underlies the mid-continent region. The Yavapai province consists of basement rock composed of juvenile crust of age 1.8-1.7 Ga that was accreted during the Yavapai orogeny that lasted from ca. 1.71-1.68 Ga, and resulted from the collision of a series of island arc systems (Whitmeyer and Karlstrom, 2007). The Mazatzal orogeny followed the Yavapai orogeny. The Jemez lineament is the proposed boundary between the two provinces. The Mazatzal province contains juvenile crust of age 1.7-1.6 Ga that was accreted during the Mazatzal orogeny, which lasted from ca. 1.65-1.60 Ga, and resulted from the collision of several crustal blocks (Whitmeyer and Karlstrom, 2007). The major rock types that are found within the Mazatzal province include 1.68-1.65 Ga volcanic rocks, many of which are volcanogenic greenstones with an ophiolitic origin (Amato *et al*., 2008). These volcanogenic greenstones typically include basalt, basaltic andesite, dacitic tuff, and rhyolite (Whitmeyer and Karlstrom, 2007). The Mazatzal orogeny resulted in the deformation of rocks that extended well into the rocks of the Yavapai province (Amato *et al*., 2008). This deformation allowed for the exhumation and exposure of both Yavapai and Mazatzal basement rocks, making those rocks susceptible to erosion and removal of sediment. The Mazatzal province runs approximately parallel to the Yavapai province, extending northeastward under the mid-continent region and into Canada (Whitmeyer and Karlstrom, 2007).

D. MIDCONTINENT CRUSTAL SOURCE ROCKS (1.3-1.5 GA)

Zircon grains within the age range 1.3-1.5 Ga proved to be an important constituent within the middle Bloyd sandstone samples analyzed. Samples of middle Bloyd sandstone that were analyzed contained a significant amount of grains within this age range, ranging from 10.8-22.0% of the grain populations within the sandstone samples. The most likely source of zircon grains ranging from 1.3-1.5 Ga within the middle Bloyd sandstone samples is the Midcontinent Granite-Rhyolite Province. Following the collision of the Mazatzal terrane and a period of tectonic quiescence from 1.6-1.55, further accretion of juvenile terrane occurred along the southern margin of Laurentia. This crust, named the Granite-Rhyolite Province, ranges in age from 1.55-1.3 Ga and is located adjacent to the Mazatzal crustal rocks (Whitmeyer and Karlstrom, 2007). The Granite-Rhyolite Province underlies a large area of the craton extending from southwest to northeast including northern Arkansas. Much of this basement rock is covered by younger strata, although the rocks of this province do crop out in a few locations. Outcrops of Granite-Rhyolite Province rocks can be found near Spavinaw, Oklahoma in the form of the Spavinaw Granite. In addition, outcrops of this basement rock can also be seen in Missouri as exposures in the St. Francois Mountain (Van Schmus, *et al*., 1986). Rocks of this province are represented as 1.55-1.4 Ga accreted juvenile crust as well as granitic plutons that range in age from 1.48-1.35 Ga in age (Whitmeyer and Karlstrom, 2007).

E. GRENVILLE PROVINCE (900-1300 MA)

Zircon grains within the age range 900-1300 Ma represent that greatest constituent of zircon grains within the middle Bloyd sandstone samples. They comprise between 38.6-56.8% of each of the sandstone samples analyzed with an overall average of approximately 51% of zircon grains among all samples. The source for these grains is interpreted to be from the Grenville Province. The Grenville Province is located to the east in the Appalachian Mountains region. The Grenville orogeny included a set of continent-continent collisions that resulted in the assembly of the supercontinent, Rodinia (Whitmeyer and Karlstrom, 2007). Rocks of this province extend from northern Mexico east and northeastward into northern Canada. The Grenville orogeny is composed of several events. It began with the suturing of the Elzevir and Frontenac blocks to the eastern margin of Laurentia ca. 1.3-1.2 Ga. This event has been coined the Elzevirian orogeny. The next stage lasted from ca. 1.19-1.11 Ga when the craton experienced the intrusion of anorthosite plutons, known as the Shawingian phase. Lastly, the Ottowan orogeny occurred ca 1.09-0.98 Ga and concluded with the final assembly of Rodinia (Whitmeyer and Karlstrom, 2007). Grenville zircons are a common constituent of sandstones throughout Laurentia. Common occurrence of Grenville age grains can be attributed to the high levels of zircons in Grenville rocks, the widespread nature of the Grenville age terranes, and the repeated and prominent uplift that occurred in association with the multiple collisions of the Grenville orogeny (Cains, 2013).

F. IAPETAN SYNRIFT (500-760 MA)

Zircons of ages 500-760 Ma represent the smallest grain constituent of the middle Bloyd sandstone. Only nine grains analyzed were identified from this time period. Although they only constitute a minor portion of the grains, they are present in several of the samples. Grains of this age are interpreted as derived from activity that is related to rifting associated with the breakup of Rodinia. Volcanic activity was ongoing in several locations during this period of rifting. The rifted margin includes the Blue Ridge, Ouachita, and Marathon Rifts. The igneous rocks associated with rifting, however, are not currently exposed due to burial by the Appalachian and Ouachita allochthons and sedimentary cover (Thomas, 2011b).

G. ACADIAN-TACONIC SOURCE TERRANES (350-500 MA)

All middle Bloyd sandstone samples analyzed contained zircon grains of age 350-500 Ma. Zircon grains of this age constituted between 2.0-6.3% of each sample analyzed. Grains within this age group are interpreted to have been derived from terranes that resulted from the Acadian and Taconic orogenies. These terranes extend along the eastern margin of the North American craton. The Taconic orogeny occurred during the Ordovician between ca 465-445 Ma. This orogenic event is interpreted to have resulted from either the collision of an island arc terrane with the eastern margin of North America or the collision of the eastern margin of the North American craton with the western margin of Gondwana (McLennan, *et al*., 2001). The Acadian orogeny took place during the Devonian, ca 400-350 Ma. It is interpreted to be the result of the collision of the microcontinent Avalon with the eastern margin of the North American craton. Volcanism was ongoing from the Taconic orogeny into the Acadian orogeny. This acts to misconstrue the age boundary between the two orogenic events. As a result, they are often grouped as a single event (McLennan, *et al*., 2001).

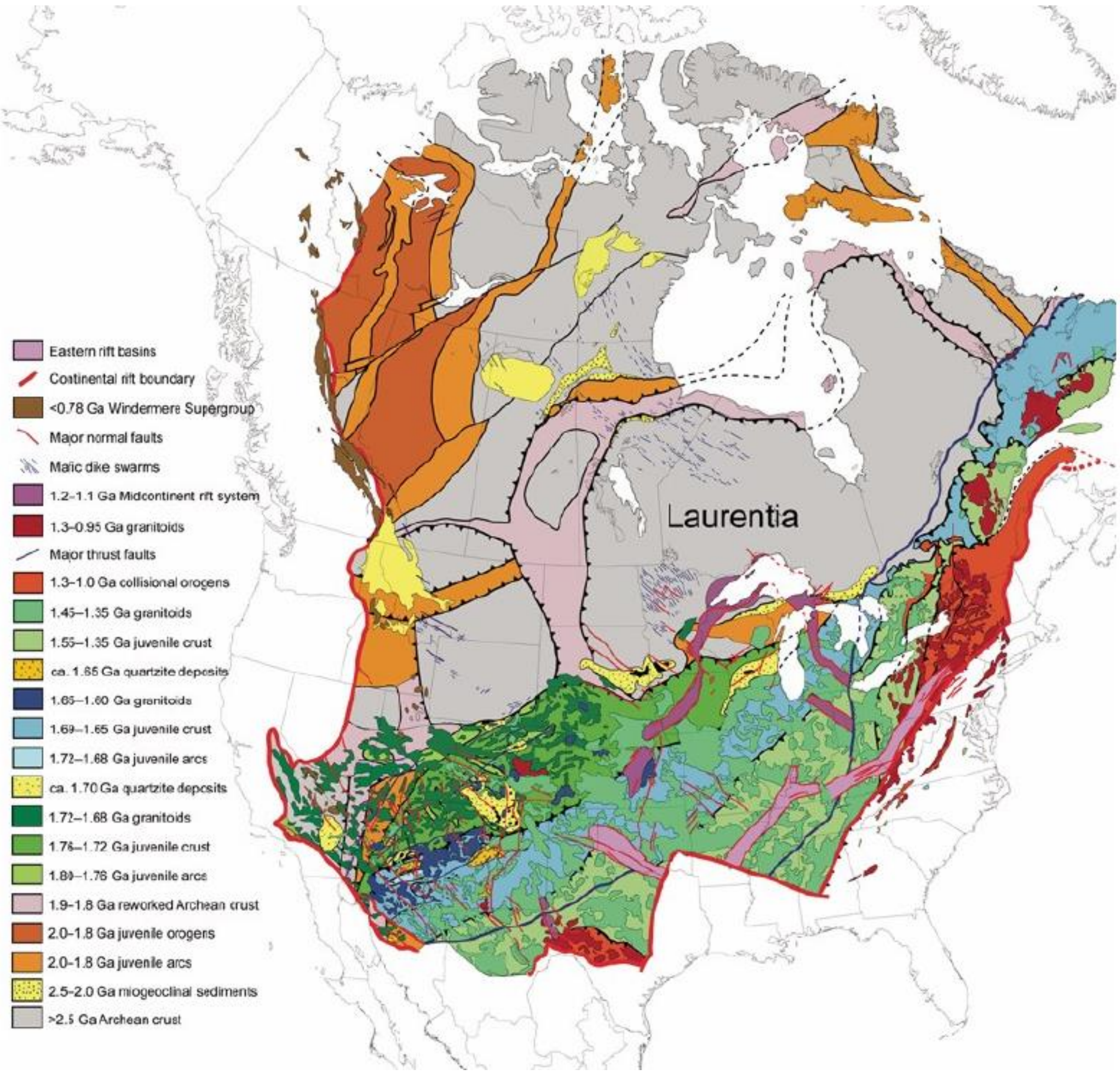


Figure 15. Precambrian Basement Features of the North American Craton (Whitmeyer and Karlstrom, 2007).

DETERMINING PROVENANCE

The difficulty of determining the provenance of a clastic sedimentary rock lies in the fact that many different variables must be considered to form an accurate hypothesis of the origin of the sediment that comprises the sandstone body. When using detrital zircon geochronology for provenance studies, several other factors must also be taken into account. These include petrographic study, a stratigraphic framework, paleogeography, tectonic settings, and transport pathways from source terranes to the location of deposition. The ages of several major Laurentian basement sources are evident in the data obtained through zircon analysis, but they must all fall into the previously mentioned framework to be considered valid source terranes for the middle Bloyd sandstone.

Petrographic data for the middle Bloyd sandstone was obtained from a study of the unit conducted by Allen (2008). In his analysis, he noted that his samples of middle Bloyd sandstone exhibited a bimodal nature. He noted two distinct groups of grain sizes that occurred in three out of seven of his samples with one being larger and more well-rounded and the second being angular and smaller in size. Most of his analyzed samples were well-sorted. In addition, he noted the pervasive presence of metamorphic rock fragments (MRFs), which are anomalous to the lower Pennsylvanian section of northern Arkansas. A terrane with abundant MRFs must be included in the provenance of the middle Bloyd sandstone. Secondly, a population of larger, well-rounded grains was persistent in the samples. These grains were likely from a recycled cratonic source. Feldspars were very rare in the samples analyzed. This is likely due the heavy weathering that they had undergone during transport from their source terrane, likely undergoing multiple cycles of sedimentation. Because of persistent weathering, source terranes that contain feldspar, including crystalline rocks and first cycle sediments, are still included as potential source terranes for sediment within the middle Bloyd sandstone (Cains, 2013). Matrix material is also scarce. This is consistent with the sorting noted for these samples as they are well-sorted in respect to sand sized grains and were deposited as part of a large braided stream system. Chert was also a rarity in the samples analyzed. This is mysterious due to the close proximity of the chert-rich limestones of the Mississippian that cover much of the region.

Utilizing middle Bloyd sandstone data compiled by Allen (2008), a ternary diagram was compiled according to the methods described by Dickinson *et al*. (1983). Using the methods described, a triangular QFL diagram was plotted using the point count data to separate out provenance terranes into continental blocks, magmatic arcs, and recycled orogens (Dickinson *et al*., 1983). The counted point data was separated out among the three vertices according to their classification. The Q vertex contains only monocrystalline quartz of both undulating and straight extinction. The F vertex includes only monocrystalline feldspar. Lastly, the L vertex contained lithics, which includes polycrystalline quartz, MRFs, and chert. Nine middle Bloyd sandstone samples were plotted on the QFL diagram. Two of the nine samples plotted fell within the classification of a craton interior source. The other seven samples plotted within a recycled orogenic source. Eight of the nine samples plotted as sublitharenites, while one sample plotted as a litharenite. Very little feldspar was identified in each of the samples (ranging from 0-2.0% of the constituents). As a result, all of the samples fall closely to the Quartz-Lithics axis. Monocrystalline quartz dominated the samples ranging from approximately 80% to 91% of each of the samples. Point count data from Allen (2008) is shown in Table 3. A provenance triangle was plotted using this data and is shown in Figure 16.

Sample Number (Allen, 2010)	Quartz	Lithics	Feldspar
1-5	82.1	15.8	2.1
1-32	85.2	13.9	0.9
1-39	86.5	12.7	0.8
1-ϕ2	90.9	9.1	0
1-71.5	68.4	31.6	0
1-72	88.7	10.9	0.4
2-13	85.8	14.2	0
2-23	90.7	9.3	0
ST-3	79.5	20.5	0

Table 3. Normalized data for plot in figure 16. Numbers in percentage (Allen, 2008).

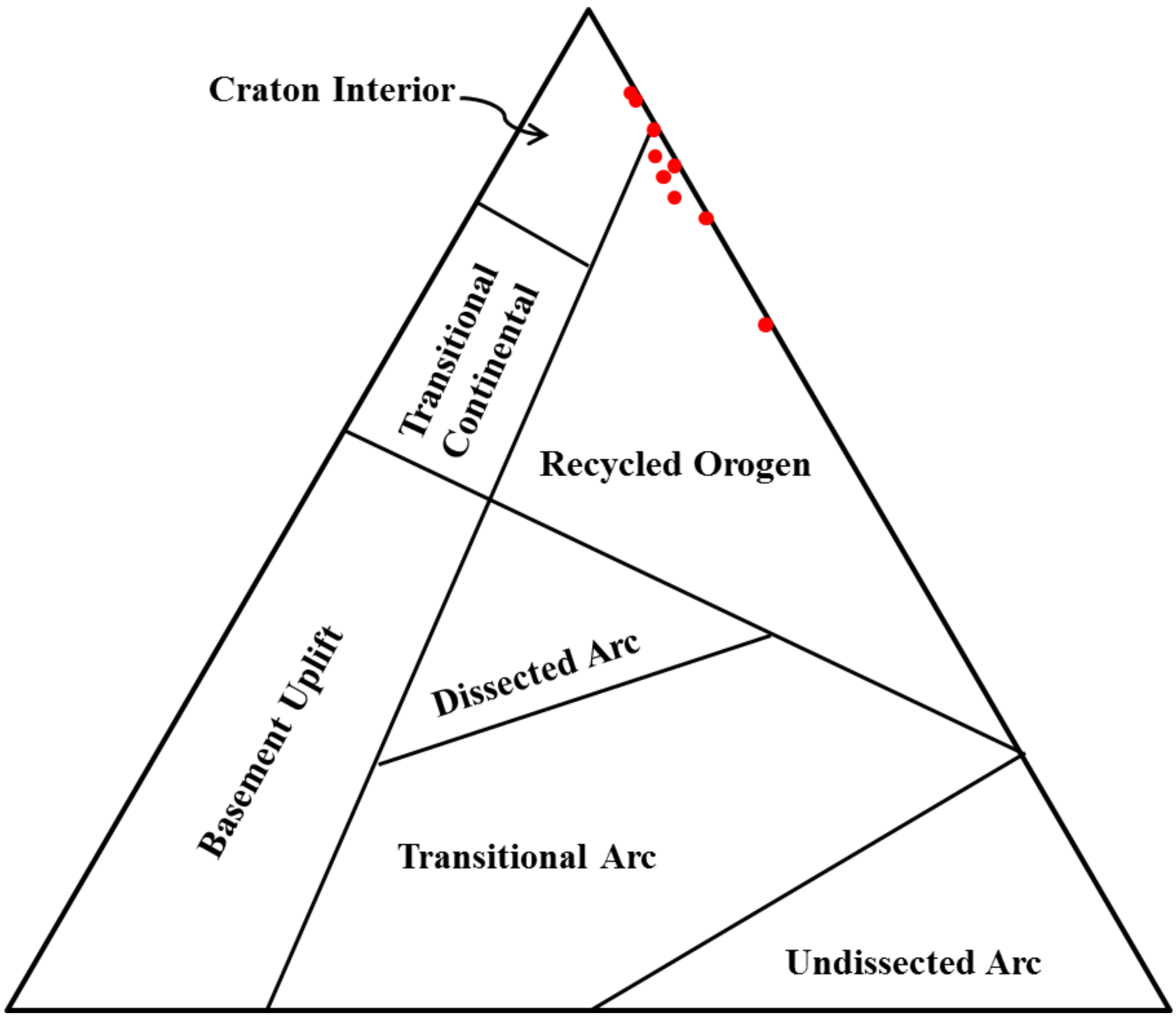


Figure 16. Dickinson Provenance Triangle for the middle Bloyd sandstone. Prediction of tectonic sources from sandstone composition. Modified from Allen, 2008. (See Table 2).

Cains (2013) conducted a study similar to this one on the provenance of the Mississippian-Chesterian Wedington Sandstone. The processes involved in his study are the same as those utilized in this project: detrital zircon geochronology, petrographic study, a stratigraphic framework, paleogeography, tectonic settings, and transport pathways from source terranes to the location of deposition. Data obtained for the Wedington Sandstone through LA-ICP-MS geochronology provided ages that indicate a strong similarity in age constituents to the middle Bloyd sandstone. Averages for both units are shown in Table 4. In addition to a similarity in the age of zircons within the samples, the two units also exhibit a similar composition. The Wedington Sandstone is classified as a quartzarenite to sublitharenite (Cains, 2013). The middle Bloyd sandstone is predominantly classified as a sublitharenite (Allen, 2008). Because of the similarity of both the ages of the zircons that comprise the units, as well as their similar compositions, based on modal analyses, it is likely that the two units share a similar provenance and derived the sediment that composes them in a very similar way.

Sample	350-500 Ma	500-760 Ma	950-1300 Ma	1.35-1.55 Ga	1.6-1.8 Ga	1.8- 2.3 Ga	>2.5 Ga
Wedington	5.3	0.9	50.3	13.3	19.2	4.7	6.3
Mid Bloyd	4.3	1.0	50.7	15.2	14.3	4.6	9.8

Table 4. Comparison of the averages (in percent) of zircon age constituents of the Wedington Sandstone (Mississippian-Chesterian) and the middle Bloyd sandstone (Pennsylvanian-Morrowan). Wedington Sandstone data from Cains, 2013.

A. ARCHEAN AND PALEOPROTEROZOIC PROVENANCE

The middle Bloyd sandstone differs in composition from other sandstone units in the Morrowan section. The middle Bloyd sandstone is classified as sublitharenite to litharenite in composition (Allen, 2008). The younger Prairie Grove and Cane Hill Sandstones lower in the Morrowan section are classified as quartzarenites (Liner, 1979; Black, 1986; Allen, 2008). The Mississippian-Chesterian Wedington Sandstone has a similar composition. It is classified as quartzarenite to sublitharenite in composition. Below the Wedington, the sandstones of the Ordovician-Lower Mississippian succession are predominantly clean, mature orthoquartzites that include the Everton, St. Peter, Clifty, and Bachelor Formation (Cains, 2013). The Wedington Sandstone is an unlikely source of recycled sediment for the middle Bloyd sandstone due to its close proximity, limited aerial extent, and lack of exposure due to cover provided by the units of the upper Chesterian and lower Morrowan that lie between the units. Detrital zircon analysis conducted by Cains (in prep) shows that the Everton, St. Peter, Clifty, and Bachelor Formations are largely composed of sediment that was sourced from the Canadian Shield and contains smaller amounts of grains of ages that correspond to Grenville, Midcontinent Granite-Rhyolite, and Yavapai-Mazatzal source terranes.

The St. Peter Formation is the most likely source of some Archean and Paleoproterozoic sediment for the middle Bloyd sandstone. Unlike the Everton, Clifty, and Bachelor Formations, the St. Peter sandstone covers a large portion of the midcontinent and extends northward beyond the thick cover provided by Lower Mississippian carbonates. This exposure allowed the St. Peter to be an available source of sediment for the middle Bloyd sandstone. Approximately 85% of zircons analyzed within a St. Peter sample corresponded to Archean and Paleoproterozoic age rocks with the remaining grains corresponding to Grenville age rocks (Cains, 2013). The St. Peter contains grains that were originally derived from sources on the Canadian Shield as well as some Grenville age sediment. The St. Peter could easily supply the sediment necessary to account for the smaller contribution (5-20%) of Archean and Paleoproterozoic grains found within the middle Bloyd sandstone samples. Although Grenville age zircons are identified in the St. Peter, it is not the major source for sediment of Grenville age within the middle Bloyd sandstone. The Grenville age zircons simply constitute too much of the composition of middle

Bloyd sandstone for the St. Peter sandstone to be a viable option as a major source of those grains.

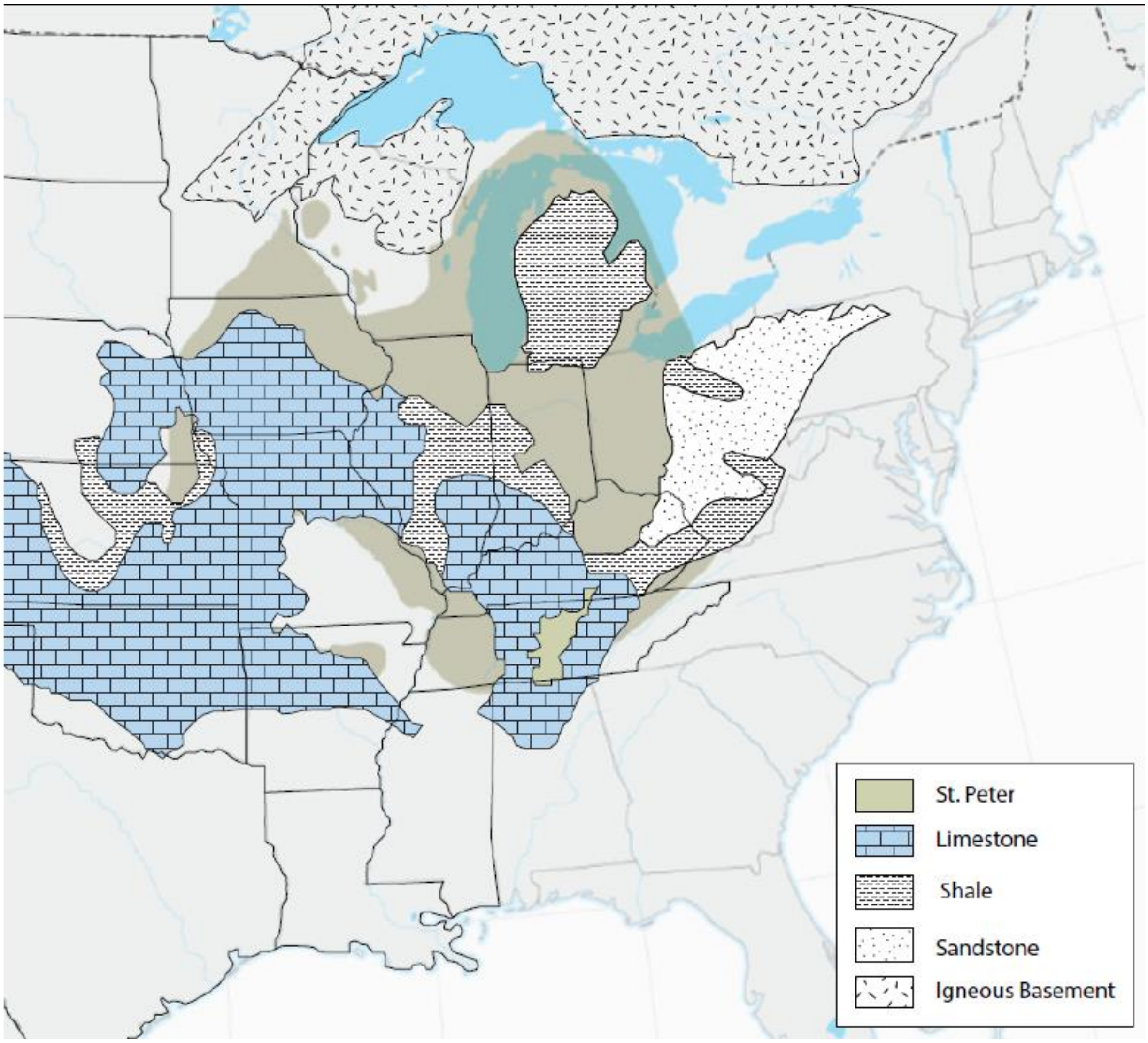


Figure 17. The above map, assembled by Cains (2013) depicts the distribution of the St. Peter Sandstone in relation to areas covered by Mississippian limestone. Only areas with limestone absent would be able to supply sediment for the middle Bloyd sandstone. (Map assembled by Cains (2013) using distribution of St. Peter from Dake, 1921, and limestone distribution from Shell, 1975).

B. MIDCONTINENT AND YAVAPAI-MAZATZAL PROVENANCE

Zircons with ages that correspond to the Midcontinent Granite-Rhyolite and Yavapai-Mazatzal Provinces constitute between approximately 20-30% of the zircons identified in the middle Bloyd sandstone. The two provinces lie adjacent to each other. Rocks of the Yavapai-Mazatzal Province are located to the north and west of the middle Bloyd sandstone (Figure 18). The Midcontinent Granite-Rhyolite rocks underlie the middle Bloyd sandstone. Rocks of this province also extend west, north, and east of the study area. Because these two provinces lie adjacent to one another, it is likely that a similar source area provided the zircons for both of these provinces that are identified in the middle Bloyd sandstone. The Nemaha Ridge and the Illinois Basin arise as the two most likely source areas for Midcontinent Granite-Rhyolite and Yavapai-Mazatzal age grains.

The first of the two proposed sources for Midcontinent and Yavapai-Mazatzal age sediment is the Nemaha Ridge. This feature extends roughly north-south from Nebraska, through Kansas, into Oklahoma. This feature cuts across rocks of both the Midcontinent Granite-Rhyolite Province as well as the Yavapai-Mazatzal Province. The Nemaha Anticline contains basement rocks that range in age from 1350 Ma to 1950 Ma (Goebel, 1968; Cains, 2013). By the time of the arrival of the early Pennsylvanian, granitic rocks of both provinces were exposed along the ridge of the structure, creating a chain of low ridges or hills that allowed sediment to be shed into surrounding basins (Merriam, 1963).

The Forest City Basin lies adjacent to the east side of the uplifted Nemaha Ridge. During the time of the early to middle Pennsylvanian, it would have been receiving sediment shed from the uplifted Nemaha Ridge, including material eroded from the exposed granitic basement rocks of the Midcontinent Granite-Rhyolite and the Yavapai-Mazatzal provinces along the crest of the ridge. It might be expected that the Forest City Basin would contain a substantial amount of coarse-grained arkosic sediment in its lower Pennsylvanian section. However, wells drilled to the lower Pennsylvanian section within the Forest City Basin discovered a very limited amount of coarse-grained arkosic sands (Lee, 1943). As a result, the uplifted ridge of basement rock along the Nemaha Ridge is likely not the direct source of the substantial amounts of Midcontinent and Yavapai-Mazatzal sediment found within the middle Bloyd sandstone. However, the Nemaha Ridge likely experienced uplift by the middle Mississippian time (Cains, 2013). The Forest City Basin is interpreted to be a post-Mississippian feature (Lee, 1943). Sediment transported eastward from the uplifted Nemaha Ridge may have been an important source that corresponds to Midcontinent Granite-Rhyolite and Yavapai-Mazatzal age basement rocks.

The Cambrian Lamotte Sandstone deposited in the region of the uplifted Nemaha Ridge likely contains sediment derived from the underlying rocks of the Midcontinent Granite-Rhyolite and Yavapai-Mazatzal provinces (Cains, 2013). The uplift of the Nemaha Ridge would have exposed this sandstone unit to erosion, making it a possible source of sediment, via recycling, for the middle Bloyd sandstone with ages that corresponded to the underlying basement rocks. However, during the early to middle Pennsylvanian, the Forest City Basin was actively receiving sediment. The presence of this active basin likely created a substantial barrier for eastward sediment transport of source material, possibly eliminating it as a potential source of Midcontinent Granite-Rhyolite and Yavapai-Mazatzal sediment for the middle Bloyd sandstone. However, uplift of the Nemaha Ridge may have occurred prior to basin formation. In addition, the Bourbon Arch was uplifted during the early Pennsylvanian. It was a feature with fairly low relief that extended northward from the western flank of the Ozark Dome (Merriam, 1963).

Although individually it may not represent a major divide for sediment transport, in conjunction with the presence of the active Forest City Basin during the early Pennsylvanian and the lack of substantial amounts of coarse-grained arkosic sandstone in the basin, it is likely that sediment derived from the region of the Nemaha Ridge was not a direct source of Midcontinent Granite-Rhyolite and Yavapai-Mazatzal sediment identified in the middle Bloyd sandstone.

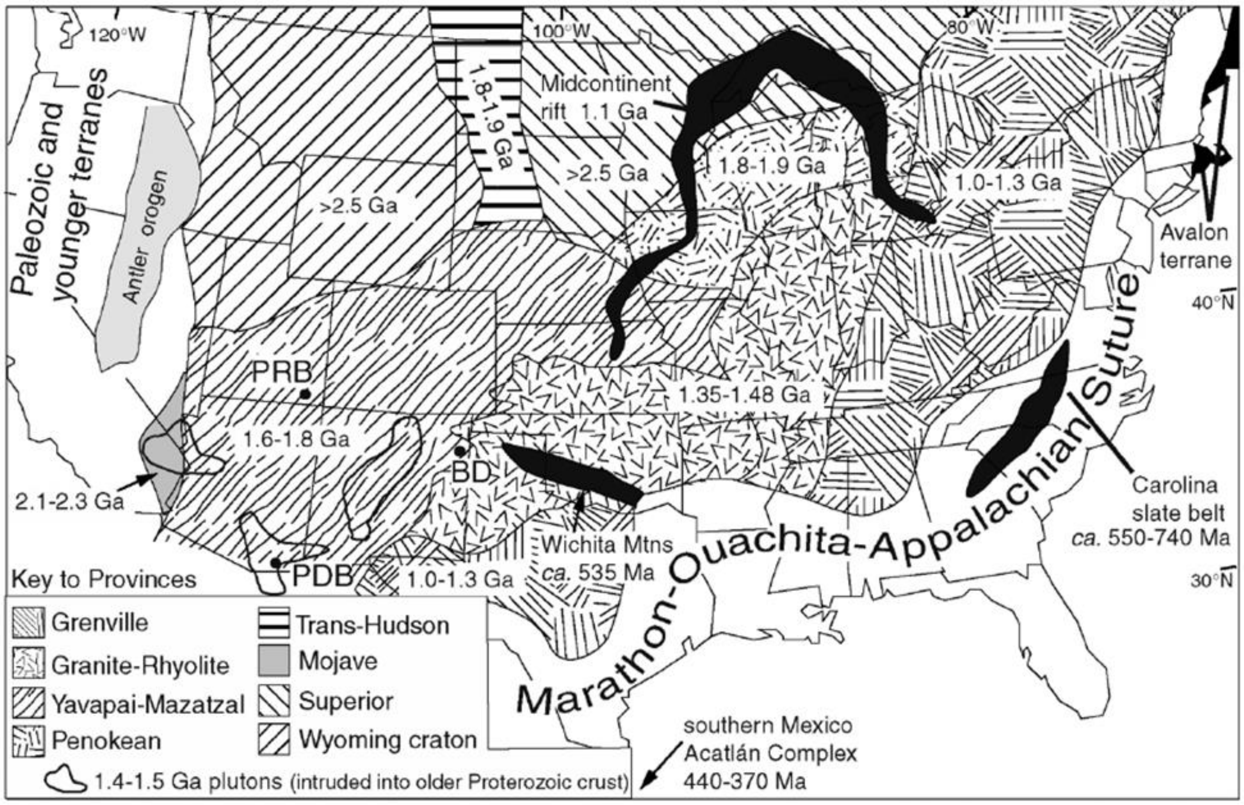


Figure 18. Basement Provinces of North America (Soreghan *et al.*, 2002).

Sandstones located within the Illinois Basin are another potential source of the Midcontinent Granite-Rhyolite and Yavapai-Mazatzal zircon grains identified in the middle Bloyd sandstone. The Illinois Basin overlies basement rocks of the Midcontinent Granite-Rhyolite Province, and it is in close proximity to the Yavapai-Mazatzal basement rocks. Wells drilled to the basement of the basin encountered granite that has been radiometrically dated between 1.2-1.4 Ga (Swann, 1968). Because of their close proximity, it is likely that sandstones within this basin would contain sediment that was originally derived from the basement rocks of the Midcontinent Granite-Rhyolite and Yavapai-Mazatzal provinces. Studies into the age of the sediment that comprises the sands within the Illinois Basin via geochronological methods would allow for the confirmation or refutation of the presence of Midcontinent and Yavapai-Mazatzal age sediment. During the Paleozoic, the Illinois Basin was structurally open to the southwest (Swann, 1968). Throughout the Paleozoic, it is likely that the Illinois Basin communicated freely with Arkansas valley trough to the southwest (Weller and Bell, 1937). Although the two regions are no longer depositionally connected, the Arkansas area is regarded to have been connected to the Illinois basin during the Morrowan time. The Pennsylvanian section within the Illinois Basin contains conglomeratic sandstones that are up-dip equivalents of the middle Bloyd sandstone in northern Arkansas (Archer and Greb, 1995). During the Pennsylvanian, clastic material was predominantly derived from the north (Swann, 1968). Sediment arrival from the north indicates that arriving sediment would likely have contained material from the Midcontinent Granite-Rhyolite and Yavapai-Mazatzal provinces, both of which lie to the north and northwest. Although the Nemaha anticline was not a direct source of sediment found in the middle Bloyd sandstone, this uplifted feature likely allowed sediment from Midcontinent Granite-Rhyolite and Yavapai-Mazatzal rocks to be eroded, transported eastward, and later reworked. Sediment would have been shed from the Nemaha uplift prior to the formation of the Forest City Basin as a sediment trap. This sediment would have been transported eastward towards the Illinois Basin. Reworking of sediment in the early Pennsylvanian, as the Illinois Basin actively received sediment from the north, would have transported Midcontinent and Yavapai-Mazatzal age sediment southwestward through the Illinois Basin. This, in conjunction with a depositional connectivity between the Illinois Basin during the Pennsylvanian, and the location of the middle Bloyd sandstone, makes sediment derived from the Illinois Basin, as well as sediment passing through the basin viable sources of Midcontinent Granite-Rhyolite and Yavapai-Mazatzal material within the middle Bloyd sandstone.

C. APPALACHIAN PROVENANCE

Sediment derived from the Appalachian region, by far, represents the largest zircon component of the middle Bloyd sandstone. In particular, grains that range from 900-1200 Ma represent approximately 39-57% of the zircon grains identified within the middle Bloyd sandstone samples. Grains within this age range are derived from the Grenville Province, making it the most substantial source of sediment for the middle Bloyd sandstone. Smaller amounts of grains from the Appalachian region also correspond to Acadian and Taconic sources. These sources represent 2-7% of the zircon grains identified in the middle Bloyd sandstone samples.

Grenville age sediment was being transported to Arkansas by at least the Early Ordovician as indicated by the presence of Grenville age zircons in Ordovician sandstones of Northern Arkansas. Although, the amount of Grenville age grains in the Ordovician sandstones cannot account for the large amount of Grenville age zircons identified in the middle Bloyd sandstone (Cains, 2013; Xie and Cains, in prep). As a result, the source of the Grenville grains must be attributed to the transport of sediment from an Appalachian source rather than the recycling of sediment from a source in closer proximity. Two scenarios arise for supplying Grenville and Acadian-Taconic sediment to the middle Bloyd sandstone. Firstly, uplift during the Alleghenian orogeny exposed Grenville crystalline basement rocks that were eroded and transported westward. Secondly, sandstones that were deposited in the Appalachian Basin during the Acadian-Taconic orogenies were uplifted during the Late Mississippian-Early Pennsylvanian by the Alleghenian orogeny and were eroded and transported westward. Both models require that sediment top the Cincinnati Arch and then pass through the Illinois Basin before being transported southwest into Arkansas.

Uplift associated with the Alleghenian orogeny was occurring during the Late Mississippian-Early Pennsylvanian in the Appalachian region. This uplift allowed Grenville crystalline basement rocks to be exposed and made available for erosion. The exposed crystalline Grenville rocks could supply the large amount of Grenville age zircons identified in the middle Bloyd sandstone as well as the pervasive MRFs that were also identified by Allen (2008) in his modal analysis of the middle Bloyd sandstone. Very little feldspar was identified in the middle Bloyd sandstone, but the transport distance of the Grenville sediment would likely be adequate to allow the feldspars to weather out (Allen, 2010; Cains, 2013). This eroded sediment would have to overfill the Appalachian Basin, overflow the Cincinnati Ach, and pass through the Illinois Basin before making it to northern Arkansas. Aside from the difficulty presented by these transport barriers, the uplifted Grenville basement rocks alone could not supply all the necessary sediment from the Appalachian region for the middle Bloyd sandstone. Grenville crystalline rock could not account for the approximately 2-7% of Acadian-Taconic source terrane grains identified in the middle Bloyd sandstone.

The second scenario that supplied Grenville and Acadian-Taconic age sediment for the middle Bloyd sandstone involves the recycling of sediments from the Appalachian foreland basin. Geochronology analysis of zircons within sandstones located within the basin indicates that the primary source of sediment for the sandstones within the basin was derived from Grenville age terrane with a lesser presence of Acadian-Taconic age grains (Park, *et al.*, 2010;

McLennan *et al.*, 2001). Synorogenic to postorogenic Devonian sandstones within the basin indicate the presence of 40% zircon grains that are consistent with crystalline rocks of the Taconic terrane (McLennan, *et al.*, 2001). The presence of a large population of Grenville age sediment, as well as the occurrence of sediment that corresponds to crystalline rocks of Acadian-Taconic ages, makes the sandstones located within the Appalachian Foreland Basin probable candidates to supply sediment of Grenville and Acadian-Taconic age for the middle Bloyd sandstone. Uplift during the Alleghenian orogeny of the Late Mississippian-Early Pennsylvanian would allow for the Cambrian-Devonian, Grenville and Acadian-Taconic-bearing sandstones to be exposed and made available for erosion.

During the Upper Ordovician, and later during the Upper Devonian, the Appalachian Basin is known to have been oversupplied with sediment. This allowed sediment to spill over the Cincinnati Arch into the Illinois Basin (Swann, 1968). It is possible that Illinois Basin sandstones that contained detritus of Grenville and Acadian-Taconic age, derived from sediment spilled over the Cincinnati Arch were recycled to provide material for the middle Bloyd sandstone. However, the presence of substantial sandstone units located in the Upper Morrowan section within the Illinois Basin, such as the Battery Rock Sandstone, present a problem. Most of the Upper Pennsylvanian sandstones in the Illinois Basin are lithic arenites, making them similar in composition to the middle Bloyd sandstone (Nelson, *et al*., 2013). Sandstones in the lower Morrowan of the Illinois Basin could not be eroding while active deposition was ongoing. This makes the recycling of Illinois Basin sandstones an unlikely major source of sediment for the middle Bloyd sandstone. The northern part of the Illinois Basin was undergoing uplift in the Early Pennsylvanian (Nelson, *et al.*, 2013). It is possible that recycled Illinois Basin sandstones in the northern portion of the Basin supplied some material, but they likely did not supply the volume of sediment necessary to account for all the sediment of Grenville and Acadian-Taconic age in the middle Bloyd sandstone.

A more likely scenario exists to explain the presence of Grenville and Acadian-Taconic age sediment in the middle Bloyd sandstone received via the Illinois Basin. It is most likely that the Alleghenian orogeny in the Late Mississippian-Early Pennsylvanian provided another period of uplift that allowed Acadian-Taconic rocks, as well as sandstones within the Appalachian Basin, to be once again eroded and transported over the Cincinnati Arch into the Illinois Basin. Once the sediment entered the Illinois Basin, it entered a large scale river system, such as that presented by Archer and Greb (1995), and it continued its transport southwest to northern Arkansas. Several incised paleovalleys have been identified in the Illinois Basin that contain crossbedded orthoquartzites and quartz-pebble conglomerates (Archer and Greb, 1995). This is consistent with the transport of material through the Illinois Basin during the Early Pennsylvanian that is similar to the material composing the middle Bloyd sandstone. Feldspars are more pervasive in the Pennsylvanian sandstones in the Illinois Basin, indicating that the rate of feldspar destruction must have been high during the transport of sediment from the Illinois Basin to northern Arkansas (Berry, 1978). The transport distance between the two regions is likely sufficient to account for the lower feldspar count in the middle Bloyd sandstone than in the Morrowan sandstones of the Illinois Basin. Crowder (1982) inferred from his compositional analysis of the middle Bloyd sandstone that the Appalachian Blue Ridge Province is consistent with the petrology of the middle Bloyd sandstone unit, and that a major fluvial transport system must have existed to transport this sediment through the Illinois Basin to northern Arkansas. Archer and Greb (1995) presented further evidence for the existence of a similar large-scale river system. It is the author's opinion that this is the most likely scenario for providing the large amount of Grenville and Acadian-Taconic age sediment identified in the middle Bloyd sandstone. Further analysis of the conglomeritic sandstones in the Morrowan section of the Illinois Basin, such as detrital zircon geochronology, would help to confirm a similar composition of ages for Morrowan, Illinois Basin sandstones and the middle Bloyd sandstone, providing further proof that the two regions were depositionally connected during the Early Morrowan.

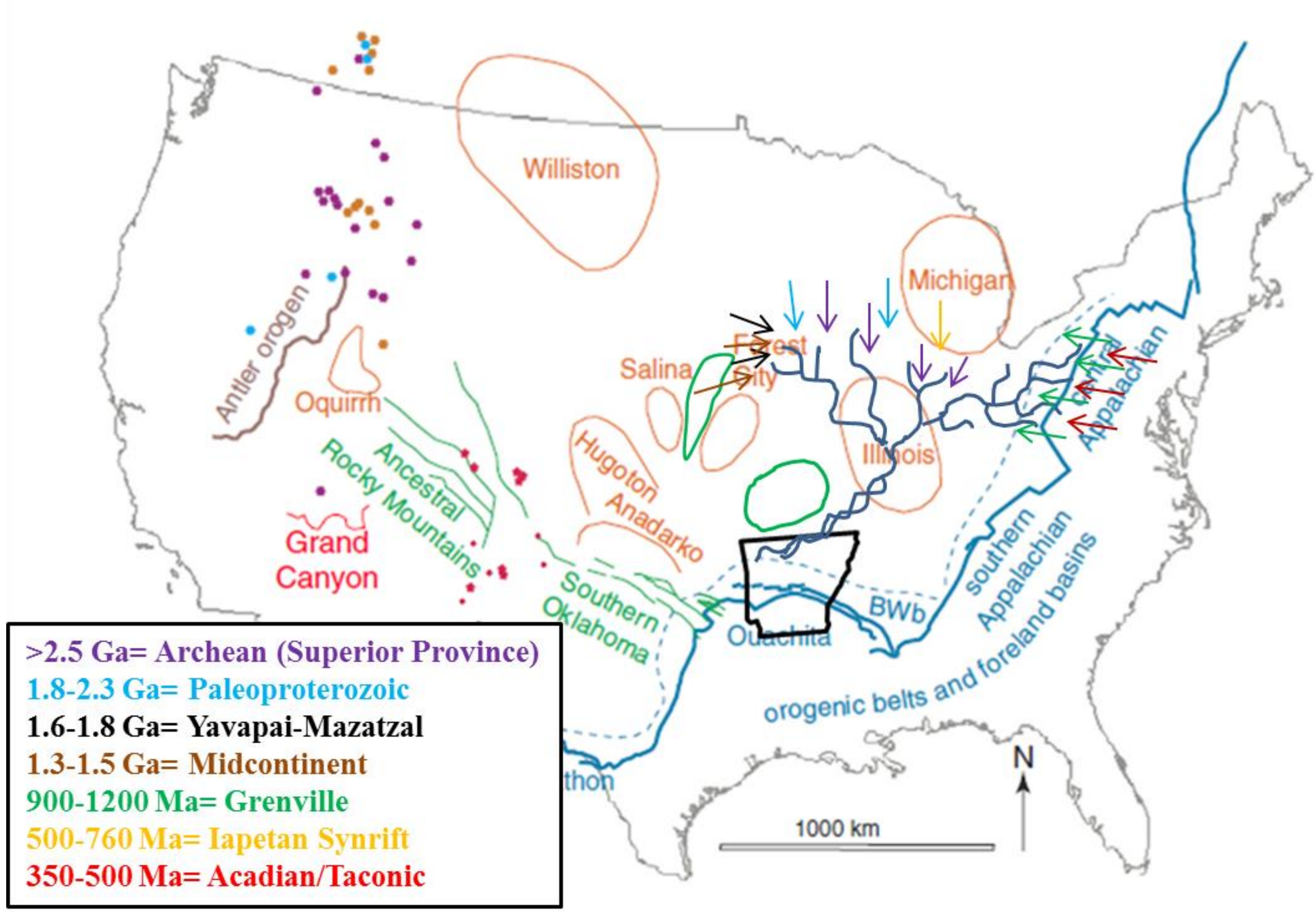


Figure 19. Interpreted sediment transport pathways for the middle Bloyd sandstone sediment into northern Arkansas with Late Paleozoic structural features. Modified from Thomas, 2011a.

VI. CONCLUSIONS

1. The Appalachian region represents the main source region for sediment that comprises the middle Bloyd sandstone. Rocks of Midcontinent Granite-Rhyolite and Yavapai-Mazatzal age represent the second most prevalent source.
2. Sediment derived from Midcontinent Granite-Rhyolite and Yavapai-Mazatzal rocks was likely eroded from the uplifted Nemaha Ridge and transported eastward towards the Illinois Basin prior to the formation of the Forest City Basin, avoiding this sediment trap.
3. Grenville, Taconic, and Acadian age sediment was derived from the Appalachian region from sedimentary and crystalline basement rocks in the Appalachian Basin that were uplifted during the Alleghenian orogeny of the Late Mississippian-Early Pennsylvanian.
4. Archean and Paleoproterozoic age sediments in the middle Bloyd sandstone were derived from the recycling of exposed sandstones located to the north of the Illinois Basin. The St. Peter Sandstone is located in this region and has a large aerial extent, making it a likely candidate as a source for grains of this age.
5. The Illinois Basin was depositionally connected to the region of northern Arkansas during the Early Pennsylvanian. The Illinois Basin was an important junction for the reception of sediment arriving from the north-northwest (Archean, Midcontinent Granite-Rhyolite, and Yavapai-Mazatzal age grains) as well as sediment derived from the Appalachian Region (Grenville and Acadian/Taconic age grains). Sediment was actively transported southward through the basin en route to northern Arkansas where the middle Bloyd sandstone was deposited in a braided fluvial system near the Morrowan-Pennsylvanian coastline.

6. Provenance of the middle Bloyd sandstone is similar to that of the Mississippian, Chesterian Wedington Sandstone.

VII. UNANSWERED QUESTIONS

Although this thesis provides an explanation for the source and transport of sediment that comprises the middle Bloyd sandstone, other questions arise which, through future investigation, may warrant a change in the interpretation that is presented. Such as, how much of an influence did eolian transport have on supplying sediment that comprises the middle Bloyd sandstone? In particular, if eolian transport is determined to be viable, how much influence did Africa, approaching from the east have? If Africa's terrane is deemed important, what did the sub-Pennsylvanian surface of Africa look like (i.e. is there a large supply of sand present and readily available for westward eolian transport)? In this thesis, Laurentian sources are assumed for the middle Bloyd sandstone, but further investigation may necessitate the inclusion of Gondwanan sources as potential sources of sediment identified in the middle Bloyd sandstone.

VIII. FUTURE STUDY

Many variables are involved when trying to determine sedimentary provenance. As a result, establishing certainty about the provenance of a unit can become very difficult. A future study using Nd isotope analysis could assist in constraining the source terranes from which sediment was derived. This analysis would allow the type of crystalline rock from which the detritus was derived to be determined. Because several terranes may share a common age in which they crystallized, Nd analysis could potentially help to determine from which crystalline terrane among those with shared ages that the middle Bloyd sediment was derived. In addition, further study of the sandstones located in the Morrowan section of the Illinois Basin may help to provide further evidence of depositional connectivity between the Morrowan sandstones of the Illinois Basin and the middle Bloyd sandstone of northern Arkansas. Lastly, the viability of westward eolian transport of sediment warrants investigation. If eolian transport is found to be important, terranes within Gondwana would also become important potential source terranes in describing the sedimentary provenance of the middle Bloyd sandstone.

REFERENCES

Allen, Daniel Eugene, 2008. Origin and Distribution of Porosity in the Middle Bloyd Sandstone, Southern Boston Mountains, Arkansas. Unpublished Undergraduate Honors Thesis, University of Arkansas, 18 p.

Amato J.M., Boullion, A.O., Serna A.M., Sanders A.E., Farmer G.L., Gehrels G.E., Wooden J.L., 2008. Evolution of the Mazatzal province and the timing of the Mazatzal orogeny: Insights from U-Pb geochronology and geochemistry of igneous and metasedimentary rocks in southern New Mexico. Geological Society of America Bulletin, v.120 p. 328-345.

Antia-Barrero, J., 2006. Stratigraphic correlation and facies interpretation of the "Middle Bloyd Sandstone" in outcrop, Johnson and Pope Counties, Arkansas. Unpublished M.S. Thesis, University of Arkansas, 49 p.

Archer, A.W., and Greb, S.F., 1995. An Amazon-Scale Drainage System in the Early Pennsylvanian of Central North America. The Journal of Geology, v. 103, p. 611-628.

Berry, Richard Allen, 1978. Stratigraphy and Petrology of the Middle Bloyd Sandstone (Morrowan) Southeast Madison County, Arkansas. Unpublished M.S. Thesis, University of Arkansas, 102 p.

Black, Bernard, 1986. Petrology and Depositional Environment of the Prairie Grove Member of the Hale Formation in Northwestern Arkansas. Unpublished Ph. D. Dissertation, University of Tulsa, 209 p.

Cains, William T., 2013. Sedimentary Provenance of the Wedington Member, Fayetteville Shale, From Age Relations of Detrital Zircons. Unpublished M.S. Thesis, University of Arkansas, 97 p.

Chang, Z., Vervoort, J. D., McClelland, W. C., and Knaack, C., 2006. U-Pb dating of zircon by LA-ICP-MS. Geochemistry, Geophysics, Geosystems, (Vol. 7, Issue 5).

Crowder, R.K., 1982. Anatomy of a Pennsylvanian fluvial sheet sandstone, northwest Arkansas. Unpublished M.S. Thesis, University of Arkansas, 112 p.

Dake, C.L., 1921. The Problem of the St. Peter Sandstone (Vol. 6, No. 1). Columbia University.

Dickinson, W. R., Beard, L. S., Brakenridge, G. R., Erjavec, J. L., Ferguson, R. C., Inman, K. F., and Ryberg, P. T., 1983. Provenance of North American Phanerozoic sandstones in relation to tectonic setting. Geological Society of America Bulletin, 94(2), p. 222-235.

Dupont, Pierre-Orly, 2008. Stratigraphic and Sedimentologic Analysis of the “Middle Bloyd” Sandstone (Morrowan) in Outcrops, Mount Judea & Lurton Quadrangle, Newton County, Northern Arkansas. Unpublished M.S. Thesis, University of Arkansas. 52 p.

Fedo, C.M., Sircombe, K.N., Rainbird, R.H., 2003. Detrital Zircon Analysis of the Sedimentary Record. In Hanchar, J. M. and Hoskin, P., (eds.), Zircon: Experiments, Isotopes, and Trace Element Investigations. Mineralogical Society of America, Reviews in Mineralogy, Chapter 10, volume 53, p. 277-303.

Glenn, John Martin, 1973. Stratigraphy and Depositional Environment of a Middle Bloyd Sandstone, Madison and Washington Counties, Arkansas. Unpublished M.S. Thesis, University of Arkansas. 60 p.

Goebel, E. D., 1968. Precambrian Rocks, The Stratigraphic Succession in Kansas: Kansas Geological Survey Bulletin, 189, p. 9-11.

Haley, B.R., Glick, E.E., Bush, W.V., Clardy, B.F., Stone, C.G. Woodward, M.B., Zachry, D.L., 1993. Geologic Map of Arkansas. Arkansas Geological Commission, scale: 1:500,000.

Henbest, L.G., 1953. Morrow Group and Lower Atoka Formation of Arkansas. Bulletin of the American Association of Petroleum Geologists, 37(8), p. 1935-1953.

Johnson, K.S., Amsden, T. W., Denison, R. E., Dutton, S. P., Goldstein, A. G., Rascoe, B., Sutherland, P. K., and Thompson, D. M., 1989. Geology of the Southern Midcontinent, Oklahoma Geological Survey, 53 p.

Lee, Wallace, 1943. The Stratigraphy and Structural Development of the Forest City Basin in Kansas. Kansas Geological Survey Bulletin 51, 142 p.

Liner, Robert, 1979. Lithostratigraphy of the Cane Hill Member of the Hale Formation (Type Morrowan), Northwest Arkansas. Arkansas Academy of Science Proceedings, v. 33, p. 49-50.

Lonigro, Nicholas Drew, 2008. Architectural Analysis of the Lower Pennsylvanian, Middle Bloyd Sandstone (Morrowan), Sand Gap Quadrangle, Northwest Arkansas. Unpublished M.S. Thesis, University of Arkansas, 64 p.

Ludwig, K.R., 2003. Isoplot 3.00 –A Geochronological Toolkit for Microsoft Excel, in Berkeley. Geochronology Center Special Publication No. 4, Berkeley, CA.

Manger, Walter L. and Zachry, Doy L., 1998. Guidebook- Morrowan (Lower Pennsylvanian) Reservoir Stratigraphy, Southern Ozark Region, Northern Arkansas. Unpublished- Fayetteville Arkansas, University of Arkansas Geosciences Department, 17 p.

Manger, Walter L. and Zachry, Doy L., 2006. Morrowan (Lower Pennsylvanian) Sequence Stratigraphy and Depositional Dynamics, Northwest Arkansas. Arkoma Basin Analysis Team Field Trip, 2006, 24 p.

Manger, W.L., Zachry, D.L., and Garrigan, M.L., 1988. An Introduction to the Geology of Northwestern Arkansas. The Compass, Sigma Gamma Epsilon, v. 65, no. 4, p. 242-257.

McLennan, S. M., Bock, B., Compston, W., Hemming, S. R., and McDaniel, D. K., 2001. Detrital Zircon Geochronology of Taconian and Acadian Foreland Sedimentary Rocks in New England. Journal of Sedimentary Research, 71(2), p. 305-317.

Merriam, Daniel, 1963. The Geologic History of Kansas. State Geological Survey of Kansas, Bulletin 162, 317 p.

Nelson, W.J., Greb, S.F., Weibel, C.P., 2013. Pennsylvanian Subsystem in the Illinois Basin. Stratigraphy, v. 10, no 1-2, p. 41-45.

Park, H., Barbeau Jr., D.L., Rickenbaker, A., Bachman-Krug, D., Gehrels, G., 2010. Application of Foreland Basin Detrital-Zircon Geochronology to the Reconstruction of the Southern and Central Appalachian Orogen. Journal of Geology, v. 118, no. 1. 22 p.

Pontiff, Jessica, 2007. Regional Stratigraphic Framework of Morrowan Strata, Northern Arkoma Basin. Unpublished M.S. Thesis, University of Arkansas, 86 p.

Porter, Matthew O’Bryhim, 2007. Facies Relationships, Reservoir Assessment and Surface-to-subsurface Correlation of the Middle Bloyd Formation (Pennsylvanian), North-Central Arkoma Basin, Arkansas. Unpublished M.S. Thesis, University of Arkansas, 87 p.

Sandlin, L. F., 1968. Geology of the Greenland Sandstone, Winslow (Pennsylvanian) Formation, Eastern Madison County, Arkansas. Unpublished M.S. Thesis, University of Arkansas, 88 p.

Shaw, C.A. and Karlstrom, K.E., 1999. The Yavapai-Mazatzal crustal boundary in the southern Rocky Mountains. Rocky Mountain Geology, v.34, p. 37-52.

Shell Oil Company, 1975. Prechesterian Mississippian Strata, Stratigraphic Atlas of North and Central America. Princeton University Press. 272 p.

Soreghan, M. J., Soreghan, G. L., and Hamilton, M. A., 2002. Paleowinds inferred from detrital zircon geochronology of upper Paleozoic loessite, western equatorial Pangea. Geology, 30(8), p. 695-698.

Swann, D. H., 1968. A summary geologic history of the Illinois Basin. Geology and Petroleum Production of the Illinois Basin, p. 3-21.

Thomas, W. A., 2011a. Detrital-zircon Geochronology and Sedimentary Provenance. Lithosphere, 3(4), p. 304-308.

Thomas, W. A., 2011b, The Iapetan Rifted Margin of Southern Laurentia. Geosphere, 7(1), p. 97-120.

Van Schmus, W.R., Bickford, M.E., Zietz, I., 1986. Proterozoic History of the midcontinent region of North America. Geology, v. 14, p. 492-496.

Vermeesch, P., 2004. How many grains are needed for a provenance study? Earth Planet. Sci. Lett. 224, p. 351- 441.

Weller, J. M. and Bell, A. H., 1937. Illinois Basin. Bulletin of the American Association of Petroleum Geologists, v. 21, n. 6, p. 771-788.

Whitmeyer, S. J., and Karlstrom, K. E., 2007, Tectonic model for the Proterozoic growth of North America. Geosphere, 3(4), p. 220-259.

Workman, Benjamin David, 2012. Sequence Stratigraphy and Detrital Zircon Provenance of the Eureka Quartzite in South-Central Nevada and Eastern California. Unpublished M.S. Thesis- Texas A&M University, Department of Geology, 96 p.

Xie, X., and Heller, P. L., 2013. U-Pb Detrital zircon geochronology and its implications: the early Late Triassic Yanchang Formation, south Ordos Basin, China. Journal of Asian Earth Sciences, p. 86-98.

Zachry, D.L., 1979. Early Pennsylvanian braided stream sedimentation, northwest Arkansas: Tulsa Geol. Soc. Spec. Pub. 1, p. 269-281.

Zachry, D.L. and Haley B.R., 1975. Stratigraphic relationships between the Bloyd and Atoka Formations (Pennsylvanian) of northern Arkansas. In Contributions to geology of the Ozarks, Arkansas Geological Commission Miscellaneous Publication 12, p. 96-106.

Appendix A- U-Pb Zircon Geochronology Data

MB 1-1

Sample MB-1-1 (Middle Bloyd Sandstone) U–Pb detrital zircon LA-ICP-MS analysis results

	Isotopic Ratio		Apparent Ages					
Sample	206/238	±1σ	206/238	±1σ (Ma)	207/206	±1σ (Ma)	Best Age	±1σ (Ma)
MB11_135	0.1606	0.0017	960.18	9.23	1011.46	13.74	1011.46	13.74
MB11_134	0.1672	0.0022	996.40	12.26	1097.81	34.23	1097.81	34.23
MB11_133	0.5720	0.0049	2915.94	20.12	2912.93	9.34	2912.93	9.34
MB11_132	0.2618	0.0023	1499.27	11.90	1526.34	14.54	1526.34	14.54
MB11_129	0.2152	0.0020	1256.69	10.48	1328.81	16.35	1328.81	16.35
MB11_126	0.1885	0.0038	1113.45	20.75	1153.69	35.58	1153.69	35.58
MB11_125	0.1481	0.0012	890.10	6.55	962.55	12.19	890.10	6.55
MB11_124	0.3213	0.0016	1796.30	8.03	1807.74	10.43	1807.74	10.43
MB11_123	0.1838	0.0021	1087.73	11.52	1057.77	13.77	1057.77	13.77
MB11_121	0.1689	0.0009	1006.15	4.84	1018.09	11.59	1018.09	11.59
MB11_120	0.1726	0.0017	1026.26	9.16	1032.32	12.95	1032.32	12.95
MB11_119	0.1803	0.0015	1068.67	8.09	1117.94	13.19	1117.94	13.19
MB11_118	0.1694	0.0023	1008.86	12.83	1081.35	24.72	1081.35	24.72
MB11_117	0.5333	0.0042	2755.17	17.68	2773.88	8.41	2773.88	8.41
MB11_116	0.1919	0.0021	1131.88	11.43	1182.70	14.76	1182.70	14.76
MB11_115	0.5193	0.0061	2696.14	25.92	2760.00	8.79	2760.00	8.79
MB11_114	0.0634	0.0010	396.53	5.76	414.49	38.69	396.53	5.76
MB11_113	0.3074	0.0028	1727.71	13.71	1786.68	12.83	1786.68	12.83
MB11_112	0.1903	0.0017	1122.91	9.01	1222.98	13.28	1222.98	13.28
MB11_111	0.1790	0.0032	1061.35	17.60	1137.64	32.59	1137.64	32.59
MB11_109	0.0699	0.0008	435.79	4.53	488.04	22.33	435.79	4.53
MB11_108	0.1759	0.0017	1044.67	9.17	1124.23	14.44	1124.23	14.44
MB11_107	0.0684	0.0010	426.44	5.76	479.01	17.47	426.44	5.76
MB11_106	0.2298	0.0032	1333.37	16.84	1346.41	21.52	1346.41	21.52
MB11_104	0.1657	0.0018	988.50	9.88	1020.90	15.37	1020.90	15.37
MB11_101	0.1662	0.0014	991.27	7.55	1010.57	10.83	1010.57	10.83
MB11_100	0.4901	0.0054	2570.92	23.44	2684.61	10.69	2684.61	10.69
MB11_99	0.1860	0.0018	1099.59	9.93	1152.20	11.21	1152.20	11.21
MB11_98	0.1675	0.0022	998.49	12.01	1070.86	21.68	1070.86	21.68
MB11_97	0.2430	0.0025	1402.09	12.71	1509.19	12.97	1509.19	12.97
MB11_96	0.1722	0.0026	1024.42	14.33	1026.09	19.05	1026.09	19.05
MB11_95	0.3002	0.0025	1692.46	12.36	1739.14	9.23	1739.14	9.23
MB11_94	0.3058	0.0030	1720.22	14.67	1788.98	12.26	1788.98	12.26
MB11_93	0.1860	0.0016	1099.57	8.82	1160.51	12.18	1160.51	12.18
MB11_92	0.1659	0.0016	989.65	9.06	1032.46	21.15	1032.46	21.15
MB11_91	0.1559	0.0014	934.02	7.60	930.91	12.73	934.02	7.60
MB11_90	0.3151	0.0051	1765.88	25.09	1764.48	16.84	1764.48	16.84

MB11_89	0.2090	0.0023	1223.72	12.26	1198.77	18.42	1198.77	18.42
MB11_86	0.5058	0.0042	2638.63	17.78	2707.77	7.23	2707.77	7.23
MB11_84	0.1833	0.0016	1084.92	8.90	1145.80	15.35	1145.80	15.35
MB11_83	0.3075	0.0027	1728.27	13.35	1731.20	9.78	1731.20	9.78
MB11_82	0.2615	0.0020	1497.31	10.17	1497.26	8.06	1497.26	8.06
MB11_81	0.2177	0.0024	1269.56	12.77	1333.88	12.08	1333.88	12.08
MB11_80	0.1686	0.0015	1004.24	8.02	1106.94	17.16	1106.94	17.16
MB11_79	0.1737	0.0016	1032.33	8.76	1108.61	12.73	1108.61	12.73
MB11_78	0.5359	0.0043	2766.31	18.15	2859.62	6.56	2859.62	6.56
MB11_77	0.1628	0.0015	972.17	8.34	1005.85	16.87	1005.85	16.87
MB11_74	0.1690	0.0011	1006.61	6.08	1099.91	10.22	1099.91	10.22
MB11_73	0.1855	0.0011	1096.88	5.82	1135.63	9.27	1135.63	9.27
MB11_70	0.2105	0.0016	1231.31	8.53	1220.99	13.20	1220.99	13.20
MB11_69	0.5303	0.0033	2742.61	13.71	2708.66	6.07	2708.66	6.07
MB11_68	0.2084	0.0020	1220.36	10.76	1210.83	17.99	1210.83	17.99
MB11_67	0.1839	0.0014	1088.32	7.36	1021.88	12.83	1021.88	12.83
MB11_65	0.1705	0.0022	1014.71	11.93	1072.24	28.64	1072.24	28.64
MB11_61	0.1997	0.0033	1173.45	17.89	1113.05	31.32	1113.05	31.32
MB11_60	0.0701	0.0006	436.86	3.77	418.18	17.31	436.86	3.77
MB11_59	0.1961	0.0017	1154.21	9.24	1142.97	11.98	1142.97	11.98
MB11_58	0.1786	0.0016	1059.46	8.56	1040.21	12.94	1040.21	12.94
MB11_57	0.2985	0.0028	1683.65	13.88	1754.44	9.92	1754.44	9.92
MB11_56	0.4651	0.0076	2461.84	33.48	2477.81	15.01	2477.81	15.01
MB11_55	0.1955	0.0020	1151.10	10.97	1137.64	14.45	1137.64	14.45
MB11_53	0.1945	0.0020	1145.70	10.71	1180.46	10.16	1180.46	10.16
MB11_52	0.1846	0.0015	1092.04	8.35	1065.57	9.57	1065.57	9.57
MB11_51	0.1826	0.0015	1081.44	8.23	1063.69	9.26	1063.69	9.26
MB11_50	0.2210	0.0020	1287.32	10.34	1272.22	9.99	1272.22	9.99
MB11_49	0.4319	0.0049	2314.22	21.91	2468.19	10.40	2468.19	10.40
MB11_48	0.1780	0.0017	1055.80	9.13	1007.02	14.23	1007.02	14.23
MB11_47	0.4465	0.0037	2379.83	16.33	2663.66	6.50	2663.66	6.50
MB11_46	0.1765	0.0014	1047.80	7.80	1156.62	8.22	1156.62	8.22
MB11_45	0.1749	0.0019	1039.29	10.60	1036.58	15.03	1036.58	15.03
MB11_43	0.1835	0.0022	1085.92	12.19	1220.93	10.10	1220.93	10.10
MB11_41	0.2400	0.0026	1386.94	13.73	1328.52	13.93	1328.52	13.93
MB11_40	0.2040	0.0021	1196.77	11.50	1162.37	10.05	1162.37	10.05
MB11_39	0.1960	0.0022	1153.78	11.96	1162.45	14.38	1162.45	14.38
MB11_38	0.3261	0.0033	1819.43	15.97	1787.04	7.62	1787.04	7.62
MB11_37	0.1830	0.0021	1083.32	11.65	1139.25	16.49	1139.25	16.49
MB11_36	0.2353	0.0025	1362.20	13.05	1322.48	10.72	1322.48	10.72
MB11_35	0.1792	0.0028	1062.75	15.09	1080.32	32.15	1080.32	32.15
MB11_34	0.1789	0.0019	1061.21	10.59	1035.87	11.04	1035.87	11.04
MB11_33	0.1752	0.0021	1040.46	11.43	1087.70	17.06	1087.70	17.06
MB11_32	0.3011	0.0034	1696.62	16.73	1627.26	11.76	1627.26	11.76
MB11_31	0.1805	0.0022	1069.83	11.93	1074.06	18.23	1074.06	18.23

MB11_30	0.2731	0.0022	1556.43	11.16	1563.07	11.01	1563.07	11.01
MB11_29	0.1719	0.0015	1022.45	8.10	1017.67	14.33	1017.67	14.33
MB11_28	0.0689	0.0006	429.80	3.38	394.01	18.76	429.80	3.38
MB11_26	0.2543	0.0022	1460.52	11.07	1487.76	7.83	1487.76	7.83
MB11_25	0.0856	0.0007	529.48	4.39	537.48	11.44	529.48	4.39
MB11_24	0.3237	0.0024	1807.62	11.64	1803.34	7.64	1803.34	7.64
MB11_22	0.2018	0.0016	1184.80	8.65	1179.89	10.48	1179.89	10.48
MB11_21	0.1738	0.0015	1033.09	8.40	1021.62	12.56	1021.62	12.56
MB11_20	0.2364	0.0020	1367.85	10.62	1316.35	9.51	1316.35	9.51
MB11_19	0.1819	0.0015	1077.34	7.93	1060.22	8.92	1060.22	8.92
MB11_18	0.1885	0.0023	1113.08	12.67	1131.15	23.32	1131.15	23.32
MB11_17	0.3345	0.0026	1860.30	12.43	1848.41	7.93	1848.41	7.93
MB11_16	0.5586	0.0046	2860.95	18.88	2794.65	5.72	2794.65	5.72
MB11_15	0.2174	0.0020	1268.28	10.55	1415.36	10.34	1415.36	10.34
MB11_14	0.1908	0.0025	1125.74	13.77	1158.34	23.20	1158.34	23.20
MB11_13	0.2032	0.0024	1192.70	12.70	1249.02	21.30	1249.02	21.30
MB11_11	0.5292	0.0046	2737.93	19.36	2739.91	7.62	2739.91	7.62
MB11_10	0.5750	0.0062	2928.45	25.18	3034.78	9.01	3034.78	9.01
MB11_9	0.2899	0.0022	1641.04	11.14	1636.64	10.34	1636.64	10.34
MB11_8	0.1729	0.0020	1028.14	10.83	985.39	20.23	985.39	20.23
MB11_7	0.3671	0.0027	2015.74	12.85	1999.69	7.89	1999.69	7.89
MB11_6	0.1840	0.0013	1089.02	7.25	1057.26	12.02	1057.26	12.02
MB11_5	0.1691	0.0019	1007.17	10.52	981.52	23.98	981.52	23.98
MB11_4	0.4841	0.0037	2545.20	15.99	2619.85	6.82	2619.85	6.82
MB11_3	0.2002	0.0014	1176.14	7.55	1167.13	8.72	1167.13	8.72
MB11_2	0.1674	0.0014	997.65	7.85	1002.93	13.83	1002.93	13.83
MB11_1	0.1758	0.0021	1043.97	11.71	1117.71	24.48	1117.71	24.48

Discordance >10%

MB11_130	0.1837	0.0031	1087.03	16.76	1233.58	37.91
MB11_128	0.0648	0.0004	404.96	2.58	474.26	22.75
MB11_127	0.0766	0.0011	475.94	6.43	587.17	47.85
MB11_122	0.1470	0.0012	884.40	6.72	1132.47	12.67
MB11_110	0.2406	0.0019	1389.85	9.65	1984.17	8.38
MB11_103	0.1676	0.0019	999.05	10.76	1221.92	15.30
MB11_102	0.0592	0.0008	370.87	5.13	1400.92	45.91
MB11_88	0.1598	0.0088	955.59	48.49	1472.28	74.50
MB11_85	0.4150	0.0042	2237.55	18.93	2633.80	8.62
MB11_76	0.4395	0.0038	2348.54	16.78	2693.89	7.50
MB11_66	0.0612	0.0016	383.20	9.79	2893.44	54.86
MB11_64	0.0724	0.0006	450.42	3.73	511.93	23.76
MB11_63	0.0667	0.0005	416.50	3.15	499.12	12.17
MB11_62	0.4364	0.0027	2334.69	11.96	2649.85	6.98
MB11_54	0.2612	0.0023	1496.12	11.66	1704.53	7.41
MB11_44	0.1293	0.0014	784.07	7.82	1220.41	9.03

MB11_42	0.0675	0.0010	420.95	6.26	350.54	42.12
MB11_27	0.0219	0.0010	139.48	6.22	1381.66	6.31
MB11_23	0.3833	0.0029	2091.70	13.37	3691.86	19.44
MB11_12	0.3416	0.0032	1894.32	15.51	2719.49	7.43

MB 1-2

Sample MB-1-2 (Middle Bloyd Sandstone) U–Pb detrital zircon LA-ICP-MS analysis results

	Isotopic Ratio		Apparent Ages					
Sample	**206/238**	**±1σ**	**206/238**	**±1σ (Ma)**	**207/206**	**±1σ (Ma)**	**Best Age**	**±1σ (Ma)**
MB12_135	0.1824	0.0015	1080.02	8.25	1156.68	14.16	1156.68	14.16
MB12_133	0.1722	0.0012	1024.36	6.53	1073.49	14.05	1073.49	14.05
MB12_132	0.1764	0.0012	1047.10	6.75	1067.80	15.19	1067.80	15.19
MB12_131	0.1959	0.0011	1153.38	6.01	1179.25	11.95	1179.25	11.95
MB12_130	0.1771	0.0016	1051.00	9.03	1093.78	20.30	1093.78	20.30
MB12_129	0.2315	0.0018	1342.47	9.57	1335.85	15.54	1335.85	15.54
MB12_128	0.5025	0.0029	2624.36	12.25	2635.89	9.62	2635.89	9.62
MB12_127	0.1970	0.0025	1159.35	13.58	1119.17	24.62	1119.17	24.62
MB12_126	0.5537	0.0055	2840.50	22.58	2874.25	10.79	2874.25	10.79
MB12_124	0.2832	0.0023	1607.44	11.56	1643.59	12.73	1643.59	12.73
MB12_120	0.1736	0.0013	1032.07	6.98	1060.67	13.16	1060.67	13.16
MB12_118	0.2490	0.0020	1433.45	10.42	1494.73	12.83	1494.73	12.83
MB12_116	0.3075	0.0022	1728.40	10.94	1756.61	11.09	1756.61	11.09
MB12_115	0.3167	0.0022	1773.71	10.88	1788.92	10.92	1788.92	10.92
MB12_113	0.3310	0.0026	1843.24	12.76	1887.99	11.60	1887.99	11.60
MB12_112	0.1822	0.0031	1078.95	16.88	1153.10	28.42	1153.10	28.42
MB12_110	0.1596	0.0013	954.77	7.01	1010.00	12.77	1010.00	12.77
MB12_109	0.1933	0.0042	1139.29	22.42	1195.16	37.68	1195.16	37.68
MB12_108	0.2570	0.0021	1474.59	11.01	1457.64	13.28	1457.64	13.28
MB12_106	0.2542	0.0021	1460.10	10.62	1454.58	11.88	1454.58	11.88
MB12_105	0.2515	0.0025	1446.19	12.92	1480.10	14.74	1480.10	14.74
MB12_104	0.3107	0.0040	1744.21	19.87	1752.69	27.90	1752.69	27.90
MB12_101	0.2989	0.0030	1685.85	14.67	1754.07	12.71	1754.07	12.71
MB12_99	0.1664	0.0015	992.20	8.11	1003.81	13.09	1003.81	13.09
MB12_96	0.1792	0.0017	1062.82	9.47	1050.86	13.56	1050.86	13.56
MB12_95	0.2413	0.0018	1393.43	9.50	1382.74	11.73	1382.74	11.73
MB12_93	0.1611	0.0016	962.76	8.67	994.49	13.38	962.76	8.67
MB12_92	0.1924	0.0015	1134.13	7.94	1152.04	12.32	1152.04	12.32
MB12_91	0.1772	0.0020	1051.78	10.87	1147.65	17.89	1147.65	17.89
MB12_90	0.2092	0.0021	1224.46	11.44	1277.29	18.73	1277.29	18.73
MB12_89	0.2019	0.0017	1185.72	9.26	1133.56	16.15	1133.56	16.15

MB12_88	0.1817	0.0023	1076.44	12.29	1147.80	20.15	1147.80	20.15
MB12_87	0.3271	0.0026	1824.51	12.42	1771.69	11.27	1771.69	11.27
MB12_86	0.2724	0.0020	1552.77	10.32	1494.65	11.41	1494.65	11.41
MB12_85	0.5192	0.0051	2695.80	21.55	2722.05	11.00	2722.05	11.00
MB12_84	0.1806	0.0017	1070.40	9.36	1059.77	17.00	1059.77	17.00
MB12_83	0.0738	0.0009	459.06	5.22	457.07	27.03	459.06	5.22
MB12_82	0.1918	0.0017	1131.13	9.08	1167.52	15.07	1167.52	15.07
MB12_81	0.2235	0.0019	1300.28	10.01	1296.60	13.33	1296.60	13.33
MB12_80	0.4863	0.0039	2554.55	16.93	2574.45	9.85	2574.45	9.85
MB12_79	0.2876	0.0020	1629.33	10.25	1677.16	10.99	1677.16	10.99
MB12_78	0.1788	0.0015	1060.15	8.19	1038.23	17.57	1038.23	17.57
MB12_77	0.2811	0.0018	1596.81	9.14	1643.61	10.78	1643.61	10.78
MB12_76	0.5320	0.0040	2749.91	16.61	2763.52	9.67	2763.52	9.67
MB12_75	0.2031	0.0014	1192.15	7.40	1187.92	12.57	1187.92	12.57
MB12_74	0.1733	0.0016	1030.18	8.57	1112.53	14.98	1112.53	14.98
MB12_73	0.3280	0.0022	1828.47	10.66	1821.73	10.64	1821.73	10.64
MB12_72	0.2012	0.0020	1181.94	10.65	1172.97	18.10	1172.97	18.10
MB12_71	0.2521	0.0017	1449.38	8.93	1504.72	11.59	1504.72	11.59
MB12_70	0.4805	0.0035	2529.54	15.37	2754.58	9.65	2754.58	9.65
MB12_68	0.1995	0.0021	1172.75	11.26	1131.12	21.59	1131.12	21.59
MB12_67	0.1781	0.0017	1056.56	9.17	1045.44	16.13	1045.44	16.13
MB12_65	0.2056	0.0023	1205.54	12.22	1178.01	13.18	1178.01	13.18
MB12_62	0.3257	0.0031	1817.67	14.90	1748.05	9.12	1748.05	9.12
MB12_61	0.2946	0.0038	1664.42	19.11	1755.46	9.01	1755.46	9.01
MB12_60	0.1941	0.0025	1143.50	13.43	1187.86	15.57	1187.86	15.57
MB12_57	0.3470	0.0030	1920.47	14.33	1846.06	8.28	1846.06	8.28
MB12_56	0.2574	0.0022	1476.68	11.45	1451.61	11.68	1451.61	11.68
MB12_55	0.1854	0.0021	1096.43	11.38	1097.97	21.15	1097.97	21.15
MB12_54	0.2655	0.0026	1517.96	13.44	1501.28	13.81	1501.28	13.81
MB12_53	0.2479	0.0043	1427.55	22.07	1353.52	19.28	1353.52	19.28
MB12_52	0.3409	0.0053	1891.10	25.59	1864.91	12.45	1864.91	12.45
MB12_51	0.5134	0.0073	2671.12	30.98	2815.87	9.52	2815.87	9.52
MB12_50	0.2215	0.0033	1289.83	17.39	1269.91	12.98	1269.91	12.98
MB12_49	0.2439	0.0040	1407.01	20.86	1431.81	17.87	1431.81	17.87
MB12_48	0.2258	0.0032	1312.55	16.91	1333.93	10.93	1333.93	10.93
MB12_46	0.1962	0.0033	1154.98	17.73	1153.21	19.98	1153.21	19.98
MB12_45	0.1772	0.0037	1051.67	20.31	1101.93	24.18	1101.93	24.18
MB12_44	0.1678	0.0023	999.74	12.90	997.59	9.71	999.74	12.90
MB12_43	0.1821	0.0027	1078.48	14.82	1049.34	14.19	1049.34	14.19
MB12_41	0.2064	0.0033	1209.69	17.71	1165.43	10.73	1165.43	10.73
MB12_40	0.2315	0.0043	1342.27	22.48	1276.63	14.00	1276.63	14.00
MB12_39	0.2058	0.0043	1206.47	23.04	1253.49	23.88	1253.49	23.88
MB12_38	0.2438	0.0045	1406.61	23.23	1546.36	13.73	1546.36	13.73
MB12_37	0.1759	0.0032	1044.30	17.68	1046.76	12.27	1046.76	12.27
MB12_36	0.2014	0.0035	1182.99	18.66	1163.16	12.03	1163.16	12.03

MB12_35	0.1740	0.0036	1033.87	19.77	1031.20	16.45	1031.20	16.45
MB12_34	0.2130	0.0039	1244.55	20.93	1183.81	12.10	1183.81	12.10
MB12_33	0.1978	0.0036	1163.28	19.51	1158.04	12.35	1158.04	12.35
MB12_31	0.1749	0.0031	1039.19	17.06	1025.55	12.62	1025.55	12.62
MB12_30	0.1754	0.0032	1041.66	17.51	1025.97	10.59	1025.97	10.59
MB12_29	0.1765	0.0038	1047.65	21.02	1100.15	22.94	1100.15	22.94
MB12_28	0.1798	0.0032	1065.70	17.47	1052.78	13.65	1052.78	13.65
MB12_27	0.3344	0.0055	1859.54	26.53	1825.24	9.46	1825.24	9.46
MB12_26	0.1724	0.0029	1025.06	15.96	998.31	17.25	998.31	17.25
MB12_25	0.2146	0.0035	1253.27	18.41	1182.03	14.85	1182.03	14.85
MB12_24	0.2525	0.0038	1451.14	19.74	1610.34	8.60	1610.34	8.60
MB12_23	0.3124	0.0034	1752.69	16.68	1747.56	10.14	1747.56	10.14
MB12_22	0.1825	0.0021	1080.76	11.44	1137.55	10.35	1137.55	10.35
MB12_21	0.1771	0.0023	1050.84	12.54	1112.07	12.63	1112.07	12.63
MB12_19	0.1969	0.0021	1158.76	11.14	1155.15	11.84	1155.15	11.84
MB12_17	0.1725	0.0019	1026.11	10.48	1016.40	11.34	1016.40	11.34
MB12_16	0.0697	0.0008	434.40	4.91	426.44	23.42	434.40	4.91
MB12_15	0.1925	0.0019	1134.75	10.28	1158.03	9.47	1158.03	9.47
MB12_14	0.4555	0.0056	2419.67	24.62	2562.66	8.36	2562.66	8.36
MB12_13	0.1710	0.0024	1017.45	12.97	1029.92	15.07	1029.92	15.07
MB12_12	0.2445	0.0031	1410.06	16.05	1451.43	10.34	1451.43	10.34
MB12_10	0.2114	0.0030	1236.21	15.78	1221.71	17.78	1221.71	17.78
MB12_9	0.3407	0.0047	1889.90	22.32	1854.24	10.81	1854.24	10.81
MB12_8	0.1754	0.0020	1041.81	10.87	1051.99	12.67	1051.99	12.67
MB12_7	0.2504	0.0035	1440.37	17.96	1430.05	14.18	1430.05	14.18
MB12_6	0.3178	0.0065	1779.11	31.90	1723.28	12.20	1723.28	12.20
MB12_5	0.0750	0.0010	466.38	6.27	461.52	16.16	466.38	6.27
MB12_4	0.1919	0.0036	1131.67	19.20	1066.15	17.79	1066.15	17.79
MB12_3	0.2047	0.0027	1200.61	14.61	1215.04	11.91	1215.04	11.91
MB12_2	0.1890	0.0032	1115.99	17.06	1137.38	11.51	1137.38	11.51

Discordance >10%

MB12_134	0.1536	0.0020	921.11	11.22	1053.88	25.86
MB12_125	0.2142	0.0014	1251.35	7.27	2185.49	10.38
MB12_123	0.1569	0.0044	939.72	24.23	2425.03	34.57
MB12_122	0.1050	0.0007	643.93	4.32	2222.24	10.69
MB12_121	0.1061	0.0019	649.93	11.24	1823.11	13.87
MB12_119	0.1926	0.0023	1135.56	12.22	1381.12	24.62
MB12_117	0.4000	0.0053	2169.10	24.26	2657.47	13.71
MB12_114	0.1442	0.0020	868.48	11.37	1379.16	23.40
MB12_111	0.4111	0.0029	2219.74	13.43	2520.17	9.99
MB12_107	0.0735	0.0011	456.93	6.82	1662.89	38.55
MB12_103	0.4131	0.0046	2228.95	21.10	2761.90	33.78
MB12_102	0.1763	0.0025	1046.54	13.77	1392.59	17.32
MB12_100	0.0665	0.0013	414.79	8.06	1607.05	49.94

MB12_94	0.0737	0.0014	458.27	8.54	759.18	22.83
MB12_69	0.0746	0.0007	463.84	4.44	553.36	29.11
MB12_66	0.3208	0.0056	1793.46	27.41	2768.34	7.34
MB12_63	0.1591	0.0017	952.05	9.43	1236.10	9.30
MB12_59	0.2553	0.0132	1465.73	67.52	3239.96	59.68
MB12_58	0.0607	0.0015	379.70	8.98	2416.78	15.70
MB12_47	0.1832	0.0030	1084.19	16.29	1343.31	22.16
MB12_42	0.2903	0.0056	1643.26	27.76	2782.88	7.73
MB12_32	0.0691	0.0012	430.50	7.04	559.59	14.83
MB12_20	0.1906	0.0023	1124.64	12.53	1992.10	8.89
MB12_18	0.5258	0.0057	2723.73	23.97	3085.66	6.71
MB12_11	0.2071	0.0037	1213.20	19.60	1402.19	14.64
MB12_1	0.1417	0.0036	854.24	20.44	1471.13	16.93

MB 1-3

Sample MB-1-3 (Middle Bloyd Sandstone) U–Pb detrital zircon LA-ICP-MS analysis results

	Isotopic Ratio		**Apparent Ages**					
Sample	**206/238**	**±1σ**	**206/238**	**±1σ (Ma)**	**207/206**	**±1σ (Ma)**	**Best Age**	**±1σ (Ma)**
MB13_124	0.1882	0.0023	1111.86	12.55	1065.73	10.34	1065.73	10.34
MB13_123	0.0770	0.0009	478.18	5.66	516.61	16.67	516.61	16.67
MB13_122	0.3234	0.0038	1806.50	18.46	1744.20	5.63	1744.20	5.63
MB13_121	0.4963	0.0059	2597.80	25.19	2751.55	5.39	2751.55	5.39
MB13_120	0.1907	0.0029	1124.95	15.82	1131.12	17.98	1131.12	17.98
MB13_119	0.1943	0.0025	1144.70	13.40	1155.62	8.70	1155.62	8.70
MB13_118	0.1790	0.0022	1061.29	12.08	1054.32	8.93	1054.32	8.93
MB13_116	0.2037	0.0113	1195.34	60.15	1229.51	57.95	1229.51	57.95
MB13_115	0.4557	0.0053	2420.75	23.49	2573.59	5.59	2573.59	5.59
MB13_114	0.2607	0.0028	1493.42	14.47	1517.58	6.46	1517.58	6.46
MB13_113	0.2832	0.0048	1607.39	24.28	1691.36	14.96	1691.36	14.96
MB13_112	0.1986	0.0027	1167.69	14.48	1251.47	28.25	1251.47	28.25
MB13_111	0.1864	0.0023	1101.76	12.72	1116.83	15.04	1116.83	15.04
MB13_110	0.2242	0.0053	1303.83	28.02	1316.11	27.42	1316.11	27.42
MB13_109	0.3210	0.0094	1794.82	45.50	1922.53	26.71	1922.53	26.71
MB13_108	0.3419	0.0040	1895.96	19.21	1886.65	7.13	1886.65	7.13
MB13_107	0.5110	0.0056	2660.90	23.66	2694.99	4.88	2694.99	4.88
MB13_106	0.2563	0.0031	1470.92	15.84	1511.50	9.49	1511.50	9.49
MB13_104	0.1747	0.0036	1037.77	19.51	1099.38	18.41	1099.38	18.41
MB13_103	0.1794	0.0031	1063.94	16.68	1059.21	7.81	1059.21	7.81
MB13_102	0.5020	0.0092	2622.25	39.54	2729.84	6.89	2729.84	6.89
MB13_101	0.3835	0.0065	2092.67	30.28	2107.33	6.20	2107.33	6.20

MB13_100	0.2806	0.0049	1594.63	24.56	1586.95	7.80	1586.95	7.80
MB13_99	0.2420	0.0043	1397.14	22.11	1356.82	10.77	1356.82	10.77
MB13_98	0.2020	0.0034	1186.13	18.18	1170.06	7.88	1170.06	7.88
MB13_97	0.2944	0.0051	1663.69	25.38	1675.50	8.91	1675.50	8.91
MB13_96	0.4873	0.0087	2558.99	37.45	2693.49	5.77	2693.49	5.77
MB13_95	0.2026	0.0038	1189.16	20.11	1208.40	12.30	1208.40	12.30
MB13_94	0.1697	0.0029	1010.63	15.93	996.80	6.83	996.80	6.83
MB13_93	0.1679	0.0031	1000.45	17.26	1025.46	8.49	1025.46	8.49
MB13_92	0.1944	0.0042	1145.04	22.56	1152.20	27.13	1152.20	27.13
MB13_91	0.0857	0.0017	529.79	9.96	559.30	32.99	559.30	32.99
MB13_90	0.1917	0.0027	1130.72	14.82	1125.30	20.79	1125.30	20.79
MB13_89	0.3039	0.0020	1710.43	9.73	1669.95	5.96	1669.95	5.96
MB13_87	0.3031	0.0037	1706.80	18.09	1679.06	14.47	1679.06	14.47
MB13_86	0.1767	0.0012	1049.17	6.64	1020.35	8.83	1020.35	8.83
MB13_85	0.2984	0.0021	1683.54	10.56	1647.85	7.12	1647.85	7.12
MB13_84	0.3128	0.0023	1754.34	11.40	1737.15	6.92	1737.15	6.92
MB13_83	0.5341	0.0038	2758.62	15.95	2713.90	5.20	2713.90	5.20
MB13_82	0.1981	0.0014	1165.15	7.53	1145.55	7.86	1145.55	7.86
MB13_81	0.1787	0.0040	1060.07	21.60	1101.08	47.72	1101.08	47.72
MB13_80	0.2510	0.0021	1443.49	10.67	1380.32	9.51	1380.32	9.51
MB13_79	0.2590	0.0017	1484.49	8.64	1445.22	6.78	1445.22	6.78
MB13_78	0.2723	0.0061	1552.56	30.58	1509.21	24.20	1509.21	24.20
MB13_77	0.3830	0.0025	2090.45	11.83	2064.68	5.80	2064.68	5.80
MB13_76	0.2273	0.0018	1320.34	9.26	1296.38	9.12	1296.38	9.12
MB13_75	0.2842	0.0044	1612.36	22.17	1540.70	9.86	1540.70	9.86
MB13_74	0.1938	0.0030	1142.03	16.23	1173.94	9.64	1173.94	9.64
MB13_73	0.1874	0.0045	1107.33	24.18	1194.54	18.96	1194.54	18.96
MB13_71	0.1767	0.0027	1049.17	14.91	1040.04	10.50	1040.04	10.50
MB13_69	0.2915	0.0046	1649.14	22.75	1663.97	8.03	1663.97	8.03
MB13_68	0.2942	0.0044	1662.53	21.71	1653.07	7.37	1653.07	7.37
MB13_67	0.5002	0.0083	2614.66	35.44	2699.53	7.17	2699.53	7.17
MB13_66	0.2041	0.0032	1197.10	17.18	1165.94	9.65	1165.94	9.65
MB13_65	0.3037	0.0045	1709.48	22.43	1734.45	5.55	1734.45	5.55
MB13_64	0.2012	0.0030	1181.65	15.95	1168.72	7.39	1168.72	7.39
MB13_63	0.2314	0.0036	1341.73	19.00	1385.51	11.47	1385.51	11.47
MB13_62	0.0760	0.0013	472.49	8.05	509.25	27.76	509.25	27.76
MB13_61	0.1798	0.0028	1066.12	15.21	1076.33	8.75	1076.33	8.75
MB13_60	0.2576	0.0018	1477.57	9.35	1441.36	9.39	1441.36	9.39
MB13_59	0.5483	0.0037	2817.93	15.37	2789.24	5.10	2789.24	5.10
MB13_58	0.2128	0.0025	1243.55	13.41	1200.02	18.76	1200.02	18.76
MB13_57	0.3110	0.0022	1745.57	10.73	1764.18	6.71	1764.18	6.71
MB13_56	0.1794	0.0014	1063.57	7.57	1026.93	10.05	1026.93	10.05
MB13_55	0.1808	0.0012	1071.20	6.67	1031.31	8.32	1031.31	8.32
MB13_54	0.1853	0.0020	1095.93	11.09	1115.29	18.23	1115.29	18.23
MB13_53	0.4634	0.0031	2454.59	13.66	2396.76	5.22	2396.76	5.22

MB13_52	0.1768	0.0012	1049.68	6.74	1026.40	10.13	1026.40	10.13
MB13_51	0.2198	0.0014	1280.97	7.61	1290.14	8.56	1290.14	8.56
MB13_50	0.2694	0.0035	1537.61	18.00	1662.94	8.87	1662.94	8.87
MB13_49	0.1827	0.0024	1081.66	12.80	1171.49	11.68	1171.49	11.68
MB13_48	0.3103	0.0039	1742.18	19.23	1830.30	8.43	1830.30	8.43
MB13_47	0.0711	0.0009	443.01	5.36	477.56	13.74	477.56	13.74
MB13_45	0.0676	0.0009	421.92	5.35	446.10	19.09	446.10	19.09
MB13_44	0.1742	0.0022	1035.15	12.24	1038.47	12.68	1038.47	12.68
MB13_43	0.2652	0.0037	1516.53	18.83	1648.72	9.84	1648.72	9.84
MB13_41	0.1564	0.0030	936.71	16.45	1039.37	31.33	1039.37	31.33
MB13_40	0.1799	0.0025	1066.21	13.70	1120.33	15.56	1120.33	15.56
MB13_39	0.1971	0.0026	1159.67	14.06	1274.67	17.17	1274.67	17.17
MB13_38	0.1849	0.0026	1093.83	14.25	1159.86	15.29	1159.86	15.29
MB13_37	0.1724	0.0024	1025.21	13.08	1049.08	9.36	1049.08	9.36
MB13_36	0.1984	0.0031	1166.80	16.47	1093.83	24.73	1093.83	24.73
MB13_35	0.1782	0.0023	1057.14	12.74	1060.55	23.90	1060.55	23.90
MB13_34	0.1874	0.0027	1107.06	14.63	1171.41	26.78	1171.41	26.78
MB13_33	0.1832	0.0017	1084.20	9.19	1019.87	11.76	1019.87	11.76
MB13_32	0.5547	0.0048	2844.68	19.87	2866.97	6.63	2866.97	6.63
MB13_31	0.2030	0.0018	1191.27	9.69	1170.68	10.39	1170.68	10.39
MB13_30	0.5548	0.0048	2844.97	19.81	2886.59	6.59	2886.59	6.59
MB13_29	0.3025	0.0026	1703.67	13.03	1726.86	8.15	1726.86	8.15
MB13_27	0.4943	0.0093	2589.30	40.07	2688.35	14.18	2688.35	14.18
MB13_26	0.1694	0.0021	1008.56	11.76	1055.13	19.81	1055.13	19.81
MB13_25	0.2034	0.0030	1193.73	16.05	1194.08	19.41	1194.08	19.41
MB13_24	0.2873	0.0036	1627.92	17.98	1653.35	10.09	1653.35	10.09
MB13_22	0.1922	0.0024	1133.02	12.95	1118.31	9.80	1118.31	9.80
MB13_21	0.0677	0.0010	422.45	6.17	404.03	31.86	404.03	31.86
MB13_20	0.5273	0.0067	2730.22	28.11	2708.65	7.37	2708.65	7.37
MB13_19	0.1922	0.0024	1133.48	12.99	1130.17	10.56	1130.17	10.56
MB13_18	0.5342	0.0073	2759.31	30.49	2810.92	8.04	2810.92	8.04
MB13_16	0.1763	0.0024	1046.98	13.35	1054.60	16.83	1054.60	16.83
MB13_15	0.1867	0.0023	1103.58	12.47	1212.04	9.52	1212.04	9.52
MB13_14	0.3186	0.0038	1783.06	18.44	1785.31	8.10	1785.31	8.10
MB13_13	0.1713	0.0021	1019.42	11.64	1006.21	11.58	1006.21	11.58
MB13_12	0.1881	0.0028	1111.14	14.96	1129.14	14.22	1129.14	14.22
MB13_11	0.2235	0.0039	1300.13	20.32	1339.87	13.56	1339.87	13.56
MB13_9	0.1695	0.0022	1009.22	11.95	1055.45	9.15	1055.45	9.15
MB13_8	0.2023	0.0025	1187.53	13.50	1267.38	9.87	1267.38	9.87
MB13_6	0.1714	0.0021	1019.59	11.47	1031.93	9.49	1031.93	9.49
MB13_5	0.1929	0.0019	1137.10	10.47	1171.13	11.34	1171.13	11.34
MB13_4	0.1777	0.0018	1054.52	9.58	1078.20	9.87	1078.20	9.87
MB13_3	0.1969	0.0019	1158.38	10.30	1176.16	8.74	1176.16	8.74
MB13_2	0.1627	0.0016	971.70	8.66	1066.69	9.09	1066.69	9.09
MB13_1	0.1995	0.0023	1172.79	12.40	1179.70	14.41	1179.70	14.41

Discordance >10%

MB13_125	0.2327	0.0030	1348.62	15.88	1943.68	7.91
MB13_117	0.3619	0.0047	1991.39	22.06	2222.36	9.42
MB13_88	0.1083	0.0016	662.59	9.21	1092.18	12.23
MB13_72	0.1925	0.0035	1134.96	18.67	1388.15	16.90
MB13_70	0.2012	0.0051	1181.55	27.45	1440.85	31.62
MB13_46	0.1707	0.0025	1015.70	13.57	1242.62	17.40
MB13_42	0.1162	0.0019	708.82	11.18	1674.82	14.37
MB13_28	0.1720	0.0017	1023.04	9.48	1242.72	14.14
MB13_23	0.1590	0.0020	950.97	11.16	1329.56	8.89
MB13_17	0.1864	0.0034	1101.80	18.56	1225.03	30.85
MB13_10	0.1403	0.0017	846.55	9.77	1357.90	8.86

MB 2-1

Sample MB-2-1 (Middle Bloyd Sandstone) U–Pb detrital zircon LA-ICP-MS analysis results

	Isotopic Ratio		**Apparent Ages**					
Sample	**206/238**	**±1σ**	**206/238**	**±1σ (Ma)**	**207/206**	**±1σ (Ma)**	**Best Age**	**±1σ (Ma)**
MB21_135	0.1560	0.0014	934.62	7.74	1018.08	17.42	1018.08	17.42
MB21_134	0.1478	0.0014	888.61	7.89	943.55	19.86	943.55	19.86
MB21_133	0.1843	0.0015	1090.35	8.30	1158.01	13.81	1158.01	13.81
MB21_132	0.2414	0.0020	1393.81	10.61	1446.99	13.33	1446.99	13.33
MB21_131	0.1555	0.0014	931.58	7.81	972.23	18.27	931.58	7.81
MB21_130	0.2550	0.0030	1464.15	15.40	1455.47	21.19	1455.47	21.19
MB21_129	0.1788	0.0017	1060.68	9.02	1116.52	15.90	1116.52	15.90
MB21_127	0.1662	0.0014	991.28	7.91	1072.60	14.47	1072.60	14.47
MB21_126	0.1785	0.0015	1058.96	8.08	1122.69	12.61	1122.69	12.61
MB21_125	0.1540	0.0018	923.52	10.06	1009.33	26.86	1009.33	26.86
MB21_123	0.1564	0.0014	936.60	7.62	993.45	15.55	936.60	7.62
MB21_122	0.1615	0.0014	964.84	7.64	1034.28	15.27	1034.28	15.27
MB21_121	0.1803	0.0016	1068.54	8.65	1153.04	15.53	1153.04	15.53
MB21_120	0.2670	0.0029	1525.32	14.70	1653.13	13.09	1653.13	13.09
MB21_119	0.1601	0.0018	957.21	10.17	1013.24	19.44	1013.24	19.44
MB21_118	0.1784	0.0020	1057.96	10.91	1187.15	18.27	1187.15	18.27
MB21_117	0.2137	0.0024	1248.44	12.99	1343.93	16.11	1343.93	16.11
MB21_116	0.1779	0.0025	1055.62	13.44	1123.73	27.15	1123.73	27.15
MB21_115	0.1710	0.0040	1017.40	21.72	1016.07	43.15	1016.07	43.15
MB21_112	0.1622	0.0018	968.81	9.72	993.37	15.72	968.81	9.72
MB21_111	0.1917	0.0020	1130.81	10.70	1157.94	13.63	1157.94	13.63

MB21_110	0.2884	0.0030	1633.44	14.98	1648.62	12.26	1648.62	12.26
MB21_108	0.2396	0.0025	1384.62	12.98	1443.64	12.41	1443.64	12.41
MB21_107	0.1980	0.0027	1164.77	14.30	1256.80	19.69	1256.80	19.69
MB21_105	0.2965	0.0030	1674.05	14.82	1727.02	11.91	1727.02	11.91
MB21_102	0.2059	0.0025	1206.85	13.12	1348.38	19.63	1348.38	19.63
MB21_99	0.2729	0.0028	1555.41	14.03	1623.45	12.12	1623.45	12.12
MB21_98	0.4828	0.0054	2539.50	23.46	2715.47	10.80	2715.47	10.80
MB21_96	0.2720	0.0029	1551.09	14.74	1637.52	13.16	1637.52	13.16
MB21_94	0.1781	0.0019	1056.59	10.46	1080.30	16.03	1080.30	16.03
MB21_93	0.1798	0.0019	1065.79	10.59	1078.26	16.33	1078.26	16.33
MB21_92	0.1795	0.0019	1064.26	10.56	1162.01	16.67	1162.01	16.67
MB21_91	0.2597	0.0027	1488.36	13.81	1626.39	12.28	1626.39	12.28
MB21_89	0.2190	0.0026	1276.74	13.56	1363.83	20.73	1363.83	20.73
MB21_88	0.1671	0.0015	996.01	8.04	1049.56	18.46	1049.56	18.46
MB21_87	0.0669	0.0006	417.34	3.92	415.01	32.65	417.34	3.92
MB21_86	0.2352	0.0022	1361.81	11.34	1504.28	15.64	1504.28	15.64
MB21_85	0.1883	0.0013	1112.31	7.12	1152.59	15.37	1152.59	15.37
MB21_84	0.4987	0.0032	2608.15	13.96	2724.69	10.50	2724.69	10.50
MB21_83	0.1956	0.0031	1151.71	16.54	1214.16	34.20	1214.16	34.20
MB21_82	0.2132	0.0015	1245.74	7.82	1305.20	14.81	1305.20	14.81
MB21_81	0.4467	0.0038	2380.47	16.79	2462.69	12.52	2462.69	12.52
MB21_80	0.1849	0.0017	1093.94	9.29	1145.65	18.77	1145.65	18.77
MB21_79	0.1759	0.0026	1044.40	14.51	1081.49	30.08	1081.49	30.08
MB21_78	0.2645	0.0019	1513.06	9.79	1639.12	13.76	1639.12	13.76
MB21_77	0.2422	0.0016	1398.28	8.19	1447.52	12.66	1447.52	12.66
MB21_75	0.1809	0.0018	1071.83	9.76	1194.55	17.91	1194.55	17.91
MB21_74	0.2330	0.0020	1350.32	10.59	1263.51	13.80	1263.51	13.80
MB21_73	0.2969	0.0032	1676.05	16.12	1664.56	18.18	1664.56	18.18
MB21_72	0.0712	0.0008	443.62	5.03	432.82	32.34	443.62	5.03
MB21_70	0.1510	0.0017	906.73	9.32	965.50	23.79	906.73	9.32
MB21_69	0.1549	0.0014	928.29	7.91	951.99	17.17	928.29	7.91
MB21_68	0.1766	0.0024	1048.13	12.94	1063.78	17.54	1063.78	17.54
MB21_67	0.1793	0.0027	1063.22	15.01	1113.47	35.04	1113.47	35.04
MB21_66	0.2094	0.0020	1225.37	10.56	1266.05	16.91	1266.05	16.91
MB21_65	0.0993	0.0009	610.50	5.04	651.30	19.16	610.50	5.04
MB21_63	0.5080	0.0056	2648.14	23.68	2564.72	13.59	2564.72	13.59
MB21_62	0.2712	0.0026	1547.01	13.20	1531.74	16.09	1531.74	16.09
MB21_61	0.2501	0.0023	1438.84	11.76	1479.10	14.97	1479.10	14.97
MB21_58	0.1633	0.0011	974.97	6.33	1002.46	14.91	1002.46	14.91
MB21_57	0.1564	0.0018	936.78	9.99	1014.47	16.49	1014.47	16.49
MB21_55	0.2527	0.0018	1452.24	9.29	1474.17	13.26	1474.17	13.26
MB21_53	0.1693	0.0026	1008.00	14.07	975.96	35.29	975.96	35.29
MB21_52	0.2576	0.0017	1477.59	8.67	1423.44	12.95	1423.44	12.95
MB21_51	0.0662	0.0006	413.25	3.46	414.08	24.32	413.25	3.46
MB21_50	0.1678	0.0018	999.84	9.71	1044.44	22.73	1044.44	22.73

MB21_49	0.2160	0.0024	1260.86	12.81	1280.26	21.10	1280.26	21.10
MB21_48	0.2073	0.0016	1214.23	8.50	1306.92	13.26	1306.92	13.26
MB21_47	0.1952	0.0014	1149.46	7.42	1157.46	13.82	1157.46	13.82
MB21_46	0.2290	0.0016	1329.38	8.29	1372.78	13.06	1372.78	13.06
MB21_44	0.1706	0.0018	1015.18	10.15	1008.54	18.37	1008.54	18.37
MB21_43	0.1972	0.0026	1160.16	14.08	1218.27	16.85	1218.27	16.85
MB21_42	0.1645	0.0022	981.86	12.16	972.29	25.23	981.86	12.16
MB21_41	0.2044	0.0023	1198.79	12.36	1185.01	16.07	1185.01	16.07
MB21_40	0.1803	0.0033	1068.74	17.77	1135.89	38.71	1135.89	38.71
MB21_39	0.2403	0.0030	1388.02	15.33	1391.13	17.15	1391.13	17.15
MB21_38	0.1790	0.0025	1061.60	13.39	1064.69	24.76	1064.69	24.76
MB21_37	0.3595	0.0037	1979.86	17.28	1978.96	12.40	1978.96	12.40
MB21_36	0.0597	0.0010	373.85	6.11	380.00	30.40	373.85	6.11
MB21_35	0.0712	0.0007	443.41	4.49	435.42	20.90	443.41	4.49
MB21_34	0.2901	0.0029	1642.25	14.29	1632.98	12.35	1632.98	12.35
MB21_33	0.2379	0.0026	1375.96	13.31	1302.79	16.53	1302.79	16.53
MB21_32	0.2022	0.0019	1186.96	10.42	1203.66	12.88	1203.66	12.88
MB21_31	0.2891	0.0049	1636.92	24.37	1646.86	24.15	1646.86	24.15
MB21_29	0.1931	0.0020	1138.03	10.83	1139.54	14.36	1139.54	14.36
MB21_28	0.1672	0.0020	996.66	10.85	1009.92	17.72	1009.92	17.72
MB21_27	0.2096	0.0030	1226.60	15.73	1228.91	16.36	1228.91	16.36
MB21_26	0.2160	0.0026	1260.75	13.73	1249.58	18.67	1249.58	18.67
MB21_25	0.1921	0.0020	1132.60	10.90	1155.17	14.87	1155.17	14.87
MB21_23	0.1964	0.0030	1156.15	16.30	1129.53	27.37	1129.53	27.37
MB21_22	0.2793	0.0026	1587.76	12.98	1706.54	8.54	1706.54	8.54
MB21_21	0.1800	0.0022	1067.12	12.22	1142.91	20.79	1142.91	20.79
MB21_20	0.1936	0.0022	1141.06	12.01	1185.65	18.02	1185.65	18.02
MB21_19	0.5290	0.0072	2737.33	30.25	2789.74	9.63	2789.74	9.63
MB21_18	0.1784	0.0017	1058.26	9.40	1097.03	10.18	1097.03	10.18
MB21_17	0.2595	0.0028	1487.29	14.15	1641.06	11.59	1641.06	11.59
MB21_16	0.1663	0.0016	991.52	8.91	986.63	12.20	991.52	8.91
MB21_14	0.1916	0.0014	1130.30	7.55	1144.52	11.46	1144.52	11.46
MB21_13	0.1708	0.0014	1016.73	7.89	1064.66	16.51	1064.66	16.51
MB21_11	0.1799	0.0017	1066.31	9.45	1019.17	18.46	1019.17	18.46
MB21_10	0.1782	0.0016	1056.90	8.48	1124.57	13.73	1124.57	13.73
MB21_9	0.1898	0.0023	1120.20	12.40	1180.78	25.58	1180.78	25.58
MB21_8	0.2268	0.0025	1317.87	13.29	1360.68	19.85	1360.68	19.85
MB21_7	0.1953	0.0025	1149.89	13.57	1109.29	26.61	1109.29	26.61
MB21_6	0.2116	0.0015	1237.25	8.09	1258.90	12.14	1258.90	12.14
MB21_5	0.2203	0.0020	1283.24	10.50	1334.15	15.06	1334.15	15.06
MB21_3	0.1698	0.0018	1010.89	9.84	1054.01	24.68	1054.01	24.68
MB21_2	0.2709	0.0021	1545.47	10.68	1700.84	10.34	1700.84	10.34
MB21_1	0.1946	0.0017	1146.25	8.90	1133.52	15.65	1133.52	15.65

Discordance >10%

MB21_128	0.2342	0.0051	1356.24	26.46	3075.17	44.17
MB21_124	0.1652	0.0014	985.42	7.75	1113.11	15.45
MB21_114	0.1613	0.0039	964.13	21.37	1137.10	48.24
MB21_113	0.1773	0.0022	1052.44	12.18	1312.58	17.95
MB21_109	0.0810	0.0018	502.20	10.73	1084.28	26.77
MB21_106	0.0639	0.0012	399.24	7.53	2112.14	58.08
MB21_104	0.1008	0.0024	618.98	14.18	1497.33	18.17
MB21_103	0.2709	0.0029	1545.58	14.73	1744.98	12.45
MB21_101	0.1714	0.0019	1019.56	10.57	1157.77	14.45
MB21_100	0.0646	0.0008	403.68	4.62	465.71	21.54
MB21_97	0.4414	0.0057	2357.09	25.59	2683.35	12.35
MB21_95	0.1672	0.0025	996.51	14.02	1282.20	32.63
MB21_90	0.1740	0.0030	1034.29	16.72	1163.52	31.05
MB21_76	0.0678	0.0006	422.94	3.50	536.41	24.52
MB21_71	0.2155	0.0037	1257.98	19.33	1512.23	28.82
MB21_64	0.0668	0.0006	416.92	3.66	492.88	19.64
MB21_59	0.0633	0.0008	395.38	4.58	324.29	44.02
MB21_56	0.1725	0.0022	1025.75	11.86	1190.52	29.37
MB21_54	0.1921	0.0017	1132.62	9.26	1336.03	21.02
MB21_24	0.1061	0.0028	650.18	16.10	889.40	55.74
MB21_12	0.1661	0.0106	990.52	58.22	1272.53	38.05
MB21_4	0.1876	0.0028	1108.42	15.41	992.61	37.40

MB 2-2

Sample MB-2-2 (Middle Bloyd Sandstone) U–Pb detrital zircon LA-ICP-MS analysis results

	Isotopic Ratio		**Apparent Ages**					
Sample	**206/238**	**±1σ**	**206/238**	**±1σ (Ma)**	**207/206**	**±1σ (Ma)**	**Best Age**	**±1σ (Ma)**
MB22_129	0.1968	0.0029	1157.85	15.65	1160.95	13.34	1160.95	13.34
MB22_127	0.1947	0.0035	1146.73	19.11	1089.41	17.68	1089.41	17.68
MB22_126	0.3232	0.0045	1805.43	22.03	1748.33	7.04	1748.33	7.04
MB22_125	0.5288	0.0081	2736.46	33.97	2673.34	6.91	2673.34	6.91
MB22_124	0.1877	0.0032	1109.11	17.26	1129.19	17.97	1129.19	17.97
MB22_123	0.1798	0.0029	1065.81	15.58	1057.54	13.62	1057.54	13.62
MB22_121	0.1746	0.0025	1037.45	13.64	1051.55	8.43	1051.55	8.43
MB22_120	0.2993	0.0041	1687.85	20.40	1745.23	6.17	1745.23	6.17
MB22_119	0.2292	0.0034	1330.48	17.94	1337.66	12.03	1337.66	12.03
MB22_118	0.1907	0.0027	1125.23	14.59	1145.81	10.34	1145.81	10.34
MB22_117	0.1728	0.0026	1027.55	14.31	1060.46	12.98	1060.46	12.98
MB22_116	0.1647	0.0023	982.74	12.96	993.97	13.07	993.97	13.07
MB22_115	0.3082	0.0024	1732.00	12.03	1802.84	8.33	1802.84	8.33

MB22_114	0.1968	0.0028	1158.15	15.11	1163.57	19.97	1163.57	19.97
MB22_113	0.5039	0.0043	2630.72	18.36	2723.51	6.13	2723.51	6.13
MB22_112	0.3891	0.0028	2118.81	13.00	2297.32	6.64	2297.32	6.64
MB22_111	0.1745	0.0011	1036.76	6.14	1084.54	7.33	1084.54	7.33
MB22_110	0.1982	0.0034	1165.78	18.52	1187.68	20.28	1187.68	20.28
MB22_109	0.1823	0.0012	1079.32	6.67	1094.15	8.07	1094.15	8.07
MB22_107	0.3173	0.0023	1776.51	11.00	1842.50	6.77	1842.50	6.77
MB22_106	0.1712	0.0012	1018.74	6.38	1019.80	9.10	1019.80	9.10
MB22_105	0.1788	0.0019	1060.31	10.32	1115.00	17.49	1115.00	17.49
MB22_104	0.3237	0.0025	1807.80	12.35	1796.72	8.99	1796.72	8.99
MB22_103	0.1815	0.0023	1075.00	12.81	1126.32	22.71	1126.32	22.71
MB22_101	0.1986	0.0017	1167.56	9.35	1243.97	12.18	1243.97	12.18
MB22_100	0.4762	0.0045	2510.88	19.76	2639.86	6.63	2639.86	6.63
MB22_98	0.1810	0.0021	1072.28	11.73	1073.03	18.70	1073.03	18.70
MB22_97	0.1813	0.0020	1073.98	10.75	1084.11	17.03	1084.11	17.03
MB22_95	0.3025	0.0025	1703.83	12.55	1732.30	7.39	1732.30	7.39
MB22_95	0.3025	0.0025	1703.83	12.55	1732.30	7.39	1732.30	7.39
MB22_94	0.4801	0.0064	2527.60	27.81	2684.68	8.22	2684.68	8.22
MB22_93	0.2967	0.0024	1674.99	12.16	1759.14	6.71	1759.14	6.71
MB22_92	0.3146	0.0029	1763.19	13.98	1800.57	7.13	1800.57	7.13
MB22_91	0.1975	0.0019	1162.01	10.01	1143.76	12.42	1143.76	12.42
MB22_90	0.1593	0.0019	952.92	10.70	1038.18	17.53	1038.18	17.53
MB22_89	0.4171	0.0036	2247.43	16.53	2450.08	5.84	2450.08	5.84
MB22_88	0.1970	0.0018	1159.07	9.49	1189.84	10.57	1189.84	10.57
MB22_87	0.4769	0.0051	2513.73	22.03	2647.96	6.98	2647.96	6.98
MB22_86	0.1893	0.0022	1117.76	11.99	1198.51	14.28	1198.51	14.28
MB22_70	0.2993	0.0023	1687.67	11.59	1670.51	7.34	1670.51	7.34
MB22_69	0.2765	0.0020	1573.67	10.06	1631.70	6.67	1631.70	6.67
MB22_68	0.1649	0.0018	983.85	9.84	993.66	15.48	993.66	15.48
MB22_66	0.3197	0.0024	1788.46	11.50	1788.08	7.04	1788.08	7.04
MB22_65	0.2364	0.0020	1367.96	10.23	1345.27	10.75	1345.27	10.75
MB22_64	0.2011	0.0016	1181.42	8.43	1208.19	10.18	1208.19	10.18
MB22_62	0.2588	0.0019	1483.46	9.91	1474.28	8.32	1474.28	8.32
MB22_61	0.1827	0.0019	1081.81	10.55	1057.82	16.45	1057.82	16.45
MB22_60	0.1912	0.0019	1127.69	10.03	1154.02	14.22	1154.02	14.22
MB22_59	0.1697	0.0015	1010.27	8.08	1033.13	12.08	1033.13	12.08
MB22_58	0.2887	0.0025	1634.83	12.26	1674.35	10.22	1674.35	10.22
MB22_57	0.2485	0.0022	1430.98	11.27	1469.62	9.36	1469.62	9.36
MB22_55	0.1974	0.0010	1161.56	5.62	1193.47	8.56	1193.47	8.56
MB22_54	0.1710	0.0010	1017.49	5.76	1027.29	10.50	1027.29	10.50
MB22_53	0.2661	0.0027	1520.97	13.86	1577.82	13.74	1577.82	13.74
MB22_52	0.2304	0.0025	1336.52	13.32	1416.19	13.18	1416.19	13.18
MB22_51	0.2893	0.0016	1637.79	8.00	1624.62	6.81	1624.62	6.81
MB22_50	0.0728	0.0005	453.25	2.99	465.94	14.62	465.94	14.62
MB22_49	0.2670	0.0019	1525.69	9.47	1577.36	9.64	1577.36	9.64

MB22_48	0.1899	0.0017	1120.81	9.10	1139.49	14.07	1139.49	14.07
MB22_47	0.1946	0.0015	1146.45	8.04	1267.29	10.18	1267.29	10.18
MB22_45	0.1725	0.0009	1026.10	5.20	1021.30	10.93	1021.30	10.93
MB22_44	0.1497	0.0016	899.35	9.03	954.38	15.41	954.38	15.41
MB22_43	0.3185	0.0016	1782.40	7.95	1734.82	7.81	1734.82	7.81
MB22_42	0.2659	0.0023	1520.09	11.50	1477.94	12.68	1477.94	12.68
MB22_41	0.1695	0.0015	1009.23	8.09	1017.19	15.31	1017.19	15.31
MB22_40	0.1782	0.0020	1056.93	11.00	1086.54	9.67	1086.54	9.67
MB22_39	0.1984	0.0023	1166.46	12.16	1112.28	8.74	1112.28	8.74
MB22_38	0.2750	0.0034	1566.18	17.29	1635.69	9.24	1635.69	9.24
MB22_37	0.1750	0.0020	1039.82	11.14	1070.05	10.43	1070.05	10.43
MB22_36	0.0630	0.0008	393.99	4.65	434.90	20.58	434.90	20.58
MB22_35	0.1919	0.0022	1131.59	11.93	1189.51	10.19	1189.51	10.19
MB22_34	0.1694	0.0018	1008.61	10.12	1045.47	8.19	1045.47	8.19
MB22_33	0.5176	0.0062	2689.12	26.13	2808.24	6.95	2808.24	6.95
MB22_32	0.1919	0.0035	1131.52	18.82	1133.86	24.22	1133.86	24.22
MB22_30	0.1774	0.0025	1052.78	13.48	1075.00	27.44	1075.00	27.44
MB22_29	0.2922	0.0024	1652.73	11.73	1665.07	12.83	1665.07	12.83
MB22_28	0.1715	0.0013	1020.23	7.37	1043.90	13.37	1043.90	13.37
MB22_27	0.1653	0.0014	986.06	7.74	1034.66	15.18	1034.66	15.18
MB22_26	0.1703	0.0013	1013.66	7.20	1059.61	13.33	1059.61	13.33
MB22_25	0.1695	0.0014	1009.33	7.90	1100.01	15.94	1100.01	15.94
MB22_24	0.5283	0.0046	2734.49	19.40	2874.19	10.67	2874.19	10.67
MB22_23	0.2008	0.0019	1179.80	9.99	1242.86	16.35	1242.86	16.35
MB22_22	0.1840	0.0015	1088.57	8.01	1178.30	14.30	1178.30	14.30
MB22_21	0.5864	0.0053	2974.71	21.33	3145.60	9.88	3145.60	9.88
MB22_19	0.3131	0.0063	1755.87	31.08	1829.37	26.63	1829.37	26.63
MB22_18	0.5018	0.0049	2621.71	20.79	2722.68	10.59	2722.68	10.59
MB22_17	0.2444	0.0019	1409.51	9.80	1512.38	12.05	1512.38	12.05
MB22_16	0.2430	0.0024	1402.36	12.26	1460.37	16.11	1460.37	16.11
MB22_15	0.2137	0.0028	1248.44	14.79	1287.58	20.50	1287.58	20.50
MB22_14	0.1800	0.0018	1066.92	9.82	1097.30	14.80	1097.30	14.80
MB22_13	0.1951	0.0019	1148.89	10.37	1180.28	14.22	1180.28	14.22
MB22_12	0.2260	0.0026	1313.58	13.84	1325.03	17.36	1325.03	17.36
MB22_10	0.1613	0.0023	964.25	12.74	1045.06	27.10	1045.06	27.10
MB22_9	0.1853	0.0020	1095.83	11.03	1088.90	19.86	1088.90	19.86
MB22_8	0.1007	0.0010	618.41	5.59	634.74	15.25	634.74	15.25
MB22_6	0.1908	0.0018	1125.48	9.72	1156.81	14.30	1156.81	14.30
MB22_5	0.1748	0.0017	1038.42	9.19	1051.53	14.88	1051.53	14.88
MB22_2	0.1816	0.0017	1075.65	9.35	1071.48	12.97	1071.48	12.97
MB22_1	0.1818	0.0017	1076.96	9.39	1129.41	14.22	1129.41	14.22

Discordance >10%

MB22_130	0.0703	0.0011	437.82	6.86	536.80	23.08
MB22_128	0.2914	0.0041	1648.63	20.56	1845.49	7.49

MB22_122	0.1815	0.0031	1075.23	16.79	1308.23	14.80
MB22_108	0.1400	0.0011	844.87	6.31	1229.00	7.53
MB22_102	0.2025	0.0031	1188.55	16.44	1367.70	21.08
MB22_99	0.3014	0.0031	1698.24	15.58	2617.85	5.09
MB22_67	0.2365	0.0019	1368.39	10.03	1547.10	6.14
MB22_63	0.2272	0.0031	1319.74	16.34	1580.05	21.09
MB22_56	0.2271	0.0026	1319.08	13.72	1763.20	44.22
MB22_46	0.1653	0.0009	986.17	5.13	1108.23	7.99
MB22_31	0.1614	0.0018	964.74	9.83	1105.31	8.52
MB22_20	0.2166	0.0026	1264.05	13.80	2444.55	49.28
MB22_11	0.3698	0.0038	2028.44	17.82	2638.01	10.26
MB22_7	0.1657	0.0016	988.45	9.09	1178.12	16.27
MB22_4	0.0657	0.0007	409.91	4.26	537.94	22.13
MB22_3	0.1671	0.0017	996.33	9.48	1111.59	16.96

MB 2-3

Sample MB-2-3 (Middle Bloyd Sandstone) U–Pb detrital zircon LA-ICP-MS analysis results

	Isotopic Ratio		**Apparent Ages**					
Sample	**206/238**	**±1σ**	**206/238**	**±1σ (Ma)**	**207/206**	**±1σ (Ma)**	**Best Age**	**±1σ (Ma)**
MB23_135	0.3052	0.0036	1716.80	17.70	1781.08	9.62	1781.08	9.62
MB23_134	0.2713	0.0033	1547.19	16.49	1649.07	10.76	1649.07	10.76
MB23_133	0.1767	0.0022	1049.15	12.12	1076.52	17.48	1076.52	17.48
MB23_132	0.1686	0.0020	1004.58	11.08	1100.59	13.49	1100.59	13.49
MB23_131	0.2238	0.0027	1302.03	14.07	1378.12	13.04	1378.12	13.04
MB23_129	0.2579	0.0030	1478.92	15.57	1563.29	11.47	1563.29	11.47
MB23_128	0.1837	0.0024	1087.33	13.04	1092.37	17.16	1092.37	17.16
MB23_127	0.1880	0.0021	1110.49	11.57	1196.13	11.44	1196.13	11.44
MB23_126	0.3034	0.0034	1707.92	16.64	1754.60	9.03	1754.60	9.03
MB23_124	0.2190	0.0029	1276.64	15.52	1355.39	17.69	1355.39	17.69
MB23_123	0.2802	0.0037	1592.34	18.63	1580.70	12.61	1580.70	12.61
MB23_122	0.0728	0.0009	452.70	5.38	451.04	14.98	452.70	5.38
MB23_120	0.1709	0.0023	1016.82	12.78	1019.41	17.85	1019.41	17.85
MB23_119	0.3227	0.0043	1802.92	21.09	1902.86	12.12	1902.86	12.12
MB23_118	0.4922	0.0068	2580.18	29.15	2713.54	9.36	2713.54	9.36
MB23_117	0.2467	0.0033	1421.38	17.14	1427.80	13.03	1427.80	13.03
MB23_116	0.1699	0.0024	1011.39	13.04	1062.62	15.20	1062.62	15.20
MB23_114	0.3063	0.0021	1722.46	10.39	1714.87	10.68	1714.87	10.68
MB23_113	0.2793	0.0018	1587.73	9.08	1721.57	10.51	1721.57	10.51
MB23_111	0.3038	0.0016	1710.18	8.03	1739.04	9.26	1739.04	9.26
MB23_109	0.2983	0.0022	1682.67	10.90	1742.65	9.76	1742.65	9.76

MB23_108	0.3309	0.0022	1842.93	10.45	1879.84	9.00	1879.84	9.00
MB23_107	0.2830	0.0023	1606.40	11.58	1636.09	12.32	1636.09	12.32
MB23_105	0.1839	0.0011	1088.13	5.97	1075.92	12.47	1075.92	12.47
MB23_103	0.3092	0.0025	1736.91	12.39	1809.03	9.06	1809.03	9.06
MB23_102	0.4695	0.0056	2481.32	24.39	2680.25	10.16	2680.25	10.16
MB23_101	0.3237	0.0035	1807.77	17.17	1909.99	14.75	1909.99	14.75
MB23_99	0.0711	0.0006	442.50	3.66	496.19	25.85	442.50	3.66
MB23_97	0.2293	0.0014	1330.70	7.31	1310.83	9.59	1310.83	9.59
MB23_96	0.2226	0.0018	1295.77	9.47	1355.69	14.11	1355.69	14.11
MB23_95	0.5168	0.0033	2685.63	14.11	2703.92	7.99	2703.92	7.99
MB23_94	0.2356	0.0015	1363.93	7.89	1381.93	11.26	1381.93	11.26
MB23_93	0.1699	0.0015	1011.74	8.22	998.16	15.19	998.16	15.19
MB23_92	0.1939	0.0013	1142.63	7.08	1159.11	12.55	1159.11	12.55
MB23_91	0.2509	0.0056	1443.28	28.72	1465.01	33.45	1465.01	33.45
MB23_90	0.3288	0.0022	1832.62	10.73	1826.32	9.88	1826.32	9.88
MB23_86	0.2538	0.0018	1457.96	9.01	1385.00	10.34	1385.00	10.34
MB23_84	0.4719	0.0035	2491.74	15.41	2488.36	9.62	2488.36	9.62
MB23_83	0.4997	0.0043	2612.59	18.53	2717.36	9.09	2717.36	9.09
MB23_81	0.1718	0.0026	1022.15	14.56	1069.05	22.76	1069.05	22.76
MB23_80	0.2049	0.0027	1201.85	14.28	1171.10	11.58	1171.10	11.58
MB23_79	0.2881	0.0041	1631.95	20.57	1631.48	13.98	1631.48	13.98
MB23_76	0.5559	0.0071	2849.52	29.21	2957.49	7.43	2957.49	7.43
MB23_75	0.2370	0.0051	1371.23	26.67	1360.68	18.55	1360.68	18.55
MB23_72	0.2075	0.0042	1215.29	22.42	1271.16	23.66	1271.16	23.66
MB23_71	0.1980	0.0025	1164.50	13.65	1159.05	9.67	1159.05	9.67
MB23_69	0.2115	0.0027	1236.90	14.42	1221.71	9.79	1221.71	9.79
MB23_68	0.4819	0.0063	2535.47	27.26	2556.40	7.92	2556.40	7.92
MB23_67	0.1757	0.0061	1043.21	33.43	1127.42	17.97	1127.42	17.97
MB23_66	0.2998	0.0104	1690.52	51.32	1637.94	11.93	1637.94	11.93
MB23_65	0.1825	0.0064	1080.49	34.77	1053.79	18.38	1053.79	18.38
MB23_64	0.4644	0.0160	2458.74	69.88	2497.68	8.30	2497.68	8.30
MB23_63	0.1717	0.0059	1021.44	32.36	1001.01	13.69	1001.01	13.69
MB23_62	0.1824	0.0066	1080.11	35.61	1083.45	24.74	1083.45	24.74
MB23_61	0.5924	0.0203	2998.99	81.79	2996.38	8.18	2996.38	8.18
MB23_59	0.0723	0.0025	450.10	14.94	468.61	15.88	450.10	14.94
MB23_58	0.5050	0.0174	2635.16	74.16	2684.29	8.35	2684.29	8.35
MB23_57	0.1691	0.0058	1006.94	32.01	958.27	14.62	958.27	14.62
MB23_56	0.3167	0.0109	1773.48	52.91	1742.78	9.02	1742.78	9.02
MB23_55	0.2707	0.0094	1544.51	47.47	1520.38	11.70	1520.38	11.70
MB23_54	0.3390	0.0116	1881.75	55.56	1843.99	8.92	1843.99	8.92
MB23_53	0.3449	0.0119	1910.24	56.68	1789.55	10.60	1789.55	10.60
MB23_52	0.0650	0.0008	406.03	5.00	450.70	26.09	406.03	5.00
MB23_51	0.1888	0.0021	1114.92	11.11	1131.72	9.90	1131.72	9.90
MB23_50	0.0624	0.0008	390.14	4.66	404.93	18.05	390.14	4.66
MB23_49	0.1781	0.0021	1056.42	11.59	1098.70	14.65	1098.70	14.65

MB23_48	0.3173	0.0037	1776.42	18.28	1797.36	11.25	1797.36	11.25
MB23_47	0.2128	0.0024	1243.87	12.72	1343.92	11.54	1343.92	11.54
MB23_46	0.1741	0.0024	1034.50	13.07	1056.26	18.87	1056.26	18.87
MB23_44	0.1976	0.0022	1162.31	11.59	1151.57	9.86	1151.57	9.86
MB23_43	0.2552	0.0030	1464.99	15.59	1491.85	11.22	1491.85	11.22
MB23_39	0.2789	0.0033	1585.72	16.43	1677.15	11.58	1677.15	11.58
MB23_38	0.1801	0.0023	1067.58	12.47	1168.57	14.50	1168.57	14.50
MB23_37	0.1875	0.0015	1107.85	8.05	1151.71	13.52	1151.71	13.52
MB23_36	0.1632	0.0011	974.42	5.87	978.14	11.24	978.14	11.24
MB23_35	0.3081	0.0021	1731.40	10.46	1855.26	8.39	1855.26	8.39
MB23_34	0.2523	0.0020	1450.30	10.48	1443.48	12.84	1443.48	12.84
MB23_32	0.3321	0.0020	1848.73	9.77	1878.70	8.95	1878.70	8.95
MB23_31	0.3209	0.0020	1793.97	9.73	1844.08	8.58	1844.08	8.58
MB23_28	0.1845	0.0017	1091.62	9.06	1185.14	11.95	1185.14	11.95
MB23_25	0.1667	0.0019	993.65	10.58	1061.87	16.60	1061.87	16.60
MB23_24	0.1693	0.0020	1008.05	11.14	1031.04	12.22	1031.04	12.22
MB23_23	0.1813	0.0017	1073.87	9.35	1077.03	11.31	1077.03	11.31
MB23_22	0.1836	0.0022	1086.60	12.06	1152.44	13.76	1152.44	13.76
MB23_21	0.2025	0.0024	1188.65	13.06	1201.63	15.16	1201.63	15.16
MB23_20	0.1714	0.0016	1019.69	8.63	1050.22	12.82	1050.22	12.82
MB23_19	0.4708	0.0041	2487.26	17.97	2666.93	7.09	2666.93	7.09
MB23_17	0.0735	0.0008	457.41	4.66	462.56	18.36	457.41	4.66
MB23_16	0.2491	0.0027	1434.06	14.07	1460.91	11.52	1460.91	11.52
MB23_15	0.1712	0.0012	1018.48	6.80	1051.12	14.60	1051.12	14.60
MB23_14	0.1764	0.0014	1047.16	7.74	1077.22	14.14	1077.22	14.14
MB23_13	0.1954	0.0020	1150.70	10.94	1164.95	10.78	1164.95	10.78
MB23_11	0.1875	0.0019	1107.99	10.45	1154.71	12.10	1154.71	12.10
MB23_10	0.2779	0.0023	1580.89	11.82	1643.95	12.95	1643.95	12.95
MB23_9	0.2383	0.0025	1377.64	13.04	1462.42	9.66	1462.42	9.66
MB23_8	0.2539	0.0018	1458.76	9.30	1495.71	10.37	1495.71	10.37
MB23_6	0.2798	0.0033	1590.60	16.55	1748.98	8.62	1748.98	8.62
MB23_4	0.1820	0.0015	1078.08	8.01	1145.31	11.08	1145.31	11.08
MB23_3	0.2844	0.0024	1613.42	11.85	1660.86	10.21	1660.86	10.21
MB23_2	0.1782	0.0023	1056.99	12.83	1080.30	24.33	1080.30	24.33
MB23_1	0.1773	0.0013	1052.05	7.31	1129.11	13.00	1129.11	13.00

Discordance >10%

MB23_130	0.1687	0.0019	1005.00	10.74	1210.23	13.68
MB23_125	0.1510	0.0022	906.78	12.18	1107.04	15.77
MB23_121	0.1257	0.0016	763.30	9.20	1340.53	10.82
MB23_115	0.1628	0.0024	972.27	13.16	1328.46	10.05
MB23_112	0.2205	0.0039	1284.28	20.82	2695.70	8.53
MB23_110	0.0826	0.0012	511.82	7.23	1477.11	11.13
MB23_104	0.0635	0.0007	396.90	4.41	481.00	32.17
MB23_100	0.2018	0.0014	1184.99	7.62	2605.37	8.41

MB23_98	0.4387	0.0032	2344.61	14.15	2767.33	8.15
MB23_89	0.1758	0.0021	1044.07	11.64	1300.92	23.23
MB23_88	0.0697	0.0007	434.10	4.18	677.25	27.32
MB23_87	0.2437	0.0016	1405.76	8.40	1869.27	9.84
MB23_85	0.2365	0.0026	1368.66	13.78	1796.90	29.77
MB23_82	0.1024	0.0251	628.29	145.20	4058.59	66.74
MB23_78	0.3385	0.0046	1879.23	22.26	2198.87	9.46
MB23_77	0.2077	0.0052	1216.34	27.70	1493.65	42.68
MB23_74	0.2575	0.0036	1476.79	18.31	1677.90	9.17
MB23_73	0.0518	0.0010	325.51	6.31	1100.55	11.30
MB23_70	0.1536	0.0023	921.10	12.61	1420.17	10.39
MB23_60	0.3144	0.0114	1762.15	55.83	2579.60	37.91
MB23_45	0.0678	0.0019	423.17	11.54	575.30	120.56
MB23_42	0.0623	0.0007	389.53	4.40	995.42	22.27
MB23_41	0.1421	0.0016	856.55	8.91	1136.62	12.32
MB23_40	0.1653	0.0020	986.18	11.18	1479.44	21.06
MB23_35	0.3081	0.0021	1731.40	10.46	1855.26	8.39
MB23_30	0.1577	0.0023	944.25	12.61	1411.32	9.74
MB23_29	0.0673	0.0009	419.77	5.50	1475.01	9.96
MB23_27	0.1443	0.0018	869.15	10.27	1581.79	29.89
MB23_26	0.0783	0.0015	486.25	8.68	1387.32	49.28
MB23_18	0.0646	0.0007	403.26	4.29	1008.16	15.01
MB23_12	0.0713	0.0005	444.15	3.18	569.84	14.99
MB23_7	0.2014	0.0026	1183.01	13.80	2381.09	34.56
MB23_5	0.0651	0.0011	406.58	6.92	753.05	17.19

MB 2-4

Sample MB-2-4 (Middle Bloyd Sandstone) U–Pb detrital zircon LA-ICP-MS analysis results

	Isotopic Ratio		Apparent Ages					
Sample	**206/238**	**±1σ**	**206/238**	**±1σ (Ma)**	**207/206**	**±1σ (Ma)**	**Best Age**	**±1σ (Ma)**
MB24_129	0.4580	0.0031	2430.78	13.85	2511.86	11.55	2511.86	11.55
MB24_128	0.2019	0.0014	1185.69	7.59	1183.20	16.43	1183.20	16.43
MB24_127	0.1690	0.0009	1006.67	5.03	1100.70	14.86	1100.70	14.86
MB24_126	0.2804	0.0017	1593.59	8.63	1665.18	12.72	1665.18	12.72
MB24_125	0.3223	0.0015	1800.81	7.26	1840.60	11.52	1840.60	11.52
MB24_124	0.1781	0.0014	1056.36	7.71	1113.57	17.48	1113.57	17.48
MB24_123	0.1723	0.0021	1024.70	11.47	1063.52	25.89	1063.52	25.89
MB24_122	0.1735	0.0017	1031.18	9.40	1122.77	23.32	1122.77	23.32
MB24_121	0.5314	0.0029	2747.51	12.22	2846.67	10.03	2846.67	10.03
MB24_120	0.4650	0.0023	2461.44	9.91	2727.81	9.96	2727.81	9.96

MB24_119	0.1781	0.0011	1056.75	6.16	1116.38	14.93	1116.38	14.93
MB24_118	0.5157	0.0022	2681.04	9.32	2770.61	9.87	2770.61	9.87
MB24_117	0.2180	0.0017	1271.56	8.94	1288.51	19.68	1288.51	19.68
MB24_115	0.1748	0.0018	1038.70	10.10	1136.36	20.00	1136.36	20.00
MB24_114	0.3215	0.0019	1796.88	9.47	1872.37	12.97	1872.37	12.97
MB24_112	0.4034	0.0029	2184.80	13.08	2315.97	12.11	2315.97	12.11
MB24_113	0.2000	0.0015	1175.51	7.88	1231.89	16.90	1231.89	16.90
MB24_111	0.0716	0.0004	445.49	2.44	431.63	17.14	431.63	17.14
MB24_110	0.1726	0.0008	1026.61	4.41	1050.01	14.51	1050.01	14.51
MB24_107	0.1633	0.0009	975.35	4.71	1025.04	18.98	1025.04	18.98
MB24_106	0.1695	0.0024	1009.44	13.02	1023.64	31.08	1023.64	31.08
MB24_105	0.1775	0.0017	1053.50	9.08	1083.89	17.54	1083.89	17.54
MB24_103	0.2031	0.0011	1191.97	5.80	1221.49	15.15	1221.49	15.15
MB24_102	0.1944	0.0007	1145.27	3.64	1160.33	13.08	1160.33	13.08
MB24_101	0.1898	0.0062	1120.45	33.64	1045.90	52.63	1045.90	52.63
MB24_100	0.0951	0.0011	585.73	6.61	602.25	19.59	602.25	19.59
MB24_99	0.2244	0.0024	1305.32	12.66	1326.40	12.71	1326.40	12.71
MB24_98	0.2579	0.0028	1479.01	14.32	1483.58	12.86	1483.58	12.86
MB24_96	0.1830	0.0022	1083.13	11.88	1161.45	16.15	1161.45	16.15
MB24_95	0.2327	0.0029	1348.75	15.04	1319.47	15.03	1319.47	15.03
MB24_94	0.1830	0.0021	1083.15	11.30	1057.93	15.53	1057.93	15.53
MB24_93	0.1714	0.0020	1020.01	11.05	1057.08	17.61	1057.08	17.61
MB24_92	0.1696	0.0019	1010.11	10.51	1067.02	16.53	1067.02	16.53
MB24_91	0.5425	0.0057	2793.97	23.94	2856.08	9.86	2856.08	9.86
MB24_90	0.1845	0.0037	1091.28	19.92	1120.16	37.95	1120.16	37.95
MB24_89	0.1820	0.0026	1077.75	14.24	1071.09	23.20	1071.09	23.20
MB24_88	0.2133	0.0026	1246.30	13.55	1266.26	17.63	1266.26	17.63
MB24_87	0.2346	0.0026	1358.74	13.33	1397.29	12.71	1397.29	12.71
MB24_85	0.1964	0.0028	1155.84	15.33	1143.17	14.17	1143.17	14.17
MB24_84	0.1638	0.0024	977.99	13.01	1008.96	14.00	1008.96	14.00
MB24_82	0.1681	0.0026	1001.80	14.21	1061.58	16.98	1061.58	16.98
MB24_81	0.2895	0.0042	1638.88	20.74	1646.85	11.46	1646.85	11.46
MB24_80	0.1723	0.0025	1025.02	13.86	1038.88	15.42	1038.88	15.42
MB24_79	0.2918	0.0044	1650.39	22.00	1699.68	13.96	1699.68	13.96
MB24_78	0.1973	0.0029	1160.87	15.63	1173.95	14.07	1173.95	14.07
MB24_77	0.2982	0.0046	1682.37	22.62	1740.36	12.51	1740.36	12.51
MB24_76	0.2630	0.0039	1504.93	19.74	1496.67	13.75	1496.67	13.75
MB24_75	0.5295	0.0090	2739.48	37.99	2814.96	11.86	2814.96	11.86
MB24_73	0.2394	0.0035	1383.51	18.18	1395.60	12.34	1395.60	12.34
MB24_71	0.2632	0.0041	1506.25	20.87	1373.41	13.94	1373.41	13.94
MB24_69	0.1708	0.0027	1016.62	14.96	1079.26	22.20	1079.26	22.20
MB24_68	0.2116	0.0035	1237.17	18.43	1317.63	17.26	1317.63	17.26
MB24_67	0.1757	0.0029	1043.31	15.63	1053.89	20.40	1053.89	20.40
MB24_66	0.1772	0.0030	1051.74	16.23	1035.17	21.03	1035.17	21.03
MB24_65	0.2034	0.0027	1193.46	14.33	1196.11	17.64	1196.11	17.64

MB24_64	0.2028	0.0026	1190.22	13.79	1181.44	15.89	1181.44	15.89
MB24_63	0.2966	0.0036	1674.66	17.85	1646.69	12.05	1646.69	12.05
MB24_62	0.5087	0.0061	2650.94	26.21	2709.88	10.01	2709.88	10.01
MB24_61	0.2857	0.0035	1620.17	17.67	1617.81	12.67	1617.81	12.67
MB24_59	0.1752	0.0022	1040.78	12.22	1076.68	14.97	1076.68	14.97
MB24_58	0.2124	0.0029	1241.72	15.39	1239.75	18.54	1239.75	18.54
MB24_57	0.4938	0.0061	2587.05	26.27	2645.86	10.38	2645.86	10.38
MB24_56	0.2493	0.0032	1435.03	16.33	1446.87	12.48	1446.87	12.48
MB24_55	0.1736	0.0030	1032.03	16.35	954.00	28.57	954.00	28.57
MB24_54	0.3369	0.0047	1871.94	22.50	1887.68	15.11	1887.68	15.11
MB24_52	0.2834	0.0034	1608.31	16.99	1632.68	11.33	1632.68	11.33
MB24_51	0.2411	0.0033	1392.43	17.28	1451.25	14.31	1451.25	14.31
MB24_50	0.1749	0.0020	1038.90	11.17	1086.10	15.02	1086.10	15.02
MB24_49	0.1860	0.0022	1099.58	11.89	1074.81	14.44	1074.81	14.44
MB24_48	0.3875	0.0044	2111.45	20.64	2190.43	11.54	2190.43	11.54
MB24_47	0.1818	0.0021	1076.98	11.56	1133.82	14.53	1133.82	14.53
MB24_46	0.1741	0.0021	1034.59	11.28	1144.12	14.64	1144.12	14.64
MB24_44	0.0797	0.0012	494.57	7.09	544.07	34.65	544.07	34.65
MB24_43	0.2546	0.0029	1462.07	14.84	1515.04	12.37	1515.04	12.37
MB24_42	0.4745	0.0060	2503.37	26.04	2697.93	11.26	2697.93	11.26
MB24_39	0.2215	0.0031	1289.76	16.15	1320.52	16.96	1320.52	16.96
MB24_38	0.2101	0.0023	1229.43	12.34	1266.26	12.76	1266.26	12.76
MB24_37	0.3014	0.0034	1698.03	16.99	1752.43	12.59	1752.43	12.59
MB24_36	0.1809	0.0021	1071.68	11.34	1154.20	15.24	1154.20	15.24
MB24_35	0.1981	0.0027	1164.86	14.30	1201.50	17.02	1201.50	17.02
MB24_34	0.1783	0.0022	1057.48	11.76	1066.47	13.30	1066.47	13.30
MB24_33	0.3065	0.0039	1723.63	19.37	1766.14	13.17	1766.14	13.17
MB24_31	0.1813	0.0029	1073.84	15.96	1126.91	24.72	1126.91	24.72
MB24_30	0.1727	0.0022	1027.03	11.88	1022.34	15.28	1022.34	15.28
MB24_29	0.3137	0.0038	1758.67	18.60	1780.35	11.37	1780.35	11.37
MB24_28	0.2769	0.0038	1575.66	19.35	1699.89	15.37	1699.89	15.37
MB24_24	0.1825	0.0023	1080.38	12.51	1057.76	15.90	1057.76	15.90
MB24_22	0.0687	0.0008	428.15	5.03	460.40	16.30	460.40	16.30
MB24_21	0.2219	0.0028	1291.90	14.56	1329.60	13.29	1329.60	13.29
MB24_20	0.0689	0.0010	429.62	5.85	463.86	18.02	463.86	18.02
MB24_18	0.3759	0.0051	2056.96	23.99	2039.92	11.00	2039.92	11.00
MB24_17	0.1950	0.0028	1148.61	14.82	1228.69	15.81	1228.69	15.81
MB24_16	0.1923	0.0027	1133.84	14.38	1152.89	15.12	1152.89	15.12
MB24_15	0.1888	0.0026	1114.94	14.13	1164.73	13.19	1164.73	13.19
MB24_14	0.2772	0.0038	1577.43	19.03	1636.36	12.36	1636.36	12.36
MB24_13	0.2807	0.0043	1594.96	21.71	1658.63	16.83	1658.63	16.83
MB24_12	0.1649	0.0024	983.88	13.10	1003.45	16.73	1003.45	16.73
MB24_9	0.1752	0.0021	1040.62	11.60	1047.09	15.03	1047.09	15.03
MB24_8	0.1710	0.0023	1017.40	12.54	1016.74	19.04	1016.74	19.04
MB24_7	0.1928	0.0023	1136.74	12.67	1113.99	14.72	1113.99	14.72

MB24_6	0.1710	0.0022	1017.89	12.27	1031.75	19.08	1031.75	19.08
MB24_5	0.1671	0.0020	996.16	11.16	1038.67	15.27	1038.67	15.27
MB24_4	0.2924	0.0034	1653.35	17.13	1645.44	11.79	1645.44	11.79
MB24_3	0.0705	0.0008	439.30	4.93	428.54	16.18	428.54	16.18
MB24_2	0.1826	0.0022	1081.18	11.93	1078.15	15.36	1078.15	15.36
MB24_1	0.3406	0.0042	1889.52	20.33	1862.39	12.71	1862.39	12.71

Discordance >10%

MB24_130	0.1604	0.0009	959.18	5.25	1083.56	13.63
MB24_116	0.1798	0.0023	1066.02	12.77	1191.27	29.37
MB24_109	0.1473	0.0025	885.96	13.84	1352.98	13.53
MB24_108	0.1503	0.0012	902.46	6.91	1011.08	17.96
MB24_104	0.1529	0.0009	917.30	5.12	1099.68	13.59
MB24_97	0.0714	0.0008	444.71	4.93	802.38	24.65
MB24_86	0.2388	0.0038	1380.67	19.81	2264.44	62.63
MB24_83	0.0664	0.0010	414.72	5.99	538.70	20.08
MB24_74	0.2320	0.0051	1344.74	26.78	2307.13	60.31
MB24_72	0.2066	0.0046	1210.70	24.78	1402.56	34.19
MB24_70	0.1976	0.0037	1162.33	19.86	2281.10	45.02
MB24_53	0.0569	0.0010	357.01	6.13	974.94	20.29
MB24_45	0.2053	0.0023	1203.74	12.13	1357.61	12.90
MB24_41	0.1280	0.0015	776.58	8.30	1352.51	13.08
MB24_40	0.3503	0.0043	1936.18	20.42	2666.74	10.28
MB24_32	0.1788	0.0029	1060.51	15.96	1295.33	23.28
MB24_27	0.2401	0.0075	1387.14	39.03	1740.00	39.28
MB24_26	0.2524	0.0031	1450.74	16.02	2565.66	10.06
MB24_25	0.0653	0.0009	407.93	5.43	479.59	20.31
MB24_23	0.1526	0.0020	915.64	11.13	1066.51	14.28
MB24_19	0.0995	0.0014	611.69	7.98	2082.83	13.04
MB24_11	0.1954	0.0028	1150.43	15.03	1312.22	15.96
MB24_10	0.2107	0.0041	1232.72	22.00	2746.08	29.33

MB 2-5

Sample MB-2-5 (Middle Bloyd Sandstone) U–Pb detrital zircon LA-ICP-MS analysis results

	Isotopic Ratio		Apparent Ages					
Sample	206/238	±1σ	206/238	±1σ (Ma)	207/206	±1σ (Ma)	Best Age	±1σ (Ma)
MB25_145	0.2079	0.0017	1217.61	9.11	1254.78	8.67	1254.78	8.67
MB25_144	0.1934	0.0018	1139.75	9.85	1231.85	13.90	1231.85	13.90
MB25_143	0.1689	0.0014	1005.87	7.47	1026.98	8.43	1026.98	8.43
MB25_142	0.1880	0.0016	1110.49	8.80	1168.82	9.74	1168.82	9.74
MB25_141	0.2912	0.0025	1647.40	12.37	1744.86	8.20	1744.86	8.20
MB25_140	0.2877	0.0026	1630.15	12.87	1653.13	9.28	1653.13	9.28
MB25_139	0.2785	0.0025	1584.03	12.76	1644.58	10.59	1644.58	10.59
MB25_138	0.1821	0.0016	1078.25	8.63	1093.26	11.18	1093.26	11.18
MB25_137	0.1694	0.0015	1008.64	8.26	1063.34	12.64	1063.34	12.64
MB25_136	0.1562	0.0014	935.88	7.87	998.96	13.48	935.88	7.87
MB25_135	0.2710	0.0021	1545.64	10.62	1625.39	7.02	1625.39	7.02
MB25_134	0.5111	0.0047	2661.26	20.06	2707.27	8.25	2707.27	8.25
MB25_133	0.1743	0.0016	1035.69	8.92	1019.19	15.89	1019.19	15.89
MB25_131	0.1641	0.0013	979.28	7.04	999.45	9.91	979.28	7.04
MB25_130	0.1724	0.0015	1025.29	8.14	1146.09	10.70	1146.09	10.70
MB25_129	0.1712	0.0018	1018.94	9.74	1038.16	17.02	1038.16	17.02
MB25_128	0.1851	0.0015	1095.02	8.27	1125.11	10.95	1125.11	10.95
MB25_126	0.0957	0.0008	589.39	4.91	593.59	15.79	589.39	4.91
MB25_125	0.5240	0.0047	2716.18	19.70	2802.88	7.50	2802.88	7.50
MB25_124	0.2555	0.0046	1466.55	23.49	1486.44	26.61	1486.44	26.61
MB25_121	0.0737	0.0006	458.19	3.49	438.35	12.83	458.19	3.49
MB25_120	0.0734	0.0006	456.46	3.64	466.54	25.04	456.46	3.64
MB25_119	0.1824	0.0015	1080.28	8.39	1125.49	19.03	1125.49	19.03
MB25_118	0.1797	0.0012	1065.11	6.58	1087.27	12.88	1087.27	12.88
MB25_117	0.3110	0.0014	1745.83	6.80	1781.98	7.51	1781.98	7.51
MB25_116	0.1693	0.0008	1008.09	4.33	1017.60	9.65	1017.60	9.65
MB25_115	0.2801	0.0013	1591.91	6.74	1643.97	8.08	1643.97	8.08
MB25_112	0.1904	0.0014	1123.44	7.58	1157.52	15.10	1157.52	15.10
MB25_110	0.3008	0.0015	1695.33	7.55	1736.99	8.27	1736.99	8.27
MB25_108	0.4877	0.0026	2560.84	11.29	2807.46	6.02	2807.46	6.02
MB25_106	0.1482	0.0010	891.13	5.52	1195.27	16.75	1195.27	16.75
MB25_105	0.1626	0.0018	971.17	10.16	1013.47	23.07	1013.47	23.07
MB25_104	0.1998	0.0020	1174.26	10.63	1174.88	12.97	1174.88	12.97
MB25_103	0.3396	0.0026	1884.65	12.64	1895.58	6.85	1895.58	6.85
MB25_102	0.1722	0.0016	1024.32	8.84	1033.60	13.43	1033.60	13.43
MB25_101	0.2899	0.0025	1640.98	12.69	1697.47	9.64	1697.47	9.64
MB25_100	0.3071	0.0024	1726.30	12.05	1740.22	7.37	1740.22	7.37
MB25_99	0.4813	0.0056	2532.87	24.11	2591.52	9.56	2591.52	9.56
MB25_98	0.5395	0.0046	2781.35	19.34	2794.41	6.72	2794.41	6.72

MB25_97	0.2370	0.0020	1370.95	10.49	1462.41	9.57	1462.41	9.57
MB25_94	0.2837	0.0023	1609.82	11.72	1735.38	7.64	1735.38	7.64
MB25_93	0.0635	0.0007	396.69	4.01	436.53	23.34	396.69	4.01
MB25_92	0.1660	0.0017	990.22	9.38	1050.57	14.93	1050.57	14.93
MB25_90	0.1688	0.0009	1005.62	4.80	1064.13	9.26	1064.13	9.26
MB25_89	0.1553	0.0010	930.60	5.36	981.38	11.93	930.60	5.36
MB25_86	0.2860	0.0014	1621.53	6.87	1647.64	7.43	1647.64	7.43
MB25_83	0.3117	0.0021	1749.17	10.28	1848.86	10.87	1848.86	10.87
MB25_82	0.4807	0.0025	2530.47	10.84	2729.19	6.02	2729.19	6.02
MB25_80	0.4740	0.0026	2500.88	11.55	2582.72	6.93	2582.72	6.93
MB25_79	0.1592	0.0009	952.26	5.15	1012.07	11.10	1012.07	11.10
MB25_78	0.1723	0.0013	1024.99	7.22	1097.92	13.68	1097.92	13.68
MB25_75	0.1608	0.0020	961.01	11.29	984.59	11.37	961.01	11.29
MB25_74	0.3126	0.0040	1753.66	19.41	1786.59	8.85	1786.59	8.85
MB25_73	0.1709	0.0023	1016.99	12.66	1076.75	15.86	1076.75	15.86
MB25_72	0.2713	0.0034	1547.20	17.37	1634.42	8.79	1634.42	8.79
MB25_71	0.1835	0.0025	1086.02	13.36	1158.14	15.50	1158.14	15.50
MB25_70	0.1717	0.0023	1021.64	12.89	1079.66	16.77	1079.66	16.77
MB25_69	0.3045	0.0039	1713.35	19.46	1785.92	10.06	1785.92	10.06
MB25_68	0.0614	0.0009	384.08	5.17	361.10	26.73	384.08	5.17
MB25_66	0.0853	0.0011	527.62	6.80	589.32	19.73	527.62	6.80
MB25_65	0.1868	0.0026	1104.07	13.98	1130.12	16.47	1130.12	16.47
MB25_64	0.2549	0.0034	1463.90	17.56	1636.25	11.59	1636.25	11.59
MB25_63	0.1621	0.0021	968.45	11.54	1035.79	10.91	1035.79	10.91
MB25_62	0.3228	0.0042	1803.15	20.48	1888.32	9.56	1888.32	9.56
MB25_61	0.2742	0.0035	1561.91	17.75	1643.63	9.66	1643.63	9.66
MB25_58	0.1006	0.0008	617.73	4.85	1810.35	9.15	617.73	4.85
MB25_57	0.4923	0.0043	2580.50	18.62	2752.63	9.38	2752.63	9.38
MB25_56	0.1865	0.0015	1102.45	8.30	1174.74	11.80	1174.74	11.80
MB25_55	0.4889	0.0037	2565.75	16.11	2672.39	7.76	2672.39	7.76
MB25_52	0.4442	0.0035	2369.45	15.55	2504.02	8.54	2504.02	8.54
MB25_51	0.2165	0.0035	1263.62	18.30	1268.22	29.04	1268.22	29.04
MB25_50	0.1555	0.0012	931.52	6.64	1011.32	11.10	1011.32	11.10
MB25_47	0.2687	0.0021	1534.38	10.65	1631.09	10.24	1631.09	10.24
MB25_46	0.1521	0.0014	912.74	8.11	997.28	17.74	912.74	8.11
MB25_45	0.3060	0.0022	1721.14	10.92	1791.95	9.49	1791.95	9.49
MB25_44	0.1850	0.0013	1094.07	7.03	1144.02	11.00	1144.02	11.00
MB25_42	0.2360	0.0020	1365.68	10.54	1440.92	12.44	1440.92	12.44
MB25_41	0.1617	0.0013	966.30	6.96	981.34	16.59	966.30	6.96
MB25_40	0.1634	0.0013	975.57	7.07	1040.76	12.63	1040.76	12.63
MB25_39	0.1699	0.0012	1011.47	6.74	1086.85	12.57	1086.85	12.57
MB25_37	0.1990	0.0015	1170.15	8.13	1148.22	12.29	1148.22	12.29
MB25_36	0.1733	0.0017	1030.22	9.50	1081.75	18.12	1081.75	18.12
MB25_35	0.2132	0.0025	1245.78	13.31	1317.41	21.92	1317.41	21.92
MB25_34	0.1488	0.0011	894.28	6.34	927.27	15.35	894.28	6.34

MB25_33	0.2746	0.0018	1564.21	9.10	1680.34	8.78	1680.34	8.78
MB25_32	0.4790	0.0036	2522.98	15.88	2663.01	8.73	2663.01	8.73
MB25_31	0.2246	0.0021	1306.31	10.80	1308.38	14.46	1308.38	14.46
MB25_29	0.1746	0.0022	1037.48	12.09	1123.47	20.20	1123.47	20.20
MB25_27	0.2013	0.0019	1182.55	10.37	1223.83	14.44	1223.83	14.44
MB25_26	0.1538	0.0016	921.97	8.84	994.41	20.60	921.97	8.84
MB25_25	0.1614	0.0015	964.47	8.24	1018.60	15.49	1018.60	15.49
MB25_24	0.1655	0.0018	987.03	10.19	1062.86	21.94	1062.86	21.94
MB25_23	0.1739	0.0015	1033.62	8.03	1095.83	11.15	1095.83	11.15
MB25_21	0.1962	0.0017	1155.00	9.42	1177.44	12.46	1177.44	12.46
MB25_19	0.2516	0.0026	1446.63	13.51	1506.05	16.38	1506.05	16.38
MB25_18	0.1857	0.0017	1098.01	9.12	1162.75	12.88	1162.75	12.88
MB25_17	0.2120	0.0019	1239.23	10.21	1319.37	12.10	1319.37	12.10
MB25_16	0.1637	0.0018	977.24	9.72	1032.77	19.30	1032.77	19.30
MB25_15	0.1718	0.0017	1021.79	9.17	1016.32	20.59	1016.32	20.59
MB25_14	0.2232	0.0019	1298.70	10.24	1369.13	12.77	1369.13	12.77
MB25_12	0.2040	0.0020	1196.71	10.84	1255.67	16.84	1255.67	16.84
MB25_11	0.2932	0.0023	1657.65	11.41	1818.17	9.19	1818.17	9.19
MB25_10	0.1618	0.0016	966.96	8.84	1006.27	16.23	1006.27	16.23
MB25_9	0.1735	0.0023	1031.45	12.69	1046.05	28.38	1046.05	28.38
MB25_8	0.1596	0.0012	954.73	6.73	1011.67	12.01	1011.67	12.01
MB25_6	0.1643	0.0013	980.35	7.41	1035.91	12.71	1035.91	12.71
MB25_5	0.5709	0.0056	2911.36	22.82	2802.39	9.91	2802.39	9.91
MB25_4	0.1657	0.0017	988.52	9.36	1023.79	22.96	1023.79	22.96
MB25_1	0.2149	0.0022	1255.04	11.75	1368.65	16.65	1368.65	16.65

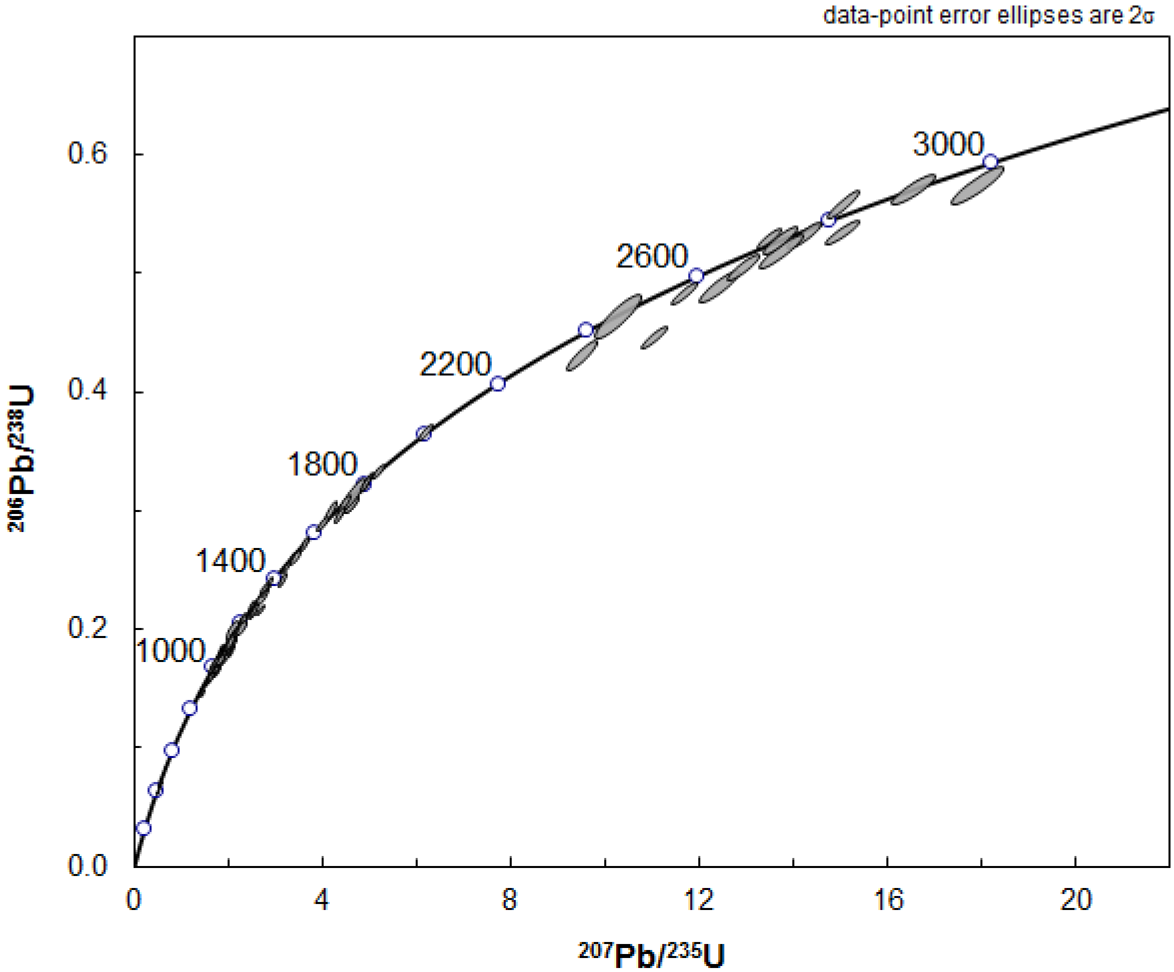
Discordance >10%

MB25_132	0.1693	0.0021	1008.08	11.59	1594.64	19.18
MB25_127	0.1830	0.0024	1083.56	12.80	1727.13	59.80
MB25_123	0.3067	0.0046	1724.31	22.90	2200.44	34.85
MB25_122	0.1159	0.0009	706.81	5.37	2025.25	6.27
MB25_114	0.5551	0.0172	2846.30	70.78	4881.97	7.81
MB25_113	0.2041	0.0012	1197.12	6.37	1460.89	9.46
MB25_111	0.2636	0.0030	1508.04	15.22	1724.58	13.67
MB25_109	0.3918	0.0048	2131.29	22.37	2723.77	7.32
MB25_107	0.0384	0.0008	243.16	5.27	1918.27	21.59
MB25_96	0.0798	0.0008	494.77	4.49	2195.14	13.04
MB25_95	0.1638	0.0022	977.67	12.34	1140.62	27.61
MB25_91	0.2951	0.0024	1666.80	12.14	1965.95	12.22
MB25_88	0.1541	0.0012	923.87	6.77	1048.50	17.23
MB25_87	0.1549	0.0011	928.46	6.14	1053.91	14.23
MB25_85	0.1788	0.0016	1060.30	8.72	1215.33	13.72
MB25_84	0.1348	0.0015	815.04	8.73	1783.21	12.20
MB25_77	0.2335	0.0016	1352.59	8.53	1529.19	8.74
MB25_76	0.1932	0.0020	1138.69	10.57	2375.11	65.75

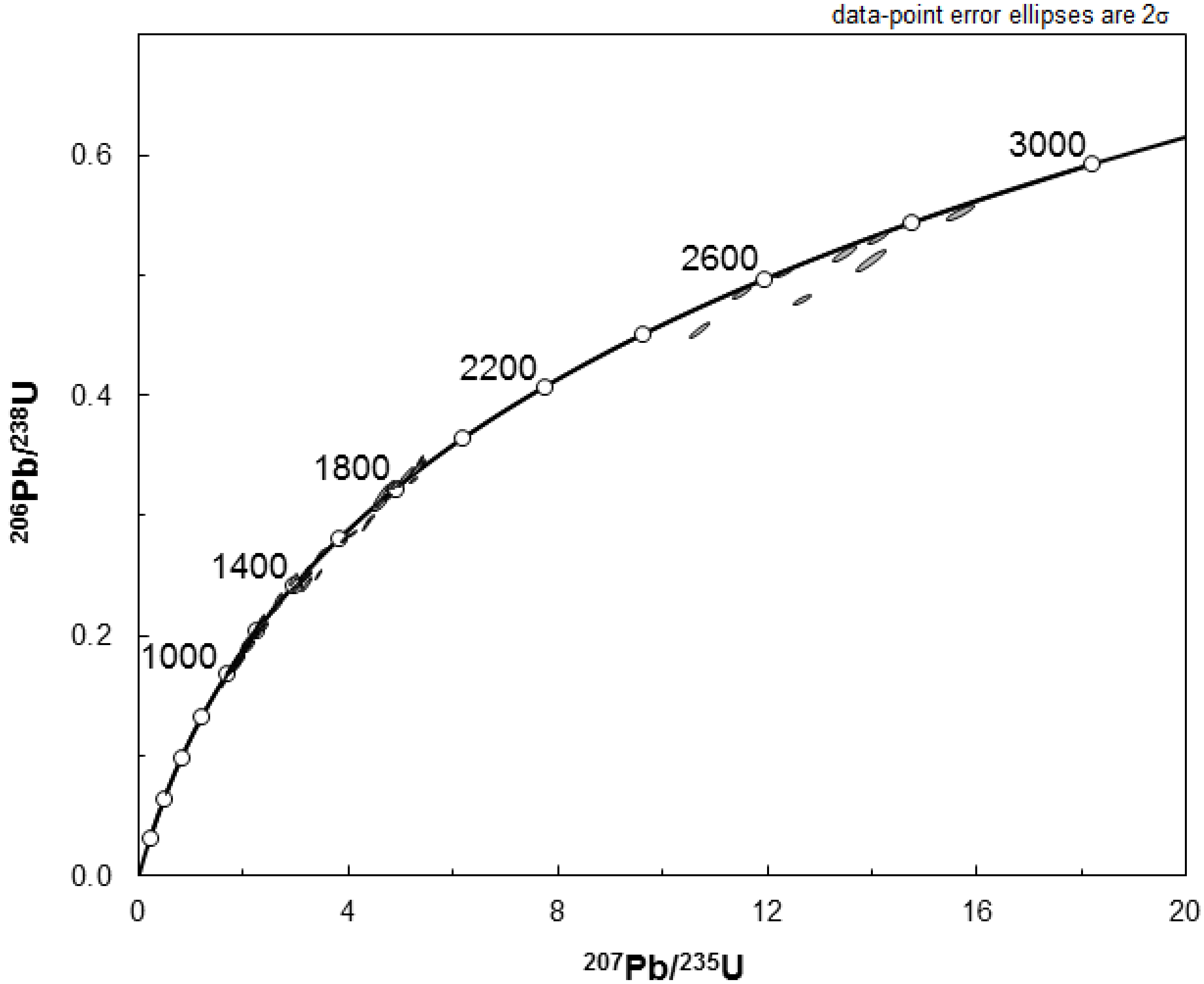
MB25_67	0.0932	0.0012	574.55	7.12	1753.46	9.82
MB25_60	0.2566	0.0021	1472.18	10.95	1794.00	9.91
MB25_59	0.1945	0.0037	1145.65	20.03	1505.66	25.72
MB25_54	0.1471	0.0015	884.74	8.30	1037.93	15.57
MB25_53	0.3217	0.0028	1798.23	13.74	2757.71	7.74
MB25_49	0.0620	0.0006	387.73	3.59	441.81	23.26
MB25_48	0.0691	0.0006	430.94	3.78	696.50	18.23
MB25_38	0.1351	0.0010	816.69	5.59	945.91	12.46
MB25_30	0.1807	0.0016	1071.01	8.95	1616.19	15.77
MB25_28	0.0658	0.0007	410.65	3.95	1652.04	65.96
MB25_22	0.2007	0.0022	1179.06	11.67	1748.46	12.10
MB25_20	0.2714	0.0024	1547.76	11.95	1791.28	9.02
MB25_13	0.1898	0.0021	1120.23	11.49	1348.41	32.82
MB25_7	0.1479	0.0017	889.41	9.69	1121.80	19.28
MB25_3	0.1734	0.0018	1030.60	9.72	1684.78	29.44
MB25_2	0.2262	0.0017	1314.69	9.14	1503.75	10.73

Appendix B- Concordia Diagrams

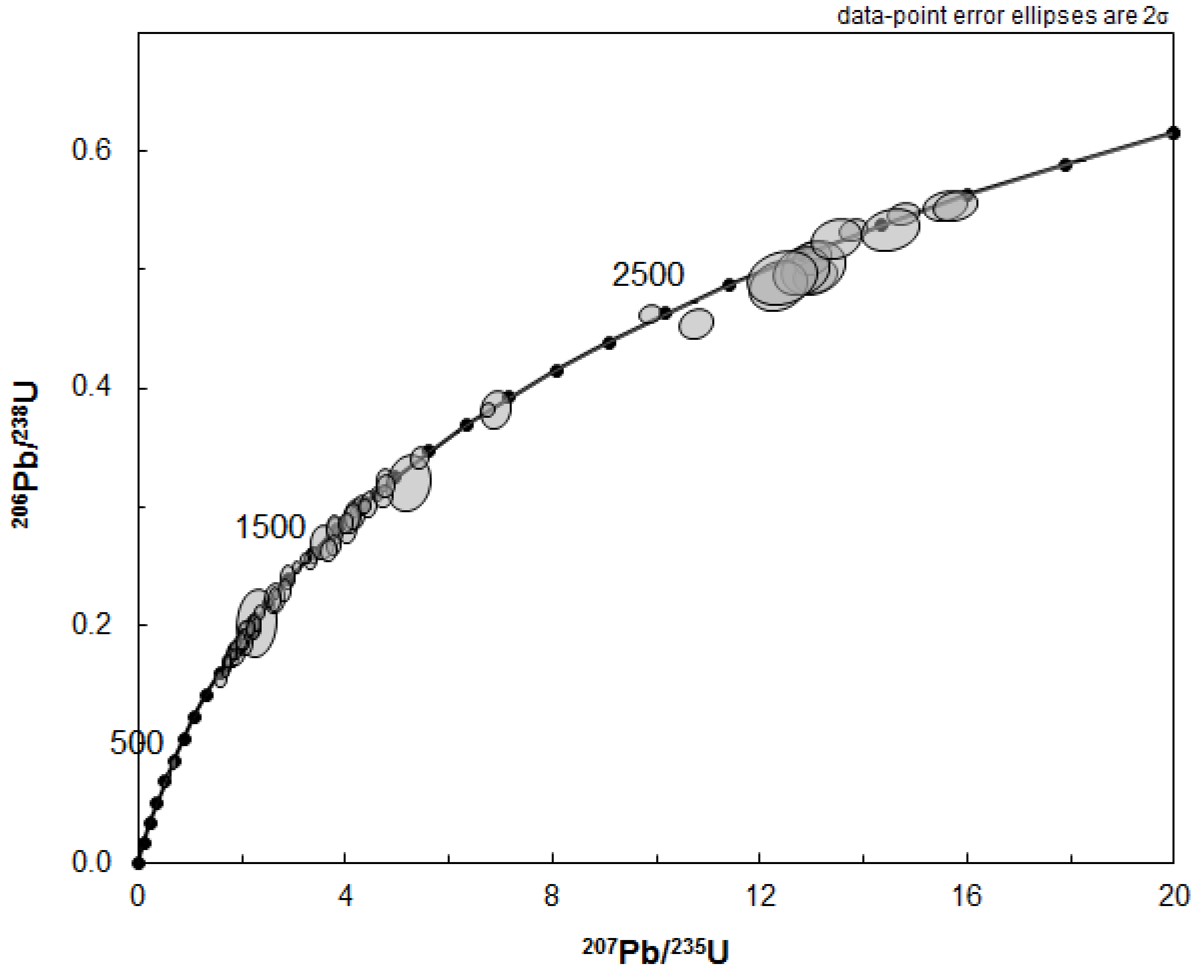
MB 1-1 Concordia Diagram



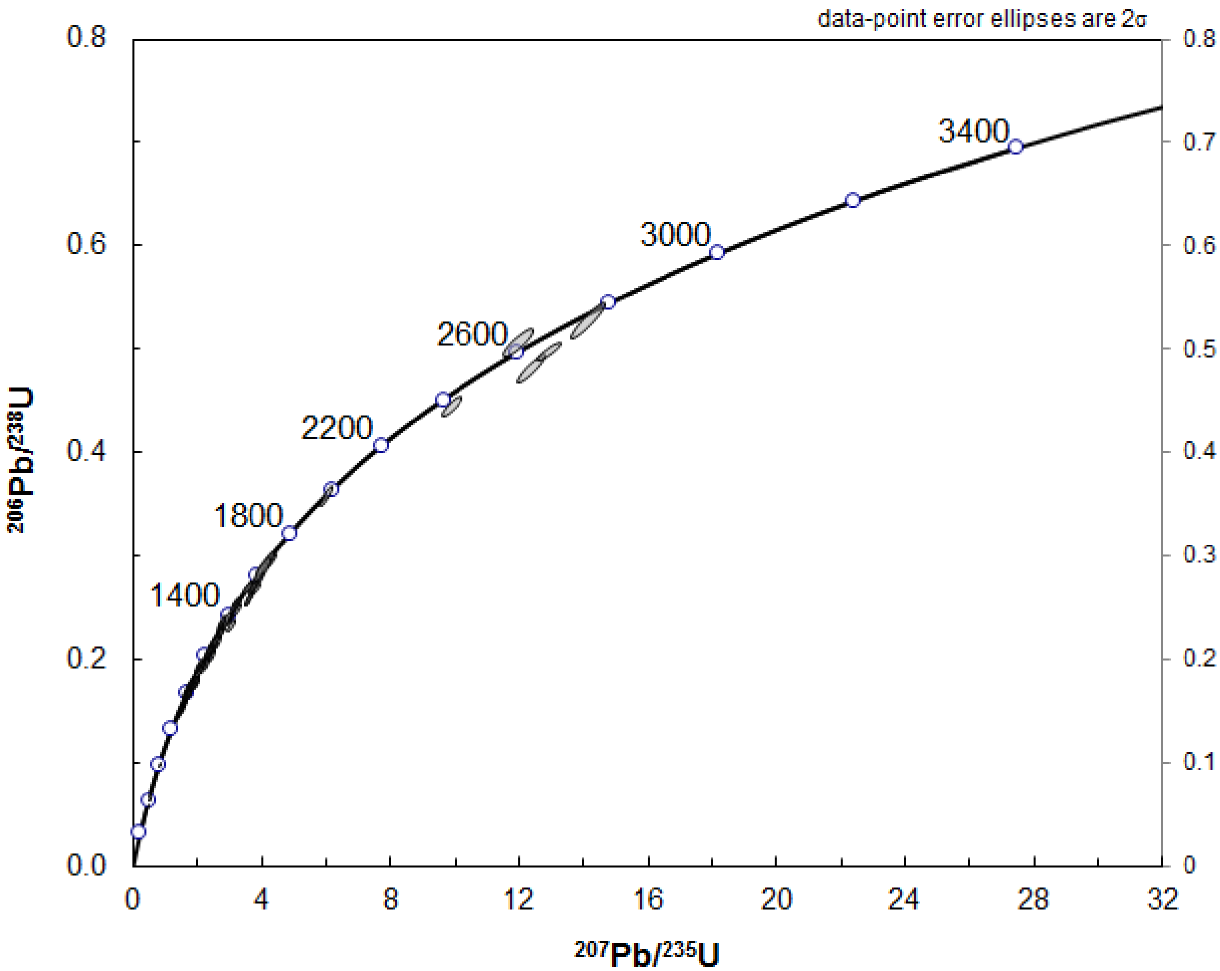
MB 1-2 Concordia Diagram



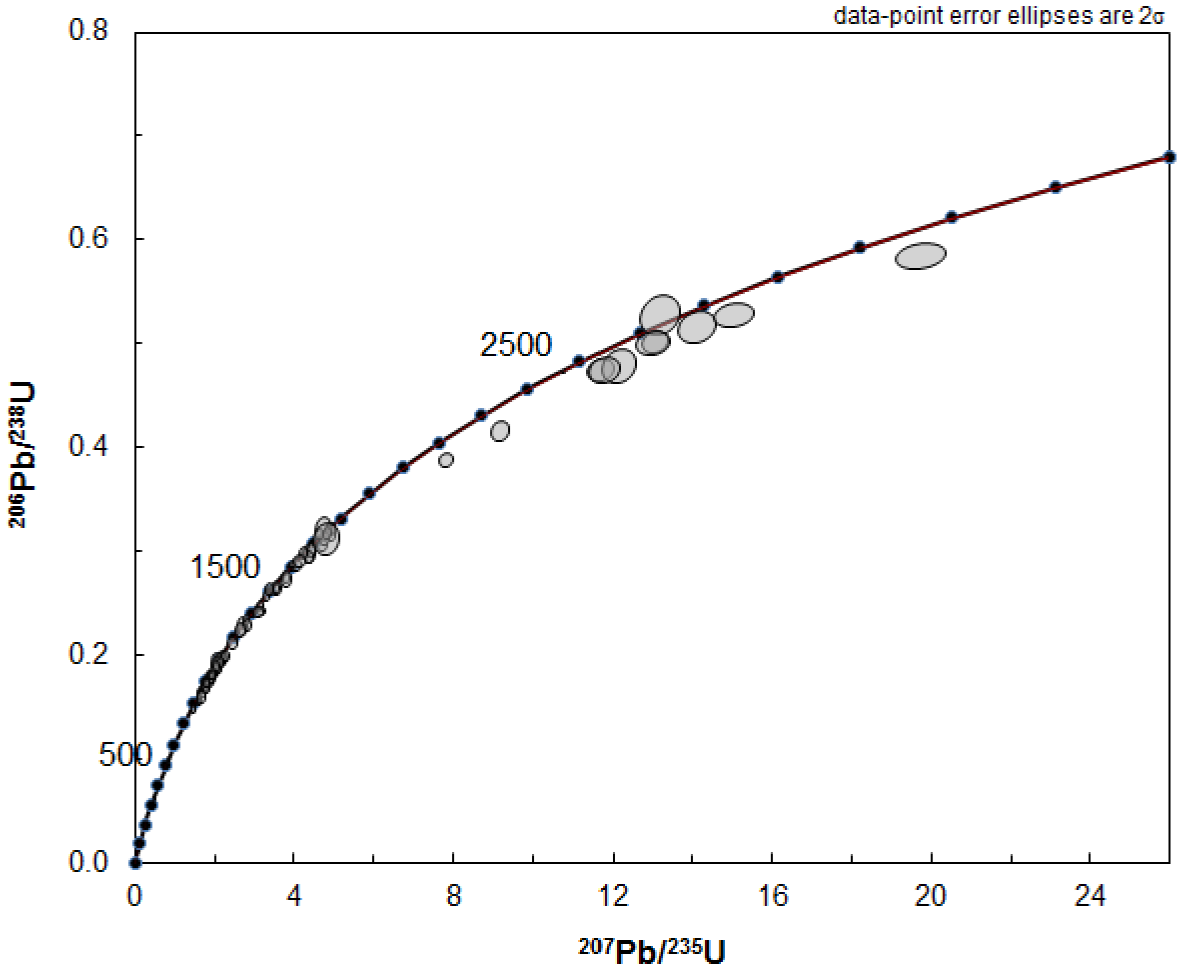
MB 1-3 Concordia Diagram



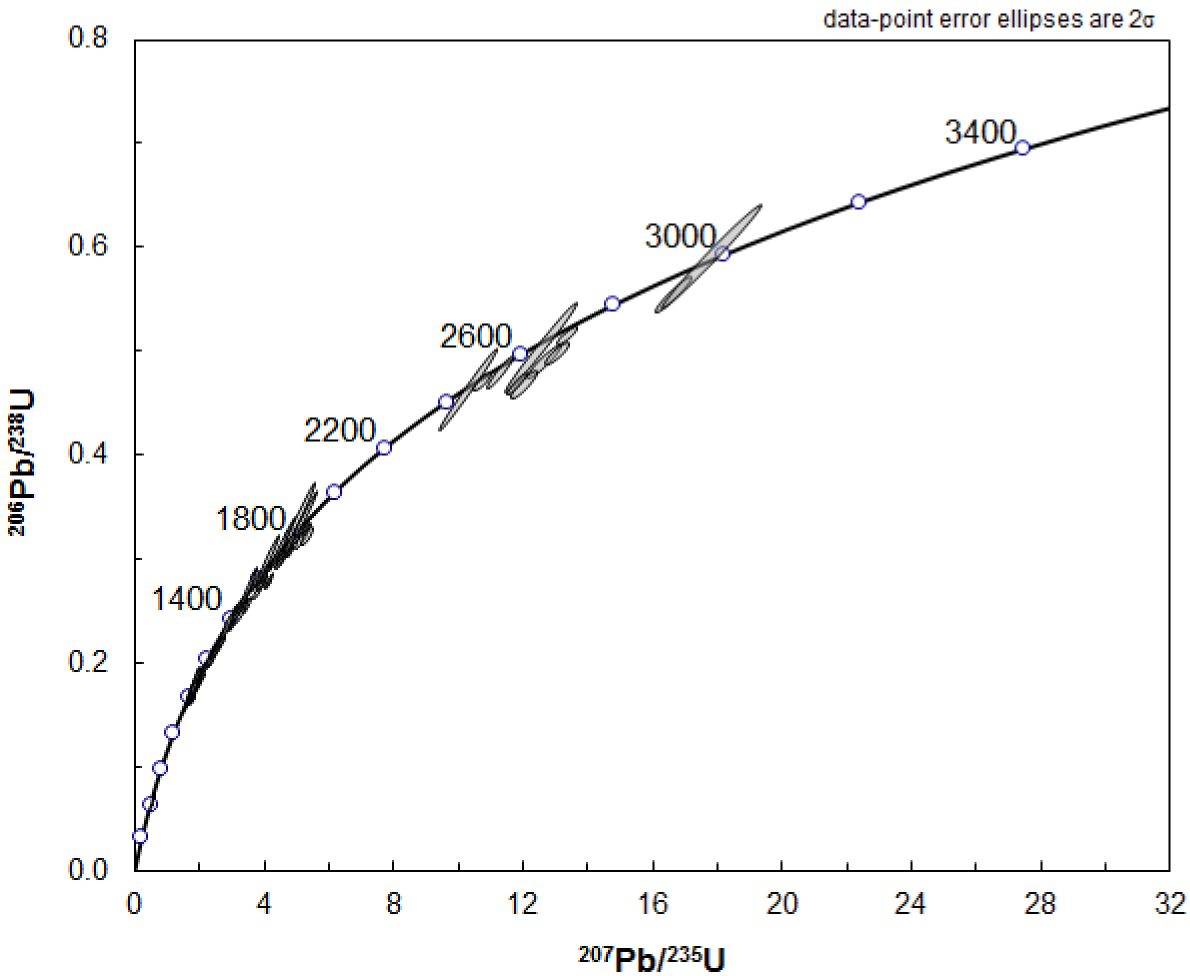
MB 2-1 Concordia Diagram



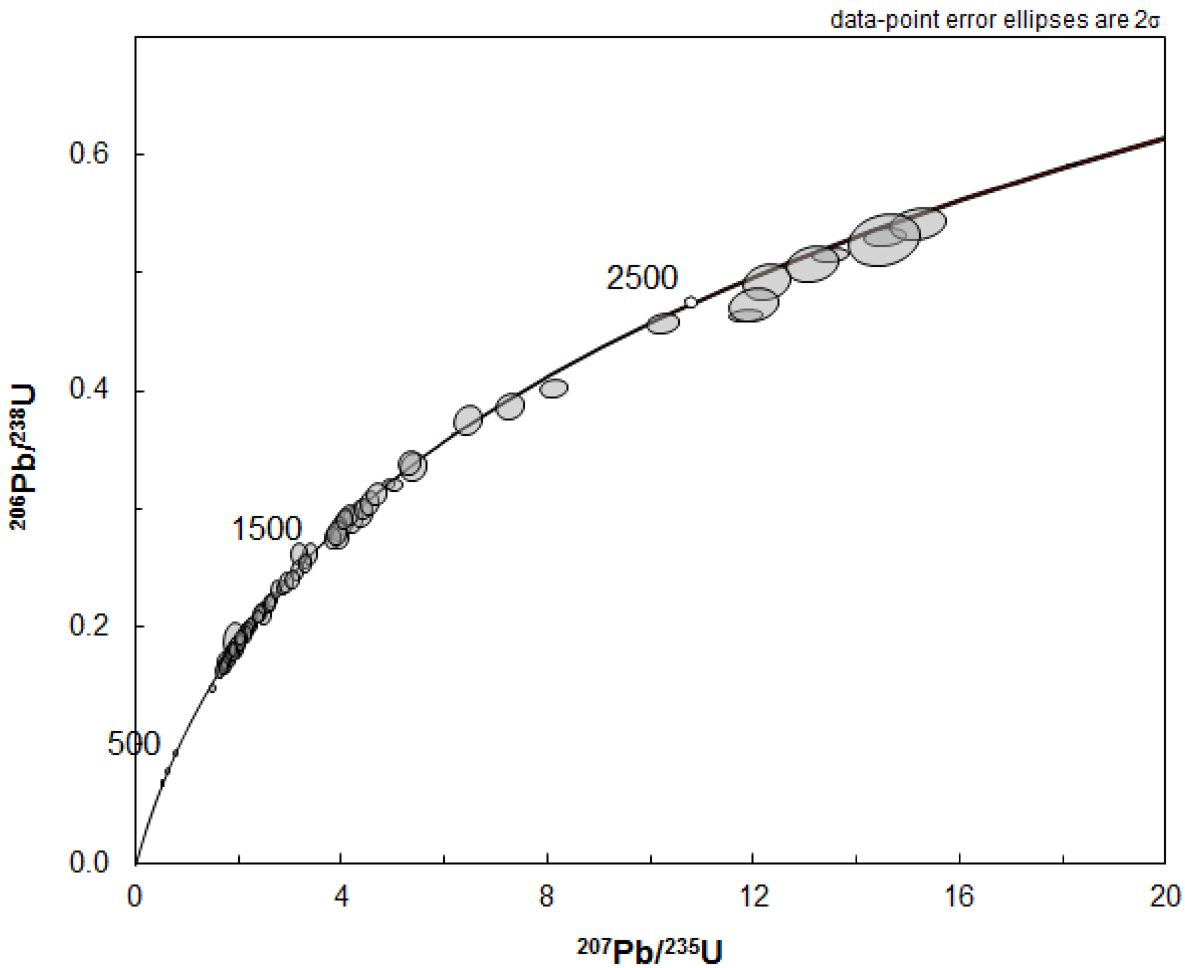
MB 2-2 Concordia Diagram



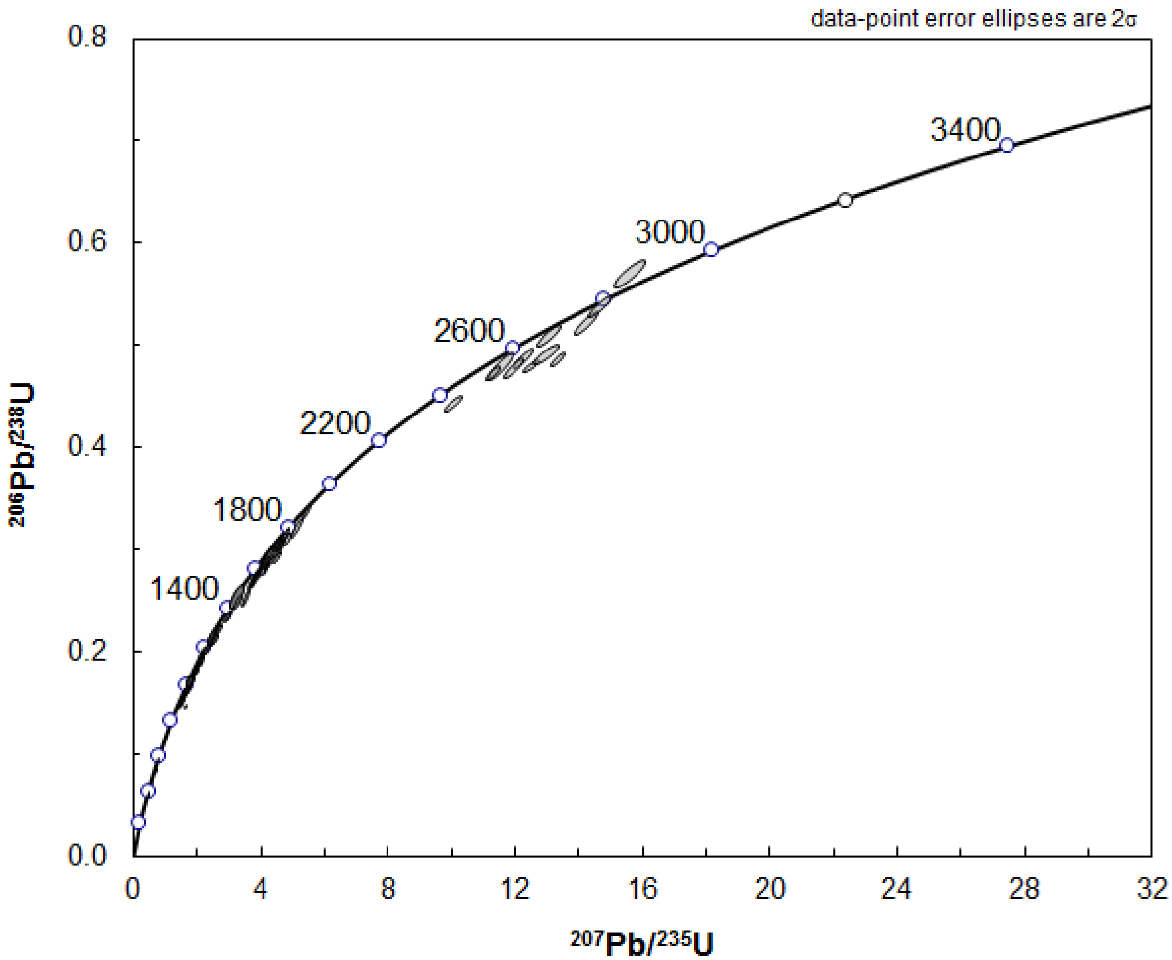
MB 2-3 Concordia Diagram



MB 2-4 Concordia Diagram

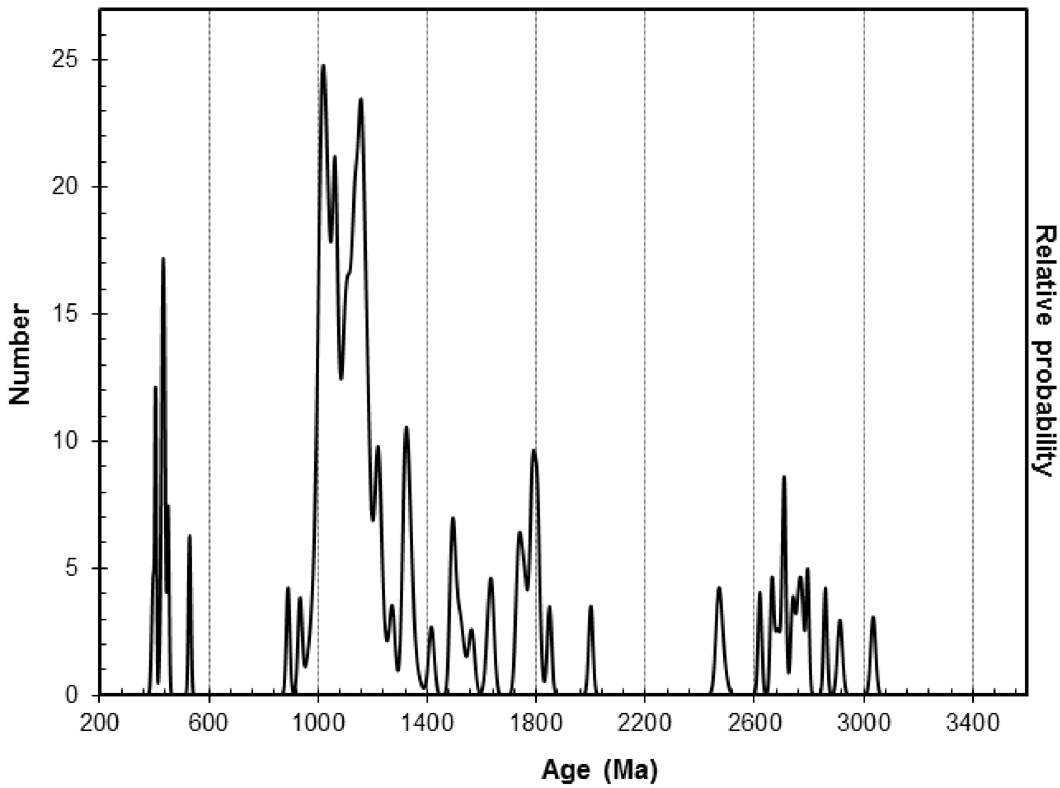


MB 2-5 Concordia Diagram

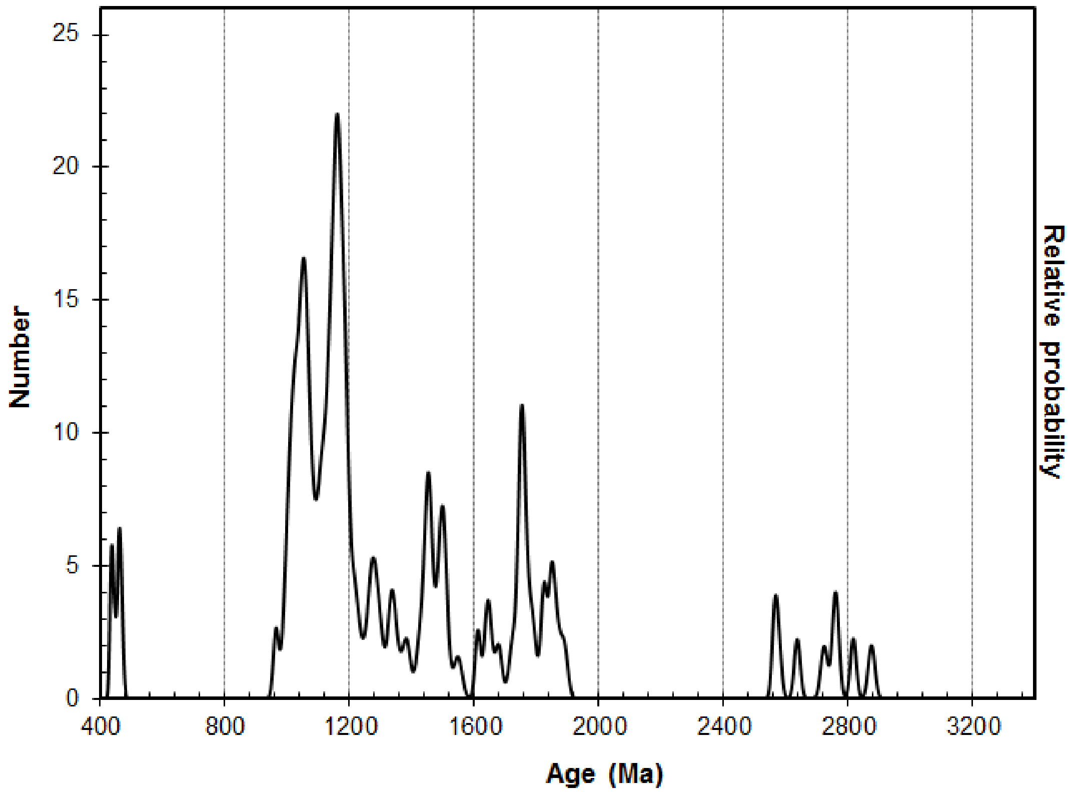


Appendix C- Probability-Density Plots

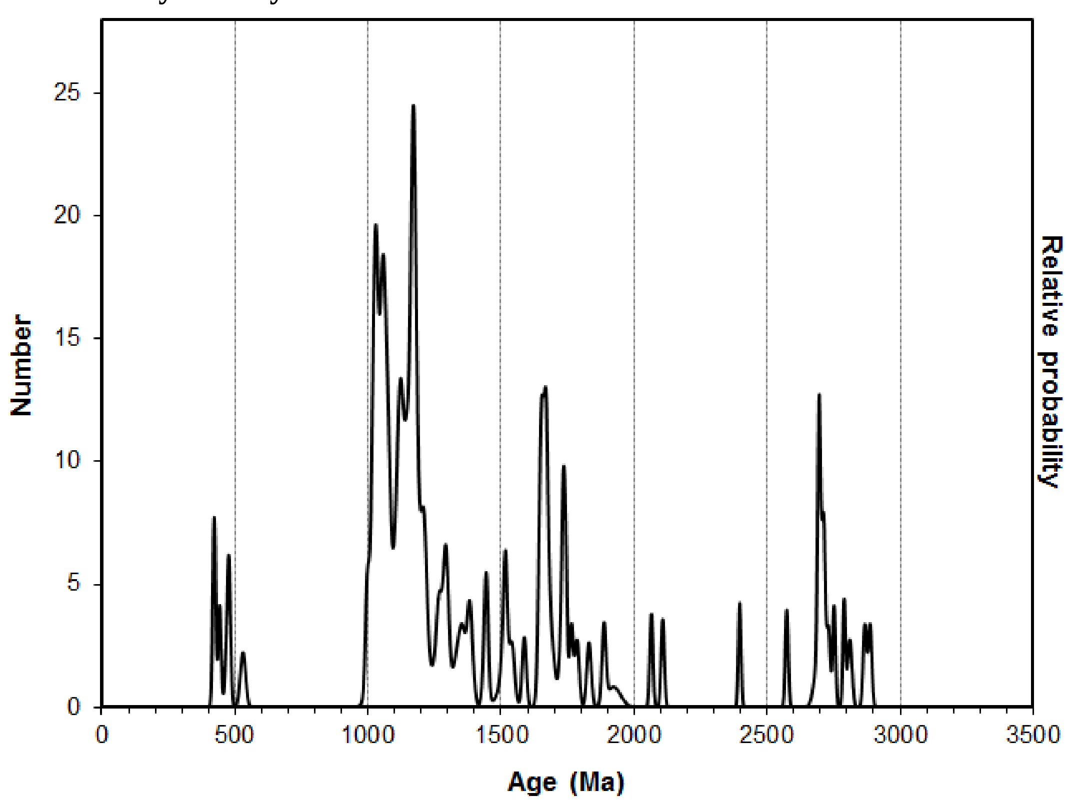
MB 1-1 Probability Density Plot



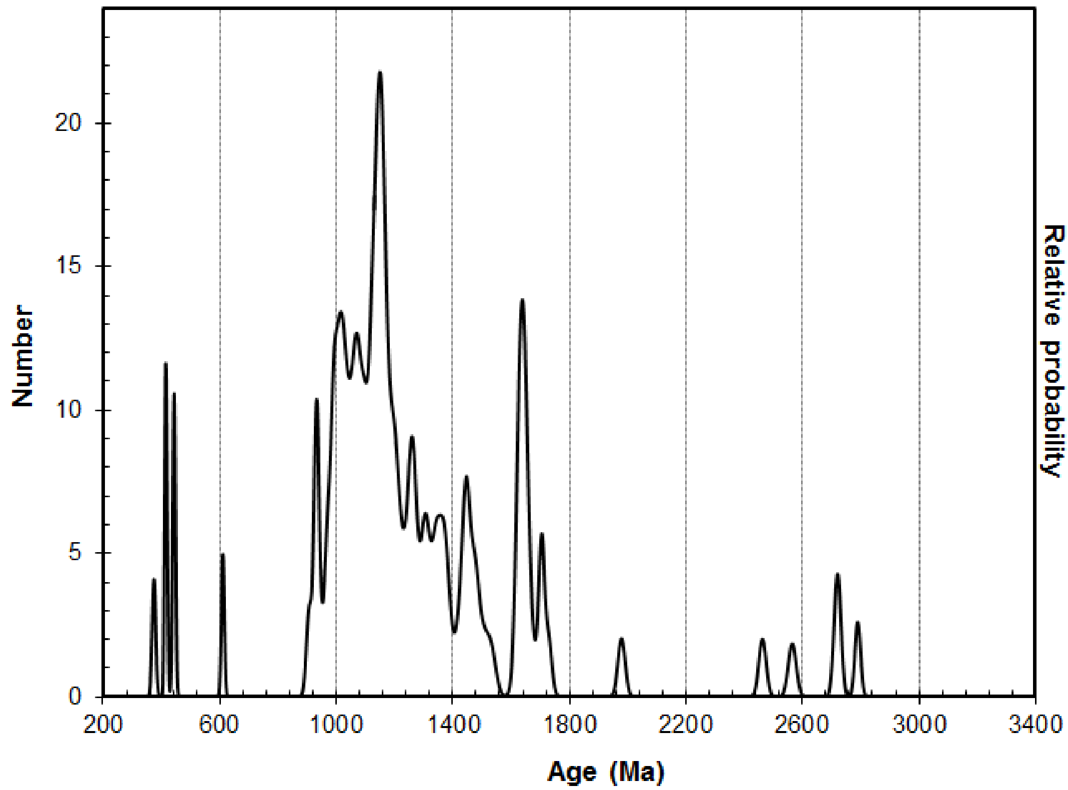
MB 1-2 Probability Density Plot



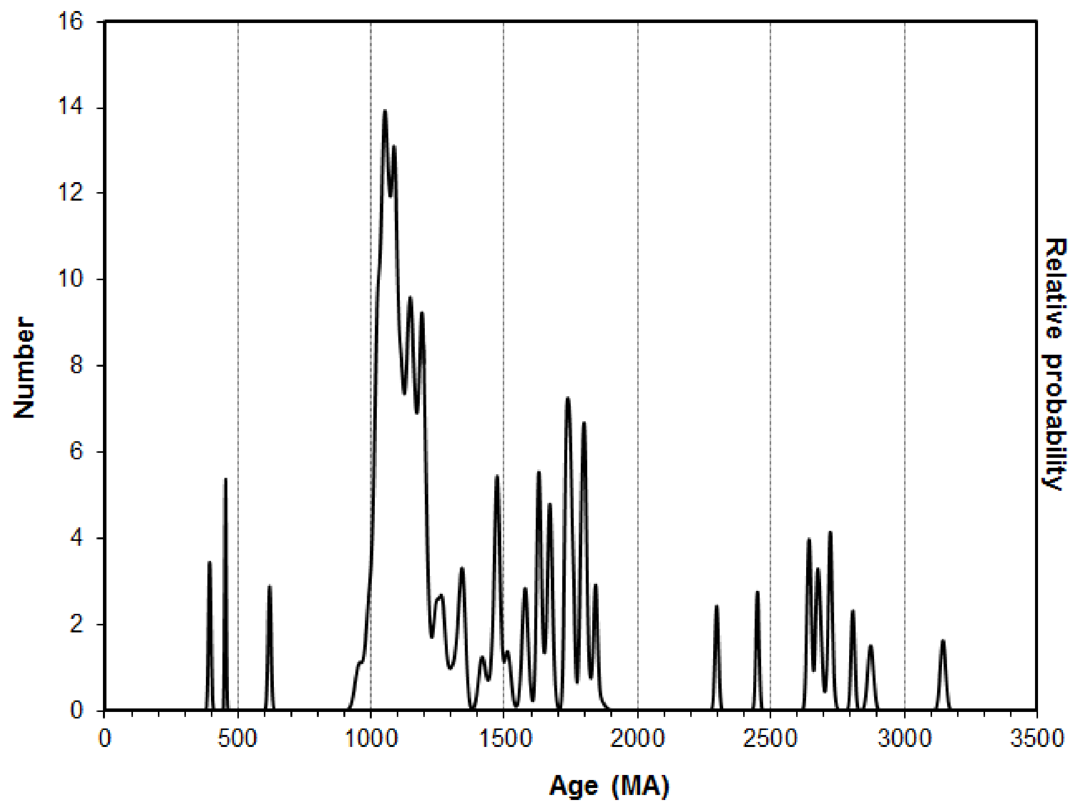
MB 1-3 Probability Density Plot



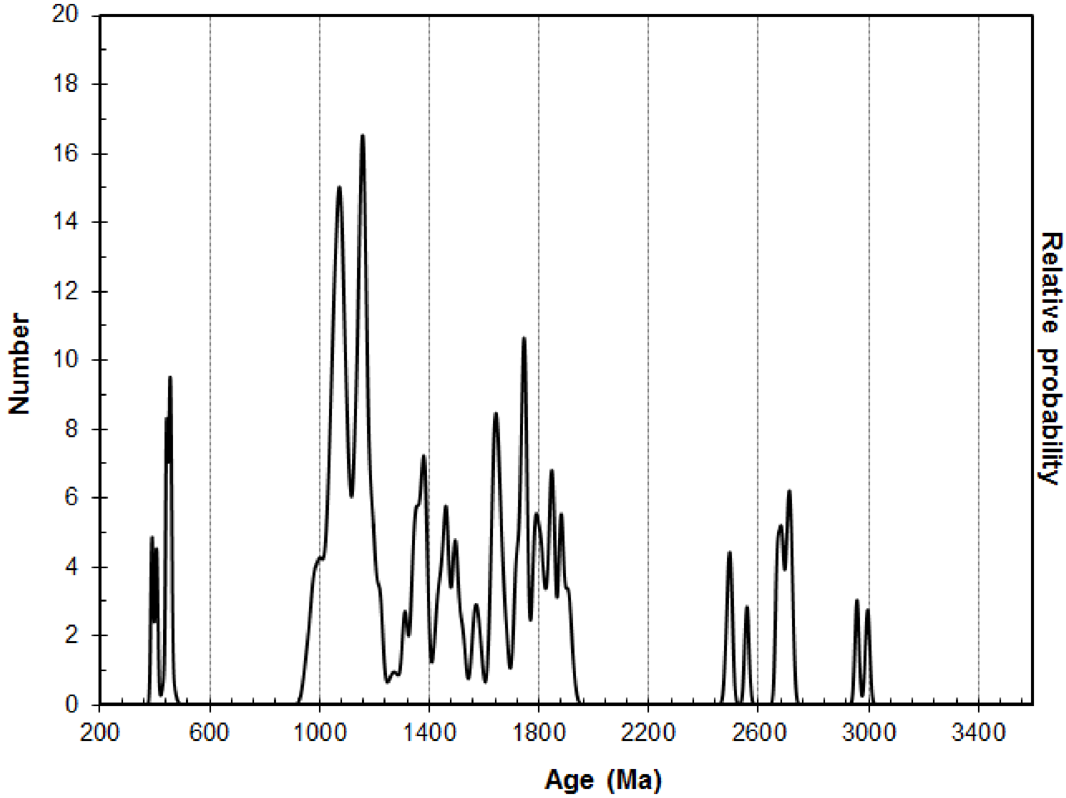
MB 2-1 Probability Density Plot



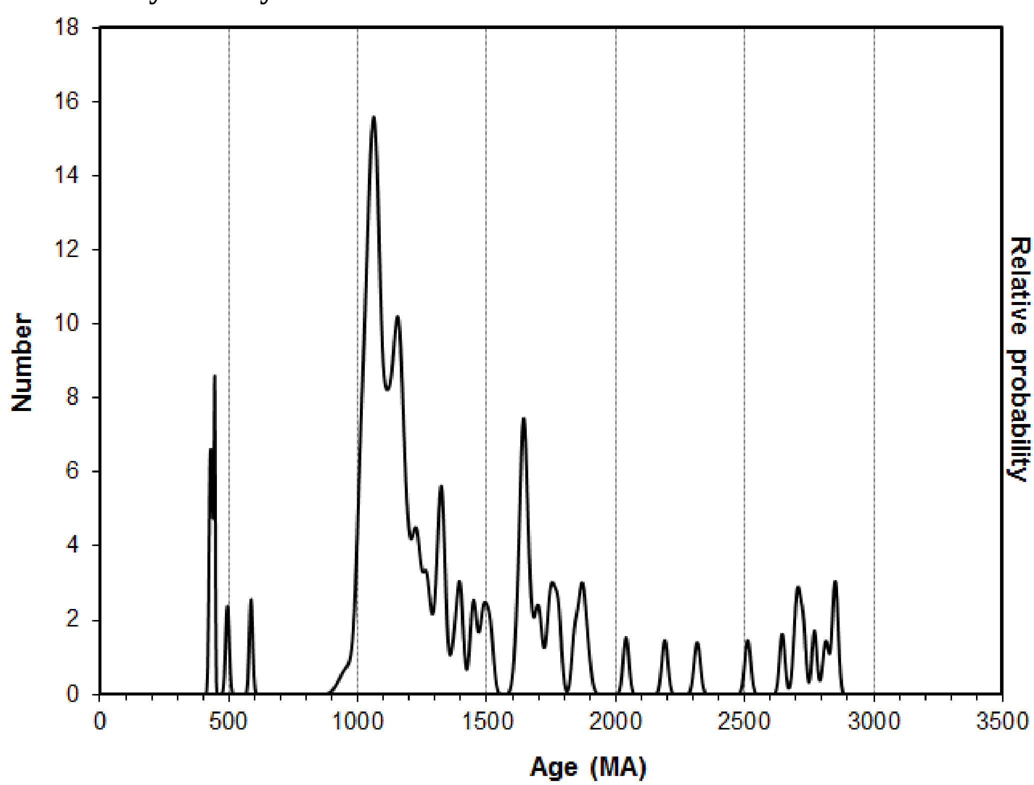
MB 2-2 Probability Density Plot



MB 2-3 Probability Density Plot



MB 2-4 Probability Density Plot



MB 2-5 Probability Density Plot