

Running Head Right: Chariton Conglomerate Zircon Ages

Evidence from Detrital Zircon Ages for Middle Pennsylvanian Uplift and Drainage in the Source Area of the Chariton Conglomerate and Marmaton Group Sandstones, Southern Iowa and Northern Missouri

SCOTT MCFADDEN¹
STEVEN H. EMERMAN^{2,*}
JANE PEDRICK DAWSON¹
KEVIN A. REY²
TRACY KEMP ANDERSON²

¹Department of Geological and Atmospheric Sciences, Iowa State University, Ames, Iowa 50011

²Department of Earth Science, Utah Valley University, Orem, Utah 84058

*Corresponding author, Tel: (801)863-6864, E-mail: StevenE@uvu.edu

Submitted to Journal of the Iowa Academy of Science, July 12, 2012

The Chariton Conglomerate is a quartz limestone conglomerate of Middle Pennsylvanian age sparsely exposed in southern Iowa and northern Missouri. In Iowa it is characterized by quartz granules and rounded crinoid columnals. The objective of this study was to use detrital zircon ages to determine the provenance of the Chariton Conglomerate and possibly associated Marmaton Group sandstone beds. Detrital zircon ages were obtained for five conglomerate and two sandstone beds of the Chariton Conglomerate in Iowa, three conglomerate beds of the Chariton Conglomerate in Missouri, and two sandstone beds of the Marmaton Group in Iowa. According to the Kolmogorov-Smirnoff Test, the 12 detrital zircon age spectra were statistically indistinguishable, consistent with a common provenance for all beds. The combined age spectrum (879 zircons) showed both a young cluster (1.1% of zircons) in the range 320-364 Ma (Late Devonian – Late Mississippian Periods) and a much older cluster (0.3% of zircons) in the range 3198-3269 Ma (Paleoarchean – Mesoarchean Eras). The Devonian – Mississippian Periods (318-416 Ma) and the Paleoarchean – Mesoarchean Eras (2800-3600 Ma) accounted for 2.8% and 3.6% of zircon ages, respectively. A model consistent with the above ages and the paleocurrent directions in the Chariton Conglomerate is an Early – Middle Pennsylvanian River originating in the Devonian – Mississippian crystalline rocks of New England and entering Minnesota – Wisconsin from the north to collect sediments from crystalline rocks of Paleoarchean – Mesoarchean age. However, a Middle Pennsylvanian uplift in

the Minnesota-Wisconsin region is also required to produce the headwaters necessary for the production of quartz granules, which is consistent with the model of hotspot epeirogeny.

INDEX DESCRIPTORS: Chariton Conglomerate, detrital zircons, hotspot epeirogeny

The Chariton Conglomerate is a quartz limestone conglomerate of Middle Pennsylvanian age sparsely exposed in southern Iowa and northern Missouri (see Fig. 1). The matrix consists of ferruginous sandstone and smaller particles of limestone (Bain 1896, Lees 1909). The cement is calcareous and is occasionally coarsely crystalline (Wallace 1941). Fragments of coal and carbonaceous materials are conspicuous (Bain 1896, Lees 1909, Wallace 1941, Gentile 1967). Wallace (1941) noted that quartz grains, ranging in size from silt to coarse sand, are always present. Kraber et al. (2007) observed that subangular to rounded quartz granules make up about 10% of the clasts. The conglomerate beds are occasionally interbedded with cross-bedded sandstones (Lugn 1927, Wallace 1941). The vast majority of the fossils are crinoid columnals, but brachiopods, corals, bryozoans, fusulinids, fish fragments and plant fossils are also present (Bain 1896, Lugn 1927, Wallace 1941, Pope et al. 2002). The very rounded crinoid columnals give clear evidence of transportation by water (Kraber et al. 2007). Although the three exposures in Missouri were classified as Chariton Conglomerate by Hinds and Greene (1915) and by Gentile (1965, 1967), they lack the quartz granules that are characteristic of the Chariton Conglomerate in Iowa, and, while crinoid columnals are present, they are not rounded (Kraber et al. 2007).

The stratigraphic position of the Chariton Conglomerate has long been debated, largely due to the scarcity of exposures and lack of visible contact with

other stratigraphic units. The stratigraphic debate is discussed in some detail here and we will argue for its importance in the Discussion section. Both Bain (1896) and Lees (1909) placed the Chariton Conglomerate above the Mystic Coal Member (see stratigraphic column in Table 1). Lees (1909) placed the Chariton Conglomerate below the Lonsdale Coal (later called the Mulberry Coal and now included within the Bandera Shale (Anderson 1998)). Later workers located the Chariton Conglomerate within what is now called the Bronson Group. Hinds and Greene (1915), Lugn (1927), Wood (1935) and Gentile (1965, 1967) all placed the Chariton Conglomerate within the Pleasanton Group (now the Bronson Group below the base of the Hertha Formation). Wilmarth (1938) described the Chariton Conglomerate as a member of the Pleasanton Formation. Wallace (1941) found fragments of *Chaetetes* and dermal denticles of fish from the Pawnee Formation and Worland Limestone Member of the Altamont Formation in the Chariton Conglomerate and noted the Chariton Conglomerate incised through the Pawnee Formation. According to Cline (1941), the Chariton Conglomerate is definitely younger than the Coal City Limestone Member of the Pawnee Formation and tentatively placed the Chariton Conglomerate between the Hertha Formation and the Exline Limestone Member of the Pleasanton Formation. Weller et al. (1942) located the Chariton Conglomerate below the Ovid Coal and above the Exline Limestone. Landis and Van Eck (1965) placed the Chariton Conglomerate at the base of the Pleasanton Formation below the Ovid Coal Bed, which they placed

below the Exline Limestone Member. Brown et al. (1977) called the Chariton Conglomerate a member of the Memorial Shale, which they placed above the Exline Limestone. (Compared to the contemporary stratigraphic column, Landis and Van Eck (1965) reverse the relative positions of the Exline Limestone and Ovid Coal, while Brown et al. (1977) reverse the relative positions of the Exline Limestone and Memorial Shale.)

The tendency from the 1980s on was to place the Chariton Conglomerate lower in the stratigraphic column within the Marmaton Group. Howe (1982) correlated the Chariton Conglomerate with the “Red Rock” sandstone, but Ravn et al. (1984) argued that the “Red Rock” sandstone is part of the much younger Floris Formation of the Cherokee Group. According to Ravn et al. (1984), the Chariton Conglomerate should not be regarded as a formal member because of the uncertainty in its stratigraphic position. Pope et al. (2002) identified in the Chariton Conglomerate the fusulinid foraminifer *Beedeina megista* (Thompson 1934), also found in the Worland Limestone, and concluded that the Chariton Conglomerate is younger than the Altamont Formation and may be as young as the lower Missourian Stage (Bronson Group). Pope et al. (2002) provisionally placed the Chariton Conglomerate in the upper Marmaton Group. The most recent Iowa Stratigraphic Column (Iowa Geological and Water Survey 2012) does not list the Chariton Conglomerate, again because of the uncertainty in its stratigraphic position.

All of the components of the Chariton Conglomerate except for the quartz clasts could have been derived from the underlying Pennsylvanian beds. The mystery of the Chariton Conglomerate is the provenance of the quartz clasts, since there is no crystalline bedrock in Iowa aside from a small outcrop of Sioux Quartzite in the farthest northwest corner of Iowa. The closest crystalline bedrock to the exposures of the Chariton Conglomerate in Iowa is 330 km away in southern Minnesota (see Fig. 2). Kraber et al. (2007) measured 16 paleocurrent directions in interbedded sandstones in the Chariton Conglomerate and found a mean direction of 178° ($SD = 35^\circ$), which was consistent with the mean paleocurrent direction of 167° found by Hansen (1978) for 343 measurements in the Cherokee Group (see Table 1) in Marion County (see Fig. 1), both indicating transport from the north during the Middle Pennsylvanian. Kraber et al. (2007) extracted 75 crinoid columnals from exposures of the Chariton Conglomerate in Iowa and measured their roundness. By carrying out laboratory experiments with rotary tumblers on quartz granules and unabraded crinoid columnals, Kraber et al. (2007) found that 0-700 km of transport was required to achieve the roundness of the crinoid columnals. Based on the above, Kraber et al. (2007) located the provenance of the quartz clasts of the Chariton Conglomerate within a wedge of radius 700 km with apex at the average position of exposures of the Chariton Conglomerate in southern Iowa and sides with orientations 323° and 33° (see Fig. 2). There are many sources of crystalline rocks within the wedge in Minnesota,

Wisconsin and the Upper Peninsula of Michigan, including rocks of Paleoproterozoic – Mesoproterozoic age (USGS 2012).

The objective of this study was to obtain detrital zircon U-Pb ages for the Chariton Conglomerate and sandstone beds of the Marmaton Group. This was the first detrital zircon dating study carried out in rocks found in either Iowa or Missouri. It was hoped that dating detrital zircons and, therefore, better establishing the provenance of the components (not only the quartz clasts) of the Chariton Conglomerate would help to address the following questions:

- 1) What were the drainage and uplift patterns during the Middle Pennsylvanian in the source area of the Chariton Conglomerate and Marmaton Group sandstones?
- 2) Do the Chariton Conglomerate exposures in Iowa and Missouri belong to the same stratigraphic unit?
- 3) Does the Chariton Conglomerate belong in the Marmaton Group?

We would have liked to have also compared the provenances of the Chariton Conglomerate with sandstones of the Bronson Group, but we were unable to locate any sandstones of the Bronson Group in Iowa.

METHODS

About 0.5 kg of rock were collected from a sandstone bed and a conglomerate bed of the six known exposures of the Chariton Conglomerate in Iowa and the three known exposures in Missouri (see Fig. 1) (Kraber et al. 2007).

After completing this study, we became aware of a reference to a seventh Iowa exposure (Beyer and Young 1903) just north of the Moravia exposure in Monroe County (see Fig. 1). Rock samples were also collected from exposures of sandstone beds of the LaBette Formation and Mine Creek Shale of the Marmaton Group (see Table 1) at locations in Iowa described as Stops One, Two and Three by Wolf et al. (1990). Although sandstone beds are uncommon in the Marmaton Group, no attempt was made to locate all exposures as was done for the Chariton Conglomerate.

The detrital zircon separation procedure is briefly described here. A document describing the complete procedure is available from the authors. The primary objective was to randomize the extraction process so as not to favor any particular size, shape or age of zircon. Rock samples were crushed and sieved and the <150 μm fraction was retained for detrital zircon separation. The fine fraction was washed to remove as much clay as possible. Grains denser than s-Tetrabromoethane (TBE) were separated in a separatory funnel, after which a Frantz magnetic separator set to 0.5 G was used to separate the low-magnetic fraction. Low-magnetic grains denser than methylene iodide were separated in a separatory funnel, after which the Frantz magnetic separator was used four times at strengths 0.75-1.5 G to again separate the low-magnetic fraction. A dental tool was finally used to remove non-zircons from the low-magnetic fraction that was denser than methylene iodide. Detrital zircons from five conglomerate beds and

two sandstone beds of the Chariton Conglomerate in Iowa, three conglomerate beds of the Chariton Conglomerate in Missouri, and two sandstone beds of the Marmaton Group in Iowa were mounted for U-Pb dating.

Detrital zircon U-Pb ages were measured in April 2009 at the Arizona LaserChron Center by laser ablation multicollector inductively coupled plasma mass spectrometry (LA-MC-ICPMS) (Gehrels et al. 2006, 2008). The procedure is described briefly here as the complete procedure is available online (Arizona LaserChron Center 2012a). The analyses involved ablation of zircon with a New Wave UP193HE Excimer laser (replaced with a Photon Machines Analyte G2 Excimer laser in May 2011) using a spot diameter of 30 μm , resulting in an ablation pit ~ 15 μm in depth. The ablated material was carried in helium into the plasma source of a Nu HR ICPMS, which was equipped with a flight tube of sufficient width that U, Th, and Pb isotopes were measured simultaneously. For each analysis, the errors in determining $^{206}\text{Pb}/^{238}\text{U}$ and $^{206}\text{Pb}/^{204}\text{Pb}$ resulted in a measurement error of ~ 1 -2% (at two standard deviations) in the $^{206}\text{Pb}/^{238}\text{U}$ age. The errors in measurement of $^{206}\text{Pb}/^{207}\text{Pb}$ and $^{206}\text{Pb}/^{204}\text{Pb}$ also resulted in ~ 1 -2% (at two standard deviations) uncertainty in age for grains that were >1000 Ma, but were substantially larger for younger grains due to low intensity of the ^{207}Pb signal. The best age was determined from the $^{206}\text{Pb}/^{238}\text{U}$ age for analyses with $^{206}\text{Pb}/^{238}\text{U}$ age <1000 Ma and from the $^{206}\text{Pb}/^{207}\text{Pb}$ age for analyses with $^{206}\text{Pb}/^{238}\text{U}$ age > 1000 Ma. Analyses were discarded if they showed $>10\%$

uncertainty (one standard deviation) or were >20% discordant or >5% reverse discordant. After 66 analyses were rejected, 879 successful analyses remained. Although the intention had been to analyze 100 zircons per sample, some samples had insufficient zircons (see Figs. 3a-c).

Detrital zircon ages were analyzed using Excel macros available on the web site of the Arizona LaserChron Center (2012b). Statistical comparison of detrital zircon spectra was carried out using the Kolmogorov-Smirnoff Test (Press et al. 1986, Berry et al. 2001, DeGraaff-Surpless et al. 2003). Age probability plots were created by producing a normal distribution curve for each detrital zircon age using the age as the mean and uncertainty as the standard deviation, and then summing the normal distribution curves for all detrital zircon ages in a sample to yield a single curve (see Figs. 3a-d). The age probability plots were normalized according to the number of constituent detrital zircon ages so that each curve contained the same area (see Figs. 3a-d).

RESULTS

Differences among detrital zircon age spectra were not statistically significant at the 95% confidence level for the Chariton Conglomerate exposures in southern Iowa (see Fig. 3a), the Chariton Conglomerate exposures in northern Missouri (see Fig. 3b), and the Marmaton Group sandstones (see Fig. 3c). Differences among detrital zircon age spectra were also not statistically significant for the combined Chariton Conglomerate in Iowa, the combined

Chariton Conglomerate in Missouri, and the combined Marmaton Group sandstones (see Fig. 3d). The common detrital zircon age spectra for all exposures is consistent with a common provenance for all exposures, which is consistent with a common stratigraphic unit for the Chariton Conglomerate in Iowa and Missouri, and with the placement of the Chariton Conglomerate within the Marmaton Group. All further analysis was carried on the combined age spectrum of all samples (879 zircons).

The youngest zircon age was (287.9 ± 24.5) Ma, which had a barely acceptable uncertainty (8.5%). Although the youngest best age lies in the Early Permian Period, the uncertainty of one standard deviation could place the age in the Early Pennsylvanian Period. The second youngest zircon age was (318.9 ± 5.6) Ma with the best age in the Late Mississippian Period. Therefore, the youngest zircon ages do not constrain the date of deposition of the Chariton Conglomerate any better than what was already known. The oldest zircon was (3639.1 ± 11.2) Ma from the Eoarchean Era. The vast majority of zircon ages (75.2%) clustered in the range 822-2351 Ma (Paleoproterozoic – Neoproterozoic Era) (see Table 2). The cluster containing the next largest number of zircon ages (12.2%) was the range 377-707 Ma (Neoproterozoic Era – Late Devonian Period) (see Table 2). There are many possible sources of zircons over such large time ranges. However, the key to identifying provenance from zircon ages is to locate age clusters of restricted time range that, hopefully, also have restricted

geographic extent. The key clusters are probably the youngest cluster (1.1% of zircons) in the range 320-364 Ma (Late Devonian – Late Mississippian Periods) and the oldest cluster (0.3% of zircons) in the range 3198-3269 Ma (Paleoarchean – Mesoarchean Eras) (see Table 2). Since geologic maps are often based upon the standard geologic time units, it is noted that the Devonian – Mississippian Periods (318-416 Ma) and the Paleoarchean – Mesoarchean Eras (2800-3600 Ma) accounted for 2.8% and 3.6% of zircon best ages, respectively. (Taking age uncertainties into account would increase the numbers of zircons falling into the above time units.)

The results necessary for determining the provenance of the Chariton Conglomerate are summarized as follows:

- 1) The components of the Chariton Conglomerate were transported into Iowa roughly from the north.
- 2) The quartz clasts and rounded crinoid columnals originated within a wedge of radius 700 km (see Fig. 2).
- 3) The source area includes crystalline rocks of Devonian – Mississippian age.
- 4) The source area includes crystalline rocks of Paleoarchean – Mesoarchean age.

DISCUSSION

The simplest model that accounts for the above results is an Early – Middle Pennsylvanian river that originated in the Devonian – Mississippian

crystalline rocks of New England, meandered through Quebec and Ontario, and entered Minnesota – Wisconsin from the north to collect sediments from Paleoproterozoic – Mesoproterozoic crystalline rocks before depositing its collection of sediments in Iowa and Missouri (see Fig. 4). The coincidence between the belt of Paleoproterozoic – Mesoproterozoic crystalline rocks and the wedge predicted by paleocurrent directions and crinoid columnar rounding in the Chariton Conglomerate is remarkable (see Figs. 2, 4). Any other model would be considerably more complex and would require transport of Devonian – Mississippian zircons from the Alabama – Virginia region or the existence of Devonian – Mississippian crystalline bedrock in Minnesota, Wisconsin or Ontario that has been removed by erosion since the Pennsylvanian Period.

The result that the Minnesota – Wisconsin region is the apparent source of quartz clasts still requires explanation. Fluvial gravel would not normally occur 3000 km from the headwaters of a major river. Therefore, the quartz clasts require Middle Pennsylvanian uplift in the Minnesota – Wisconsin region so that this region became a new source of headwaters. One possibility is that the Early – Middle Pennsylvanian river (see Fig. 4) acted as an antecedent river cutting a deep gorge through uplifted cliffs of Paleoproterozoic – Mesoproterozoic crystalline rock so that there may have been a continuous contribution of Devonian – Mississippian zircons even during the uplift. The proper stratigraphic position of the Chariton Conglomerate can now be seen as having possible critical

importance for understanding the mid-continental Paleozoic geology as it dates the hypothesized Minnesota – Wisconsin uplift.

It is interesting that Prof. Blakeley's North American Paleogeographic Map for the Late Pennsylvanian (300 Ma) (Colorado Plateau Geosystems 2012) shows highlands in Minnesota and Wisconsin, although this choice is not justified in his bibliography (Rich 1977). In an abstract Morgan (1980) argued in favor of the northeast – southwest motion of North America over a hotspot beginning in the Middle Devonian so that uplift progressively occurred from Colorado to Minnesota. An absolute plate motion of about 1.5 cm yr^{-1} would place the hotspot under Minnesota by the Middle Pennsylvanian. This concept was called hotspot epeirogeny (Neill 1976, Crough 1979) and has been applied to various areas of Phanerozoic uplift (Crough 1981, 1984, McHone 1981, Washington 1989, Morgan 1997, Sengor 2001). Unfortunately, there does not seem to have been any follow-up to Morgan's (1980) suggestion of a Devonian – Pennsylvanian North American hotspot track.

CONCLUSIONS

The vast majority of North American detrital zircon geochronology has been carried out in the Cordilleran, Rocky Mountain and Appalachian regions. This study has used detrital zircon geochronology in Iowa and Missouri to show evidence for an Early – Middle Pennsylvanian river originating in New England and entering Minnesota – Wisconsin from the north and for Middle

Pennsylvanian uplift in the Minnesota – Wisconsin region. Prior to this study, the uplift was known only from relatively unsubstantiated suggestions and the major river was entirely unknown. It is hoped that this study will stimulate further research in detrital zircon geochronology in the mid-continent of North America.

ACKNOWLEDGEMENTS

This research was partially funded by a grant from the College of Science and Health Scholarly Activities Committee (Utah Valley University) and by the Department of Geological and Atmospheric Sciences (Iowa State University). The Arizona LaserChron Center is funded by National Science Foundation grant NSF-EAR 1032156. We are grateful to Carl Jacobson for suggesting the use of detrital zircon ages to address the problems described in this study.

LITERATURE CITED

- ANDERSON, W. I. 1998. Iowa's geological past: Three billion years of change. University of Iowa Press, Iowa City, Iowa.
- ARIZONA LASERCHRON CENTER. 2012a. Publication tools.
<https://sites.google.com/a/laserchron.org/laserchron/home/>
- ARIZONA LASERCHRON CENTER. 2012b. Analysis tools.
<https://sites.google.com/a/laserchron.org/laserchron/home/>
- BAIN, H. F. 1896. Geology of Appanoose County. Pages 363-438. *In* Iowa Geological Survey, vol. 5, annual report, 1895, with accompanying papers. S. Calvin and H. F. Bain (eds.), Iowa Geological Survey, Des Moines, Iowa.
- BERRY, R. F., G. A. JENNER, S. MEFFRE, and M. N. TUBRETT. 2001. A North American provenance for Neoproterozoic to Cambrian sandstones in Tasmania? *Earth and Planetary Science Letters* 192:207-222.
- BEYER, S. W. and L. E. YOUNG. 1903. Geology of Monroe County. Pages 353-433. *In* Iowa Geological Survey, vol. 13, annual report, 1902, with accompanying papers. S. Calvin and A. G. Leonard (eds.), Iowa Geological Survey, Des Moines, Iowa.
- BROWN, L. F., S. W. BAILEY, L. M. CLINE, and J. S. LISTER. 1977. Clay mineralogy in relation to deltaic sedimentation patterns of Desmoinesian cyclothems in Iowa – Missouri. *Clays and Clay Minerals* 25:171-186.

- CLINE, L. M. 1941. Traverse of upper Des Moines and lower Missouri series from Jackson County, Missouri, to Appanoose County, Iowa. *Bulletin of the American Association of Petroleum Geologists* 25:23-72.
- COLORADO PLATEAU GEOSYSTEMS, INC. 2012. North American paleogeographic maps. <http://cpgeosystems.com/nam.html>.
- CROUGH, S. T. 1979. Hotspot epeirogeny. *Tectonophysics* 61:321-333.
- CROUGH, S. T. 1981. Mesozoic hotspot epeirogeny in eastern North America. *Geology* 9:2-6.
- CROUGH, S. T. 1984. Seamounts as recorders of hot-spot epeirogeny. *Geological Society of America Bulletin* 95:3-8.
- DEGRAAFF-SURPLESS, K., J. B. MAHONEY, J. L. WOODEN, and M. O. MCWILLIAMS. 2003. Lithofacies control in detrital zircon provenance studies: Insights from the Cretaceous Methow basin, southern Canadian Cordillera. *Geological Society of America Bulletin* 115:899-915.
- GEHRELS, G.E., V. VALENCIA, and A. PULLEN. 2006. Detrital zircon geochronology by Laser-Ablation Multicollector ICPMS at the Arizona LaserChron Center. Pages 67-76. *In* *Geochronology: Emerging opportunities*. T. Loszewski and W. Huff (eds.). Paleontological Society Short Course, Paleontological Society Papers 11, Boulder, Colorado.
- GEHRELS, G. E., V. VALENCIA, and J. RUIZ. 2008. Enhanced precision, accuracy, efficiency, and spatial resolution of U-Pb ages by laser ablation–

multicollector–inductively coupled plasma–mass spectrometry.

Geochemistry, Geophysics, Geosystems, 9. doi:10.1029/2007GC001805.

GENTILE, R. J. 1965. Mineral commodities of Putnam County. Geological Survey and Water Resources Report of Investigations No. 29, Rolla, Missouri.

GENTILE, R. J. 1967. Mineral commodities of Macon and Randolph Counties. Geological Survey and Water Resources Report of Investigations No. 40, Rolla, Missouri.

HANSEN, D. L. 1978. The distribution of Cherokee sandstones, Marion County, Iowa. M.S. Thesis, Earth Sciences Dept., Iowa State University, Ames, Iowa.

HINDS, H. and F. C. GREENE. 1915. The stratigraphy of the Pennsylvanian Series in Missouri. Missouri Bureau of Geology and Mines, Vol. 13, Second Series, Jefferson City, Missouri.

HOWE, W. B. 1982. Stratigraphy of the Pleasanton Group, Pennsylvanian System in Missouri. Open File Report OFR-82-10-GI, Geology and Land Survey Division, Missouri Department of Natural Resources, Rolla, Missouri.

INTERNATIONAL COMMISSION ON STRATIGRAPHY. 2012. International stratigraphic chart.

[http://www.stratigraphy.org/column.php?id=Chart/Time Scale](http://www.stratigraphy.org/column.php?id=Chart/Time%20Scale).

IOWA GEOLOGICAL & WATER SURVEY. 2012. Iowa stratigraphic column.

<http://www.igsb.uiowa.edu/webapps/geosam/>.

KRABER, J. C., S. H. EMERMAN, M. R. BENNETT, L. R. HAWKINS, J. E.

MOORE, R. ELLENWOOD, K. L. ROBSON, and A. FINKEN. 2007.

Laboratory abrasion of crinoid columnals and the provenance of the Chariton Conglomerate, south-central Iowa. *Journal of the Iowa Academy of Science* 114:44-53.

LANDIS, E. R. and O. J. VAN ECK. 1965. Coal resources of Iowa. Technical Paper No. 4, Iowa Geological Survey, Iowa City, Iowa.

LEES, J. H. 1909. General section of the Des Moines Stage of Iowa. Pages 589-604. *In* Iowa Geological Survey, vol. 19, annual report, 1908, with accompanying papers. S. Calvin and J. H. Lees (eds.), Iowa Geological Survey, Des Moines, Iowa.

LUGN, A. L. 1927. Geology of Lucas County. Pages 101-237. *In* Iowa Geological Survey, vol. 32, annual reports, 1925 and 1926, with accompanying papers. G. F. Kay and J. H. Lees (eds.), Iowa Geological Survey, Des Moines, Iowa.

- MCHONE, J. G. 1981. Mesozoic hotspot epeirogeny in eastern North America; discussion and reply. *Geology* 9:341-343.
- MORGAN, J. P. 1997. Hotspot epeirogeny revisited; effects of plume-lithosphere interaction on volcanism and relief. Abstracts with Programs – Geological Society of America 29:165-166.
- MORGAN, W. J. 1980. Hotspot tracks on continents and unconformities. Abstracts with Programs – Geological Society of America 12:487.
- NEILL, W. M. 1976. Mesozoic epeirogeny at the South Atlantic margin and the Tristan hot spot. *Geology* 4:495-498.
- POPE, J., B. WITZKE, G. LUDVIGSON, and R. ANDERSON. 2002. Bedrock geologic map of south-central Iowa: Discussion. OFM-02-1, Iowa Geological Survey, Iowa City, Iowa.
- PRESS, W. H., B. P. FLANNERY, S. A. TEUKOLSKY, and W. T. VETTERLING. 1986. Numerical recipes: The art of scientific computing. Cambridge University Press, Cambridge.
- RAVN, R. L., J. W. SWADE, M. R. HOWES, J. L. GREGORY, R. R. ANDERSON, and P. E. VAN DORPE. 1984. Stratigraphy of the Cherokee Group and revision of Pennsylvanian stratigraphic nomenclature in Iowa. Technical Information Series No. 12, Iowa Geological Survey, Iowa City, Iowa.

- RICH, M. 1977. Pennsylvanian paleographic patterns of the western United States. Pages 87-111. *In* Paleozoic paleogeography of the western United States. SEPM Symposium 1. J. H. Stewart, C. H. Stevens, and A. E. Fritsche (eds.), Society for Economic Paleontologists and Mineralogists, Bakersfield, California.
- SENGOR, A. M. C. 2001. Elevation as indicator of mantle-plume activity. Pages 183-225. *In* Mantle plumes; their identification through time. Special Paper – Geological Society of America, Vol. 352. R. E. Ernst and K. L. Buchan (eds.), Geological Society of America, Boulder, Colorado.
- THOMPSON, M. L. 1934. The fusulinids of the Des Moines Series of Iowa. University of Iowa Studies in Natural History, New Series No. 284 16:277-332.
- USGS (U. S. GEOLOGICAL SURVEY). 2012. Resources for the Geologic Map of North America. <http://ngmdb.usgs.gov/gmna/>.
- WALLACE, M. H. 1941. Chariton Conglomerate in Lucas and Marion Counties, Iowa. Transactions of the Kansas Academy of Science 44:322-326.
- WASHINGTON, P. A. 1989. Medium-duration low-stands of sea-level recorded in Cambrian and Ordovician strata of the Champlain Valley (VT & NY); possible evidence of mantle plume activity. Abstracts with Programs – Geological Society of America 21:94.

- WELLER, J. M., H. R. WANLESS, L. M. CLINE, and D. G. STOOKEY. 1942. Interbasin Pennsylvanian correlations, Illinois and Iowa. *Bulletin of the American Association of Petroleum Geologists* 26:1585-1593.
- WILMARTH, W. G. 1938. *Lexicon of geologic names of the United States (including Alaska)*. United States Geological Survey Bulletin 896, Washington, D. C.
- WOLF, W., J. POPE, and A. CHANTOONI. 1990. A.M.A.T.E.U.R.: A Marmaton, amateur-led trek to exposures unexplored near the Raccoon River (southeast Dallas County). Guidebook 52, Geological Society of Iowa, Iowa City, Iowa.
- WOOD, L. W. 1935. The road and concrete materials of southern Iowa. Pages 15-310. *In Iowa Geological Survey, vol. 36, annual reports, 1930, 1931, 1932, and 1933, with accompanying papers*. G. F. Kay and J. H. Lees (eds.), Iowa Geological Survey, Des Moines, Iowa.

Table 1. Simplified stratigraphic column for the Pennsylvanian System in Iowa, including all groups and any other stratigraphic units mentioned in the text (modified from Iowa Geological & Water Survey (2012)).

Waubansee Group

Shawnee Group

Douglas Group

Lansing Group

Kansas City Group

Bronson Group

Hertha Formation

Pleasanton Formation

Manly-Guthrie Mountain Shale

Ovid Coal

Exline Limestone

Marmaton Group

Memorial Shale

Altamont Formation

Worland Limestone

Bandera Shale

Pawnee Formation

Coal City Limestone

Mine Creek Shale

Labette Formation

Mystic Coal

Cherokee Group

Floris Formation

Table 2. Detrital zircon age clusters: Combined Chariton Conglomerate and Marmaton Group sandstones.

Range (Ma)^a	Zircons^b	Geologic Time Units^c
320-364	10 (1.1%)	Late Devonian – Late Mississippian Periods
377-707	107 (12.2%)	Neoproterozoic Era – Late Devonian Period
822-2351	661 (75.2%)	Paleoproterozoic – Neoproterozoic Eras
2434-3025	89 (10.1%)	Mesoarchean – Paleoproterozoic Eras
3198-3269	3 (0.3%)	Paleoarchean – Mesoarchean Eras

^aAge clusters obtained from AGE PICK program (Arizona LaserChron Center 2012b). Clusters with fewer than three zircons omitted. Range contains ages within two standard deviations of the mean.

^bNumber of zircon ages within cluster with percentage of total (N = 879) in parentheses. Percentages add to 98.9% because nine zircons did not fall into any clusters.

^cInternational Commission on Stratigraphy (2012)

FIGURE CAPTIONS

- Fig. 1** Samples were collected from six exposures of the Chariton Conglomerate in Iowa and three in Missouri. Exposures are named after the nearest village, except for S & S, which is the name of the active quarry. The three exposures in Missouri lack the quartz granules and rounded crinoid columnals that are characteristic of the Chariton Conglomerate in Iowa. Two sandstone beds of the Marmaton Group (labeled after the stratigraphic unit) were studied for comparison with the Chariton Conglomerate.
- Fig. 2** Paleocurrent directions and comparison of rounded crinoid columnals with laboratory experiments predicted that the quartz clasts and crinoid columnals of the Chariton Conglomerate originated in a wedge of radius 700 km with apex at the average position of exposures of the Chariton Conglomerate in southern Iowa and sides with orientations 323° and 33° (Kraber et al. 2007). There are many sources of crystalline rocks within the wedge in Minnesota, Wisconsin and the Upper Peninsula of Michigan, including rocks of Paleoproterozoic – Mesoproterozoic age (USGS 2012).
- Fig. 3a** Differences among detrital zircon age spectra for exposures of the Chariton Conglomerate in southern Iowa were not statistically significant at the 95% confidence level according to the

Kolmogorov-Smirnoff Test. Exposures are ranked from north (top) to south (bottom). All exposures are conglomerate beds unless otherwise indicated. Number of zircons dated at each exposure is shown in parentheses.

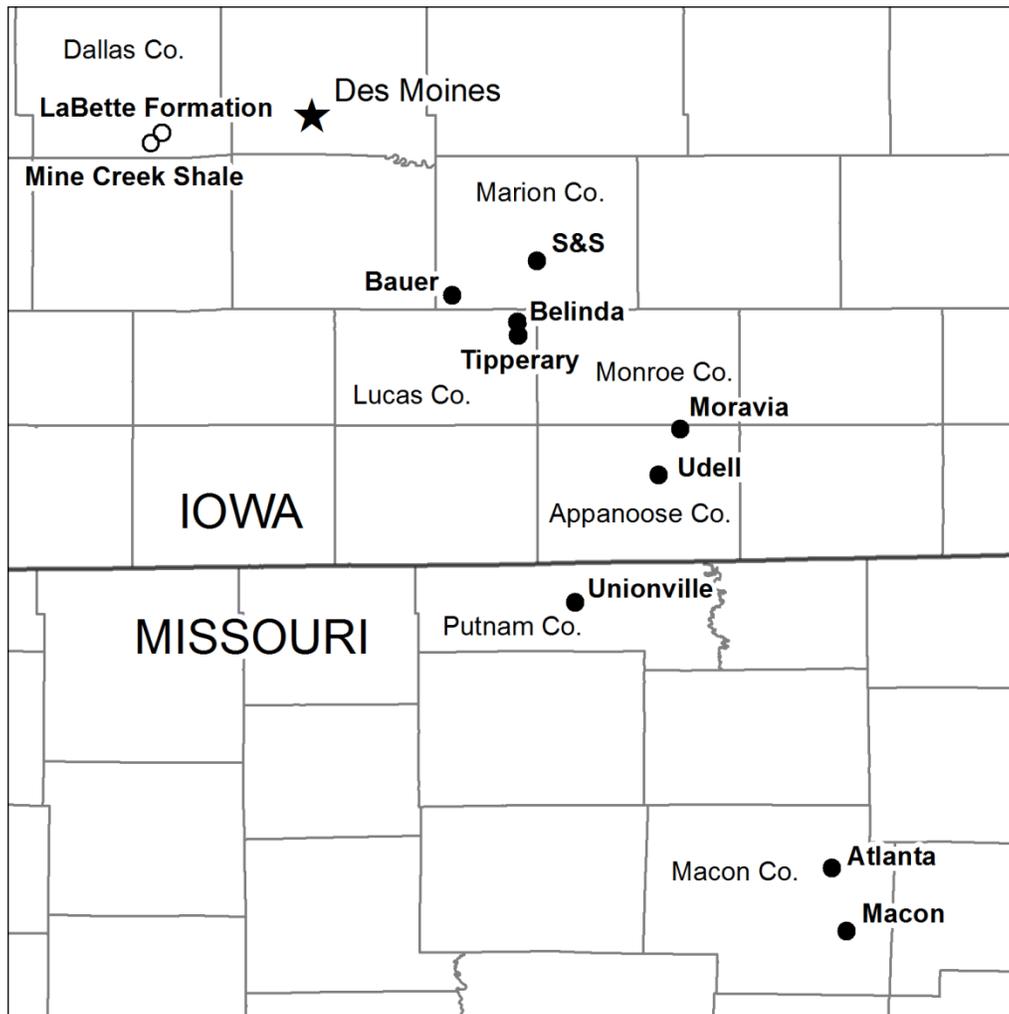
Fig. 3b Differences among detrital zircon age spectra for exposures of the Chariton Conglomerate in northern Missouri were not statistically significant at the 95% confidence level according to the Kolmogorov-Smirnoff Test. Exposures are ranked from north (top) to south (bottom). All exposures are conglomerate beds. Number of zircons dated at each exposure is shown in parentheses.

Fig. 3c Differences between detrital zircon spectra for Marmaton Group sandstones were not statistically significant at the 95% confidence level according to the Kolmogorov-Smirnoff Test. Number of zircons dated for each exposure is shown in parentheses.

Fig. 3d Differences among detrital zircon spectra for combined samples of the Chariton Conglomerate in Iowa, combined samples of the Chariton Conglomerate in Missouri, and combined samples of the Marmaton Group sandstones were not statistically significant at the 95% confidence level according to the Kolmogorov-Smirnoff Test. On that basis, provenance analysis was carried out on the

combined age spectrum of all samples. Number of zircons in each grouping is shown in parentheses.

Fig. 4 An Early-Middle Pennsylvanian river originating in present-day New England and entering present-day Minnesota-Wisconsin from the north is consistent with paleocurrent directions and the combination of Devonian-Mississippian and Paleoproterozoic-Mesoarchean detrital zircon ages. Middle Pennsylvanian uplift within the Minnesota-Wisconsin region is consistent with a source of quartz clasts within the wedge-shaped zone (Kraber et al. 2007). Geologic units are based on USGS (2012).



Legend

- Chariton Conglomerate
- Marmaton Group sandstone

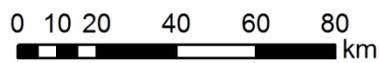


Fig. 1

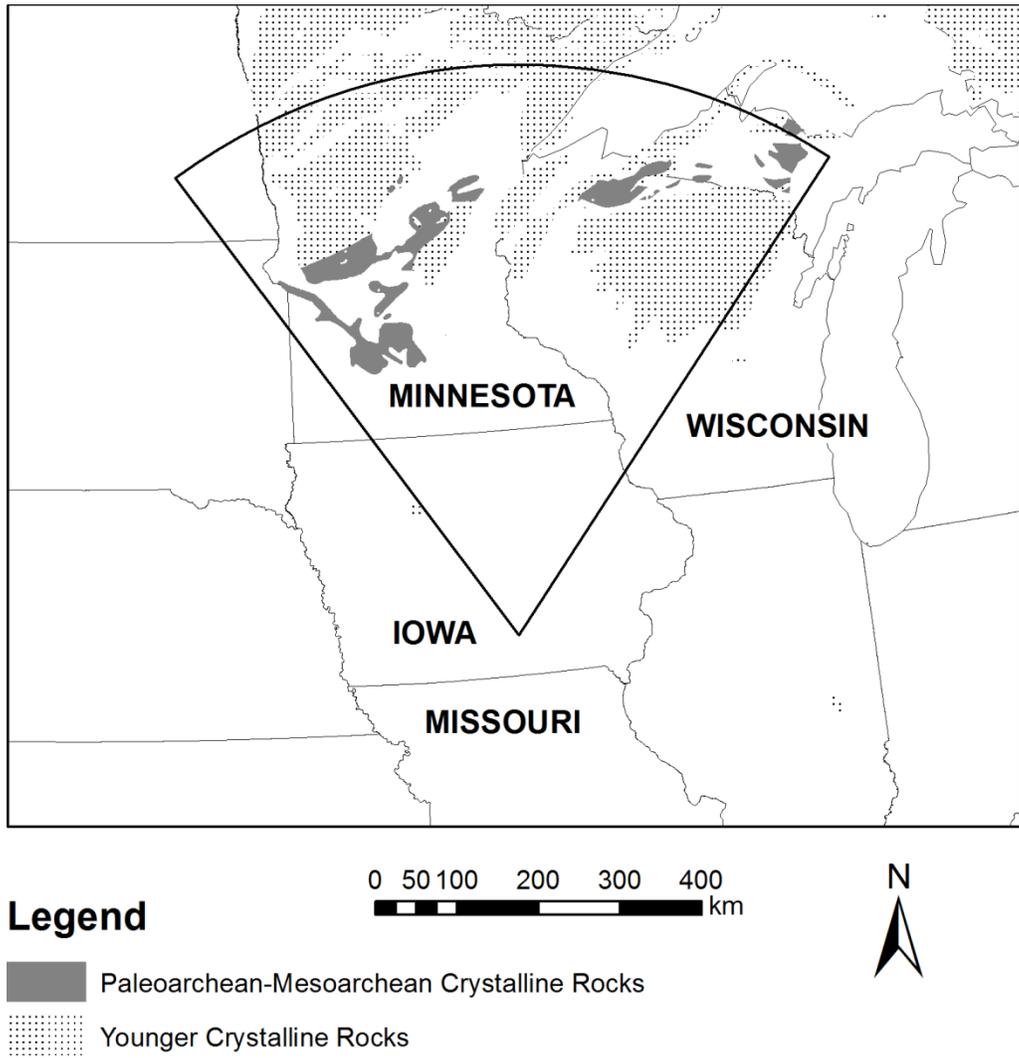


Fig. 2

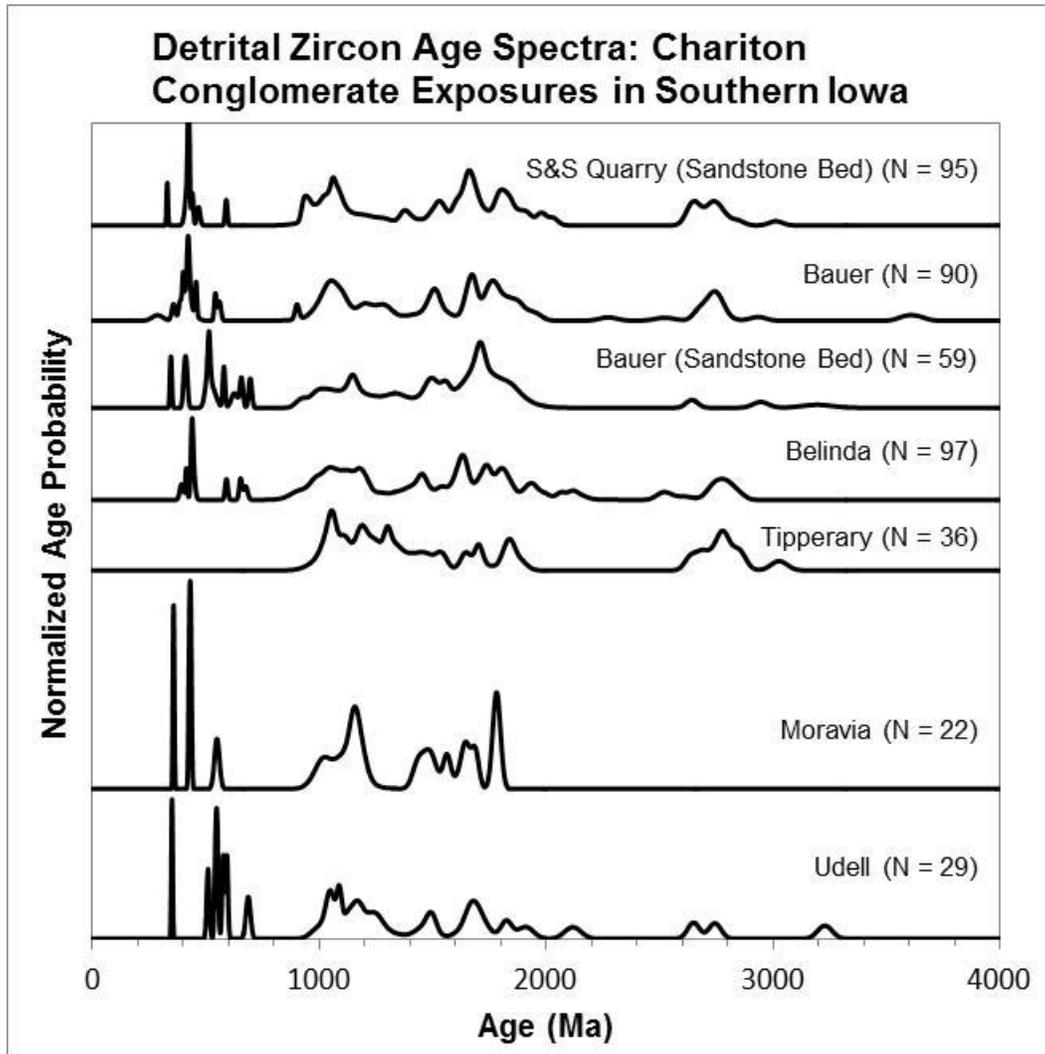


Fig. 3a

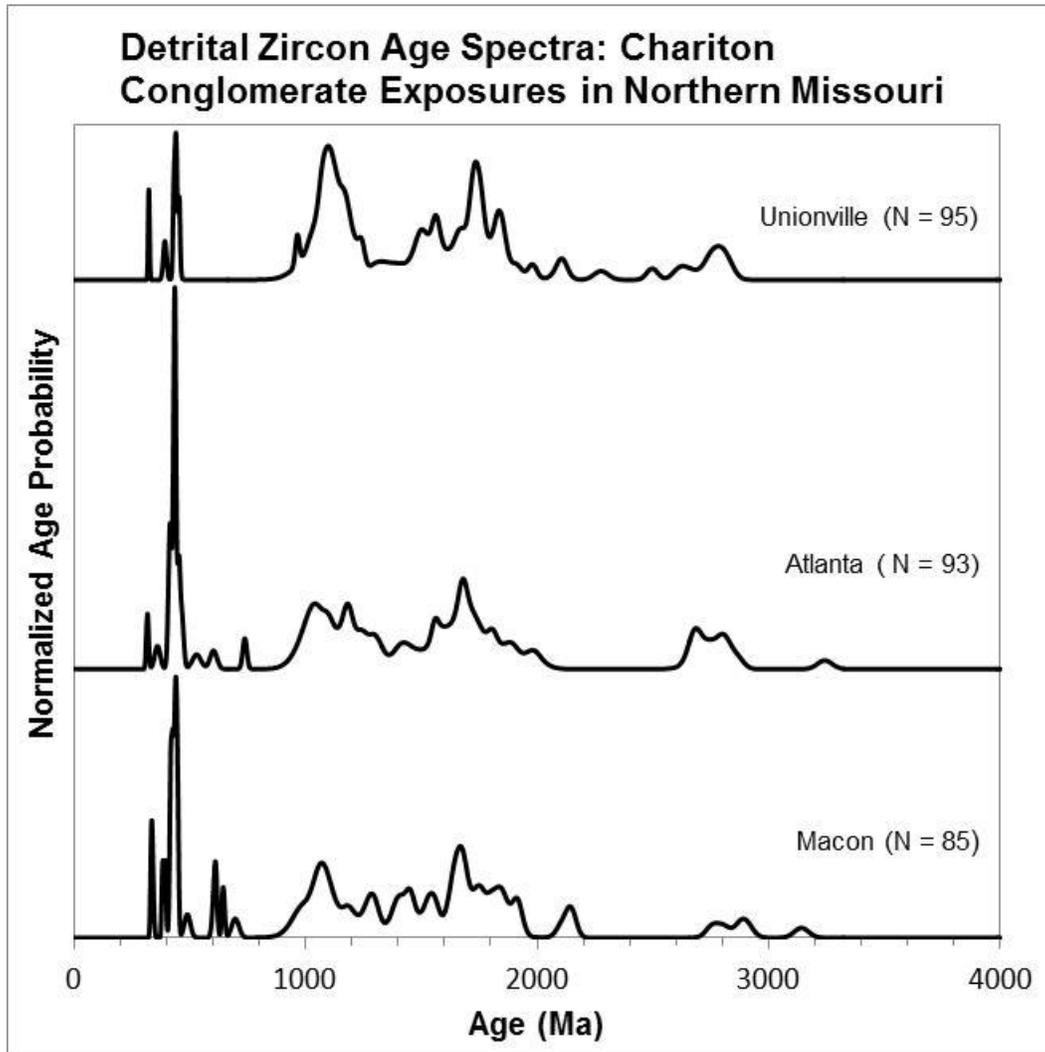


Fig. 3b

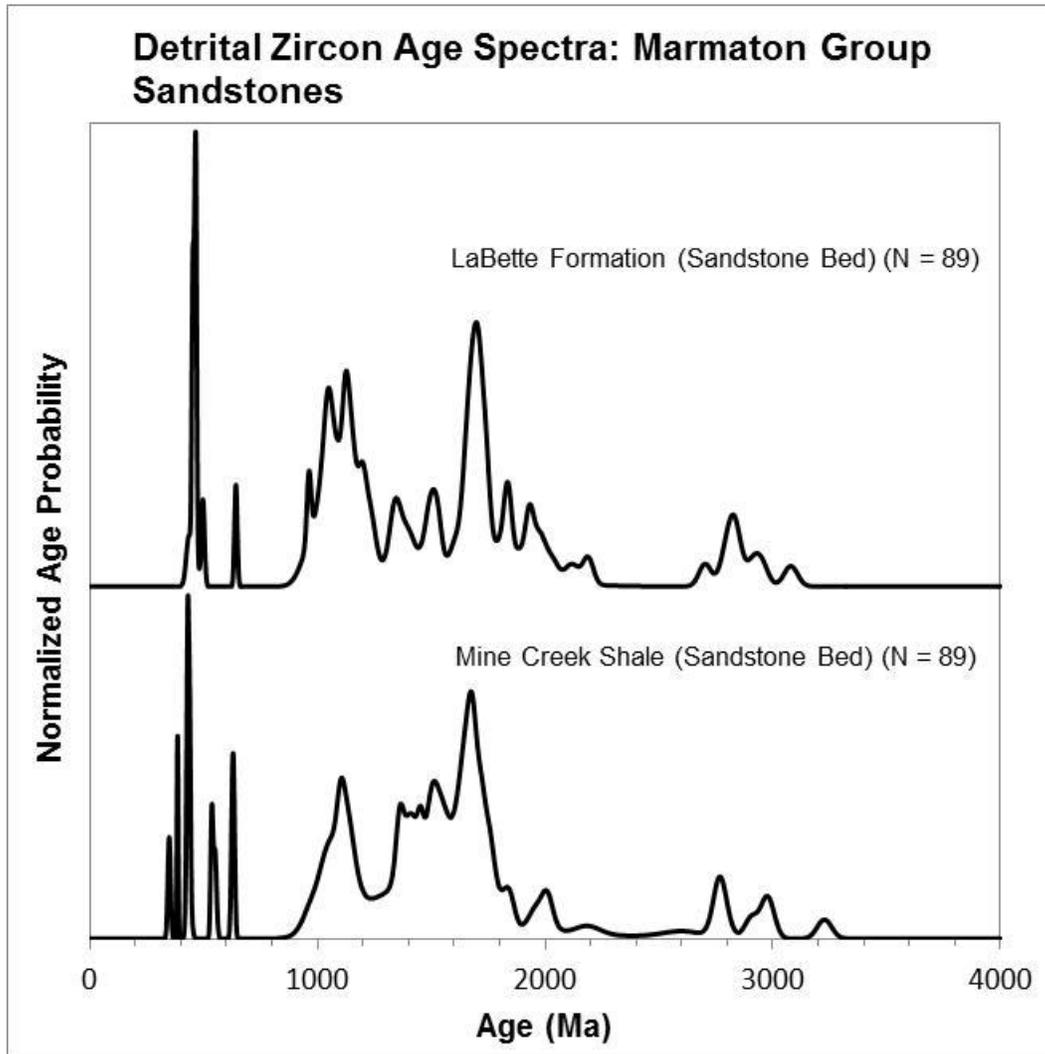


Fig. 3c

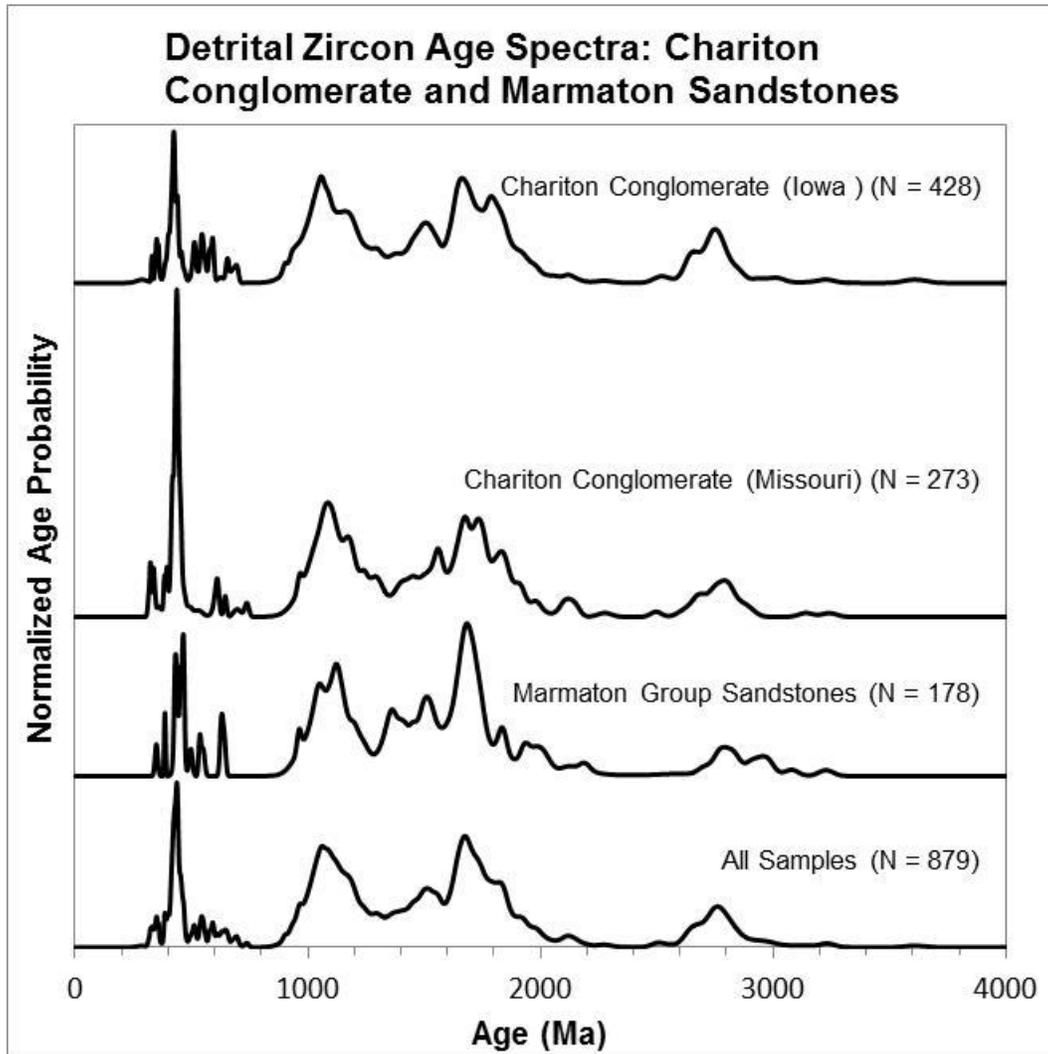


Fig. 3d

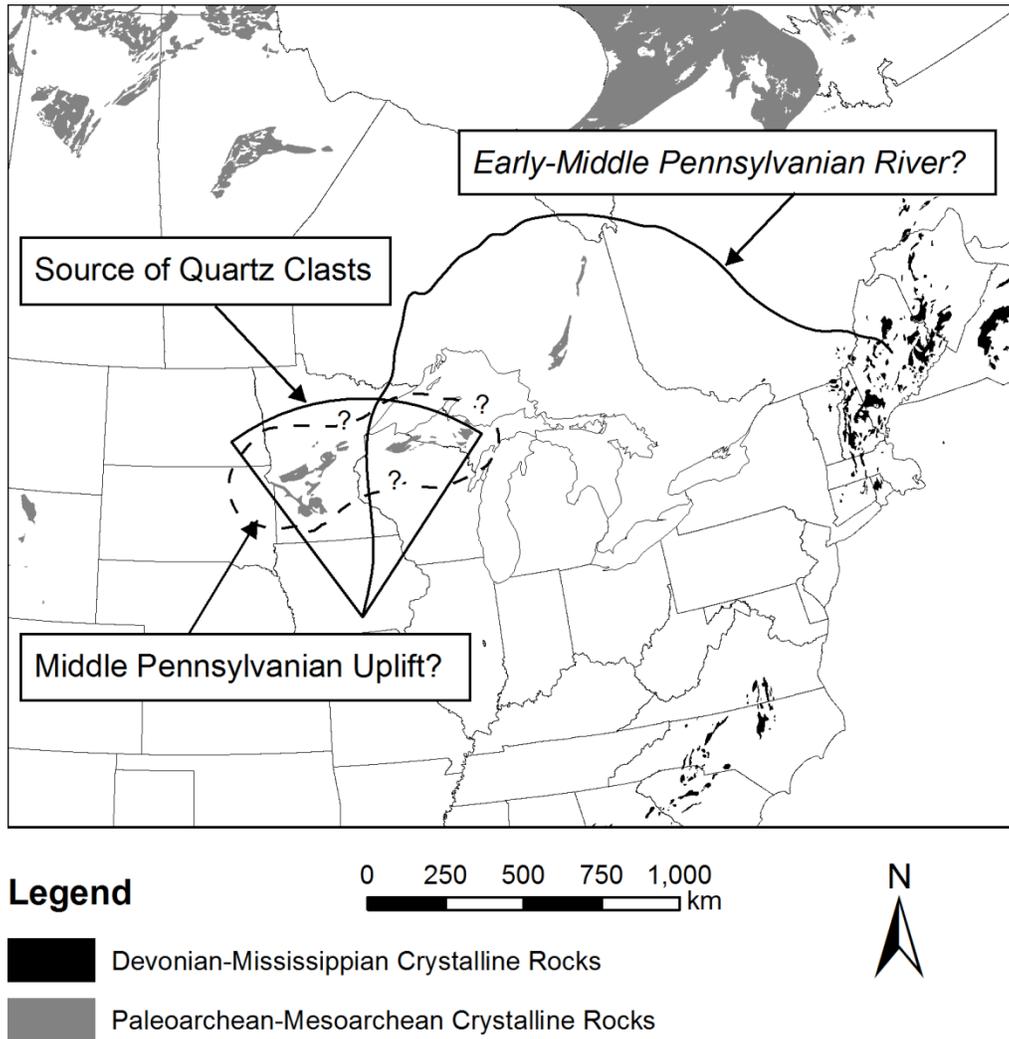


Fig. 4