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Laboratory Abrasion of Crinoid Columnals and the Provenance of the Chariton Conglomerate, South-Central Iowa

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The Chariton Conglomerate is a quartz limestone conglomerate of Pennsylvanian age found in six exposures in southern Iowa and three exposures in northern Missouri. Distinctive features of the exposures in Iowa include quartz granules and rounded crinoid columnals. The objective of this study was to determine whether the quartz clasts could have originated in the crystalline rocks of Minnesota or Wisconsin. The average paleocurrent direction measured in interbedded sandstones was 178° (S.D. = 35°). The average roundness of 75 crinoid columnals extracted from four exposures in Iowa was 30% (S.D. = 14%), defined as

$$roundness(\%) = \frac{D - d}{D} \times 100,$$

where D is the maximum columnal diameter and d is the diameter of the flat circle at the end of the columnal. Previously unabraded crinoid columnals were abraded in rotary tumblers, which were filled 90% with water and 10% with a mixture representative of the Chariton Conglomerate. The roundness values of the experimentally abraded columnals were consistent with the roundness values of the columnals collected in the field (within one standard deviation of the mean for the field data) for tumbling times in the range 0–33 days. Assuming the travel distance corresponding to one revolution is the circumference of the barrel, the experimental roundness values were consistent with the field roundness values for travel distances in the range 0–700 km, which is sufficiently far to include the crystalline rocks of Minnesota and Wisconsin.

The Chariton Conglomerate is a quartz limestone conglomerate of Pennsylvanian age found in six exposures in southern Iowa and three exposures in northern Missouri (see Figs. 1–4). 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. However, it is our observation 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). Although it has not been previously mentioned in the literarure, the very rounded crinoid columnals give clear evidence of transportation by water (see Figs. 5a–b).

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. 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)]. 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. 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 does not list the Chariton Conglomerate (Iowa Geological Survey 2008), 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

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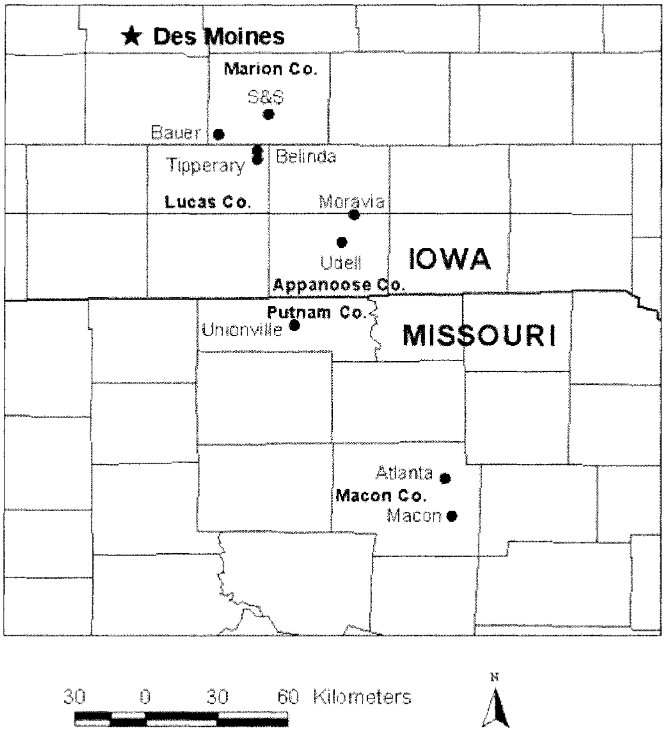

Fig. 1. Exposures of the Chariton Conglomerate. Exposures are named after the nearest village, except for S & S, which is the name of the active quarry. The three exposures in Missouri lack the quartz granules and rounded crinoid columnals that are characteristic of the Chariton Conglomerate in Iowa.

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. 6). There are two possible explanations for the presence of the quartz clasts:

1) During the Pennsylvanian Period, there was exposed crystalline bedrock in Iowa that has since been completely eroded away or buried.
2) The quartz clasts in the Chariton Conglomerate were carried from Minnesota or Wisconsin at least 330 km before deposition in southern Iowa.

The first explanation would require a radical rethinking of the geologic history of Iowa. Therefore, the objective of this paper was to determine whether the data are consistent with the second explanation.

The objective was addressed by asking two questions about the Chariton Conglomerate:

1) Are the paleocurrent directions in the interbedded sandstones consistent with transport from crystalline bedrock to the north?
2) Is the distance required to round the crinoid columnals comparable to the distance from the exposures of the Chariton Conglomerate to the crystalline bedrock in Minnesota or Wisconsin?

The second question was answered by abrading unaltered crinoid columnals in a rotary tumbler with a representative mix of the components of the Chariton Conglomerate. Lewin and

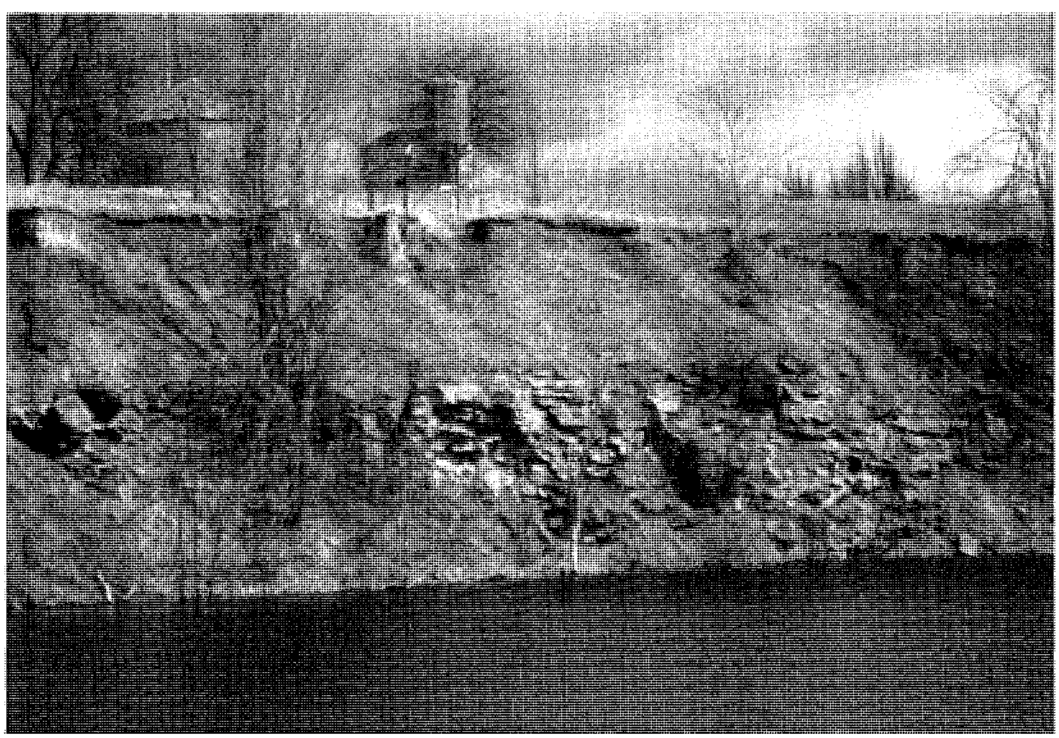

Fig. 2. Exposure of the Chariton Conglomerate in an abandoned quarry near Bauer, Iowa.

Fig. 3. Cross-bedded sandstone between conglomerate beds of the Chariton Conglomerate near Bauer, Iowa.

Brewer (2002) reviewed over 120 years of laboratory studies of abrasion and concluded that no abrasion device adequately represents all aspects of abrasion in a natural stream. Lewin and Brewer (2002) found that rotary tumblers best represent grinding with minor representation of percussion (cracking, splitting, chipping). Previous studies that have compared results of laboratory abrasion to rounding of rocks and fossils in the field include Adams (1978), Matthews (1983), Bigelow (1984), Argast et al. (1987), Lewis et al. (1990), Kodama (1994) and Beavington-Penney (2004).

OUTCROP LOCATIONS

All nine known exposures of the Chariton Conglomerate, six in southern Iowa and three in northern Missouri, were visited in this study (see Fig. 1). Although the three exposures in Missouri were classified as Chariton Conglomerate by Hinds and Greene (1915) and 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. As all exposures were difficult to locate, the latitude and longitude are given for the benefit of other workers (see Table 2). The S & S exposure is an active quarry, the Atlanta, Bauer, Belinda and Unionville exposures are abandoned quarries, the Tipperary and Udell exposures are on exposed hillsides, the Moravia exposure is in a stream bank, and the Macon exposure is in a road cut. At the Bauer and Belinda exposures, cross-bedded sandstone is interbedded with conglomerate and paleocurrent directions were measured in the sandstone.

METHODS

Some crinoid columnals could be extracted on site by hand or with the aid of a rock hammer. Additional samples of conglomerate were brought back to the laboratory and soaked for 10 minutes in 15% acetic acid, after which partially exposed columnals could be extracted by hand or with pliers or a metal spatula. Fully embedded columnals could not be extracted by this process. It was determined that the mild acid treatment did not affect the roundness of the columnals. A total of 75 columnals were extracted from four exposures in Iowa. It was not possible to extract columnals from the Moravia and Udell exposures, although rounded columnals were present. The maximum columnal diameter, D, and the diameter of the flat circle at the end of the columnal, d, were measured with an Olympus SZX12 microscope with Image-Pro Express 4.0 software (see Figs. 5a–b). Columnal roundness was defined as

$$\textit{roundness}(\%) = \frac{D - d}{D} \times 100.$$

Unabraded columnals were purchased for abrasion in rotary tumblers. The commercial crinoid columnals were filled with secondary calcite and were clearly derived from an indurated limestone. The crinoid columnals incorporated in the Chariton Conglomerate must also have been filled with secondary calcite and derived from indurated limestone as unaltered crinoid bioclasts (called stereoms) could not have survived transportation over long distances, especially in a medium that included quartz granules (Sprinkle 1987). The tumbler barrels had a height of 6.7 cm and a circumference of 30 cm (inner dimensions) and rotated at 50 rpm. A wide range of preliminary trials were carried out with various proportions of water, columnals, limestone clasts and quartz clasts. It was found that when columnals were tumbled with water alone, they broke and became neither rounded nor polished. When columnals were tumbled with water and limestone clasts, they became polished, but not rounded. When columnals were tumbled with water and quartz clasts, they were rounded, but not polished. Both the rounding and polishing

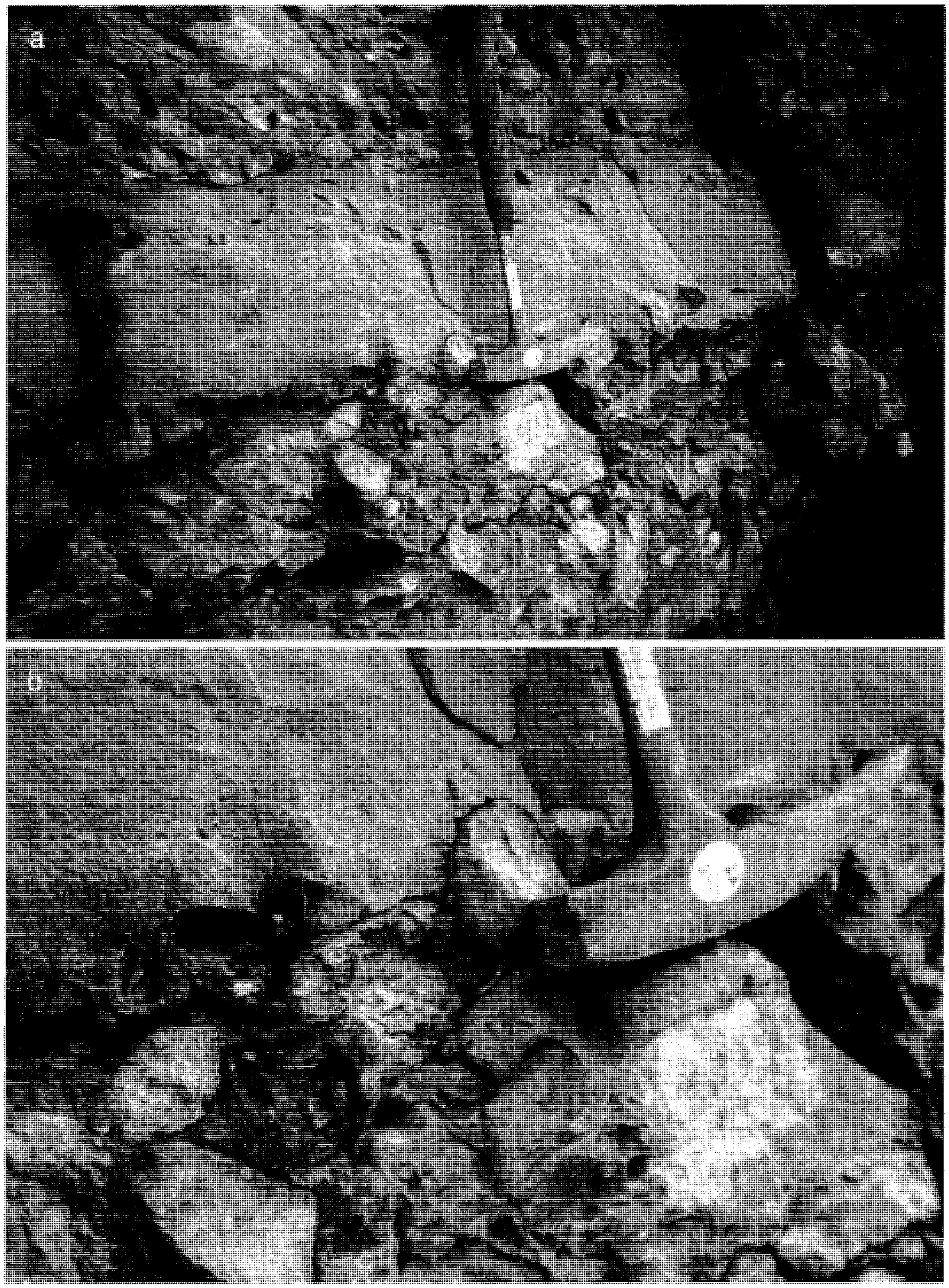

Fig. 4a. Sandstone bed between conglomerate beds of the Chariton Conglomerate at S & S Quarry.
Fig. 4b. Close-up of the Chariton Conglomerate at S & S Quarry.

observed in the columnals in the field were achieved only when crinoid columnals were tumbled with both limestone and quartz clasts.

On the basis of the preliminary trials, we decided to fill the barrels 90% by volume with water and 10% with a mixture representative of the Chariton Conglomerate. The mixture was determined to be 80% limestone clasts in the range 1–5 mm, 10% quartz clasts in the range 2–4 mm, and 10% unabraded columnals (all percentages by volume). There were 11 treatments with tumbling times of 12 hours, one day, two days, four days, six days, seven days, eight days, 13 days, 14 days, 56 days, and 77 days. Each treatment involved two to four barrels and 18–59

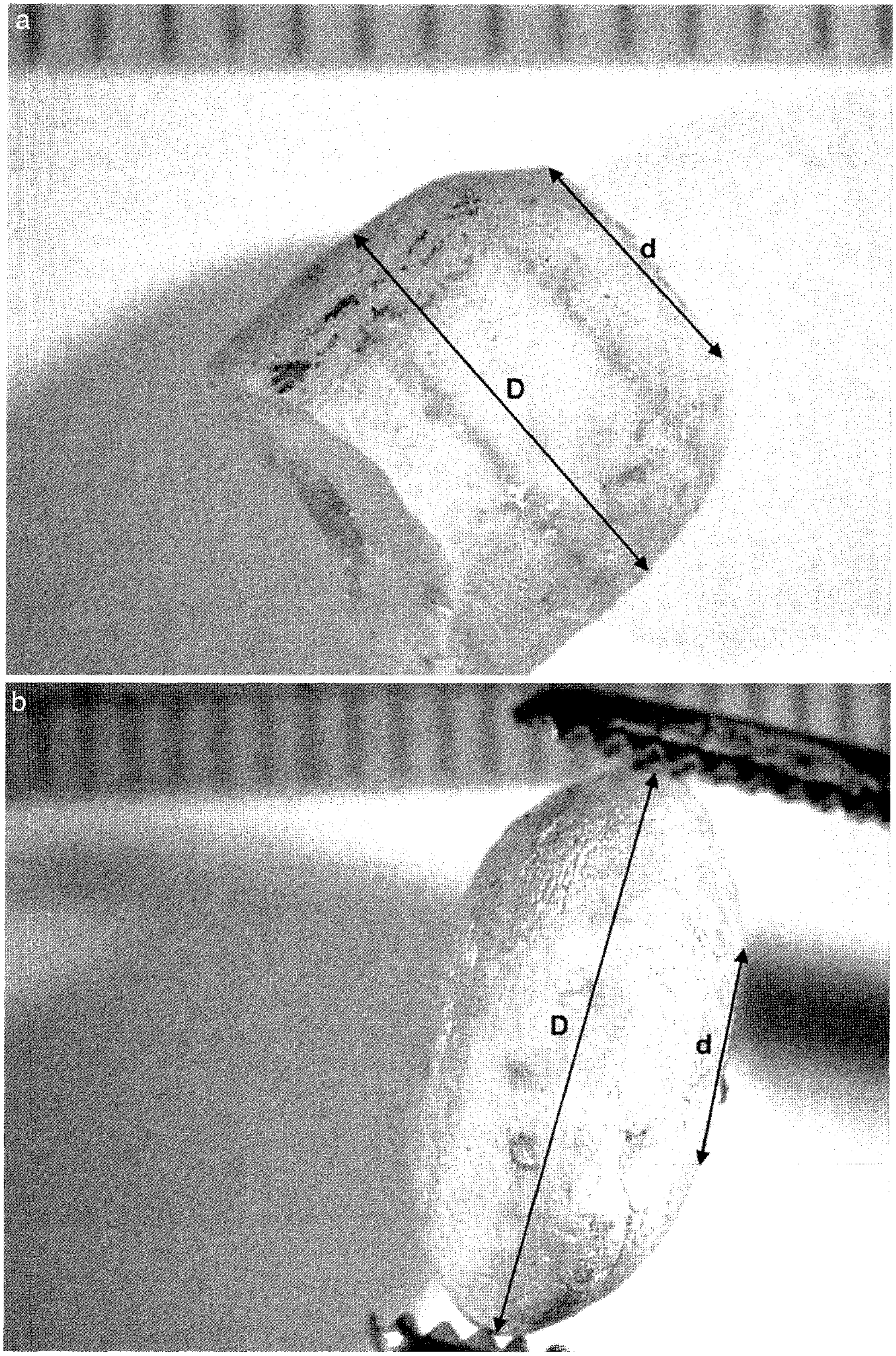

Fig. 5a. Photograph of rounded crinoid columnal from Belinda exposure showing measurement of diameter, D, and diameter of flat region at end of crinoid columnal, d (mm scale in background).

Fig. 5b. Photograph of rounded crinoid columnal from exposure at S & S quarry showing measurement of diameter, D, and diameter of flat region at end of crinoid columnal, d (mm scale in background).

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 Survey (2008)).

Waubansee Group
Shawnee Group
Douglas Group
Lansing Group
Kansas City Group
Bronson Group
Hertha Formation
Pleasanton Formation
Exline Limestone Member
Marmaton Group
Altamont Formation
Worland Limestone Member
Bandera Shale
Pawnee Formation
Coal City Limestone Member
Labette Formation
Mystic Coal Member
Cherokee Group
Floris Formation

columnals. After tumbling, the roundness of each columnal was determined using the above formula. We also measured the roundness of 32 unabraded columnals.

RESULTS

Paleocurrent directions and columnal roundness values were similar among the exposures from which data were obtained. The mean paleocurrent direction was 148° (S.D. = 22°) at the Bauer exposure and 206° (S.D. = 13°) at the Belinda exposure (see Figs. 7a–b). The mean paleocurrent direction for the two exposures combined was nearly due south (mean = 178°, S.D. = 35°) (see Fig. 7c). The columnal roundness values ranged from 28% (S.D. = 11%) at the Belinda exposure to 34% (S.D. = 20%) at the Bauer exposure (see Figs. 8a–d). There was no systematic variation in columnal roundness in the downstream direction. The mean roundness for all 75 columnals was 30% (S.D. = 14%) (see Fig. 8e). The distribution of columnal roundness values was skewed in the direction of smaller values (see Fig. 8e).

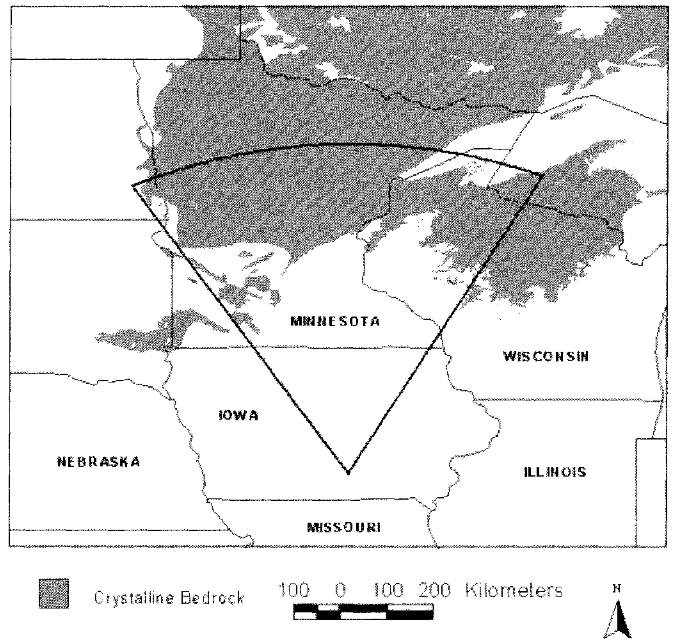

Fig. 6. Wedge of possible provenance of the Chariton Conglomerate superimposed on map of crystalline bedrock in Minnesota and Wisconsin (Hearn et al. 2003). The apex of the wedge is located at the average position of exposures of the Chariton Conglomerate in southern Iowa. The radius of the wedge is 700 km and the sides of the wedge have orientations 323° and 33° (the reverse of the average paleocurrent direction plus or minus one standard deviation).

The linear correlation between time of tumbling and mean columnal roundness was excellent ($r^2 = 0.75$) (see Fig. 9). There was a significant jump between the roundness of the unabraded columnals (mean = 14.8%, S.D. = 7.6%) and the roundness after tumbling for 12 hours (mean = 23.9%, S.D. = 6.9%). If the unabraded columnals are excluded, the goodness-of-fit r^2 improves to $r^2 = 0.81$. The roundness values of the experimentally abraded columnals were consistent with the roundness values of the columnals collected in the field (within one standard deviation of the mean for the field data) for tumbling times in the range 0–33 days. The appropriate travel distance corresponding to one revolution of the tumbler barrel has been debated, with estimates ranging from 0.6–1.0 times the

Table 2. Location of exposures of the Chariton Conglomerate.

Exposure[a]	County (State)	Tier, Range	Latitude (°N)	Longitude (°W)
Atlanta	Macon (MO)	59N, 14W	39.8946	92.4303
Bauer	Marion (IA)	74N, 21W	41.1938	93.2903
Belinda	Lucas (IA)	73N, 20W	41.1322	93.1438
Macon	Macon (MO)	57N, 13W	39.7523	92.3977
Moravia	Appanoose (IA)	70N, 17W	40.8900	92.7736
S & S	Marion (IA)	75N, 20W	41.2709	93.0993
Tipperary	Lucas (IA)	73N, 20W	41.1019	93.1421
Udell	Appanoose (IA)	69N, 17W	40.7860	92.8236
Unionville	Putnam (MO)	65 N, 18W	40.3991	92.9024

[a]Exposures named after closest village, except for S & S, which is the name of the active quarry.

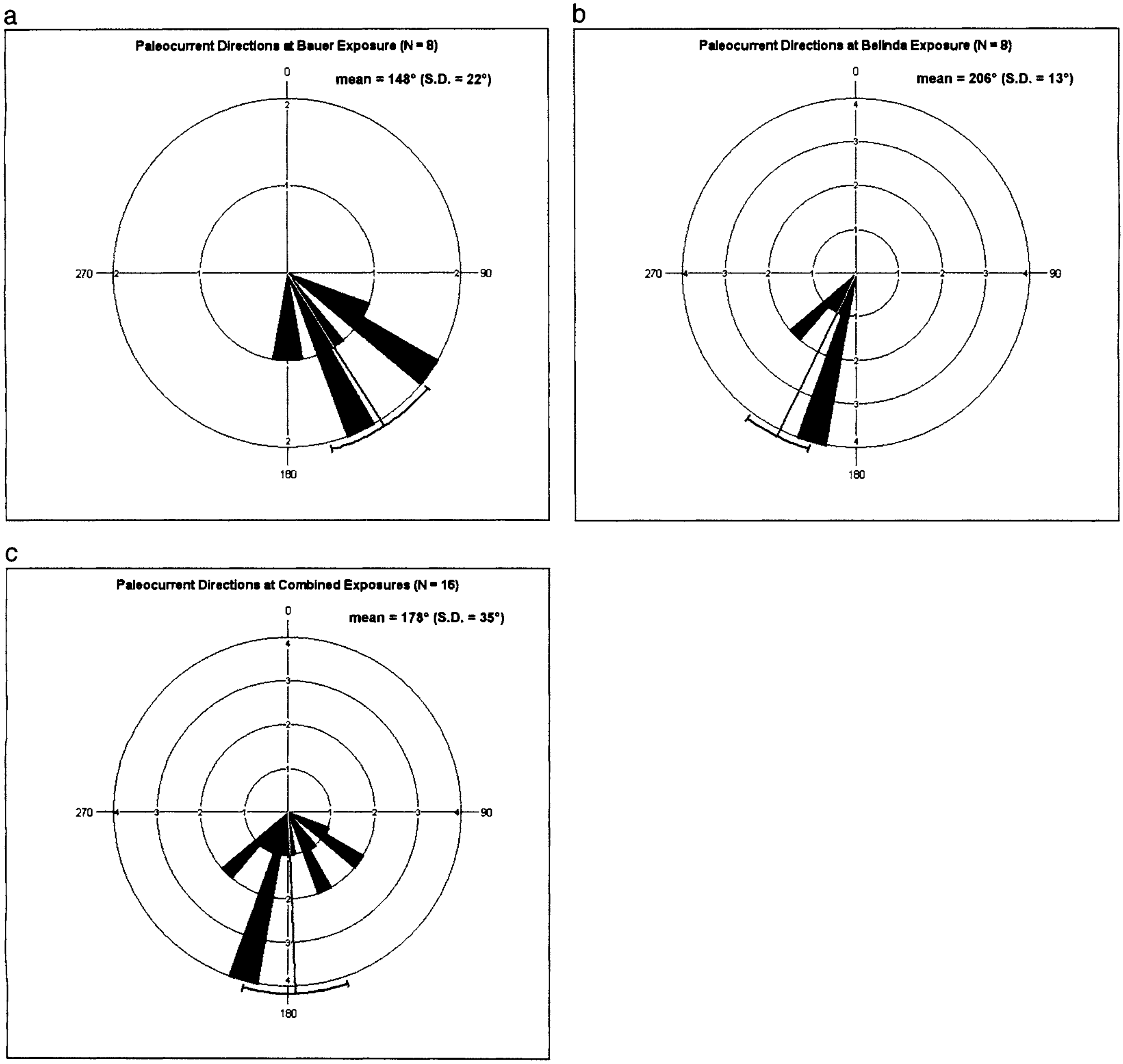

Fig. 7a. Paleocurrent directions at Bauer exposure. Rose diagram indicates mean with 95% confidence interval.

Fig. 7b. Paleocurrent directions at Belinda exposure. Rose diagram indicates mean with 95% confidence interval.

Fig. 7c. Combined paleocurrent directions for both exposures. Rose diagram indicates mean with 95% confidence interval.

circumference (Wentworth 1919, Adams 1978, Matthews 1983, McKnight 1989, Lewin and Brewer 2002). Based on the upper estimate, the experimental roundness values were consistent with the field roundness values for travel distances in the range 0–700 km.

DISCUSSION

Hansen (1978) made 343 measurements of paleocurrent directions in sandstones of the Cherokee Group (see Table 1) in Marion County (southern Iowa) and found an average paleocurrent direction of 167°. This is consistent with the average direction of 178° (S.D. = 35°) found in this study, which indicates transport from the north throughout Middle Pennsylvanian time. The wedge-shaped region shown in Figure 6 indicates the possible provenance of the Chariton Conglomerate. The apex of the wedge is located at the average position of exposures of the Chariton Conglomerate in southern Iowa. The radius of the wedge is 700 km and the sides of the wedge have orientations 323° and 33° (the reverse of the average paleocurrent

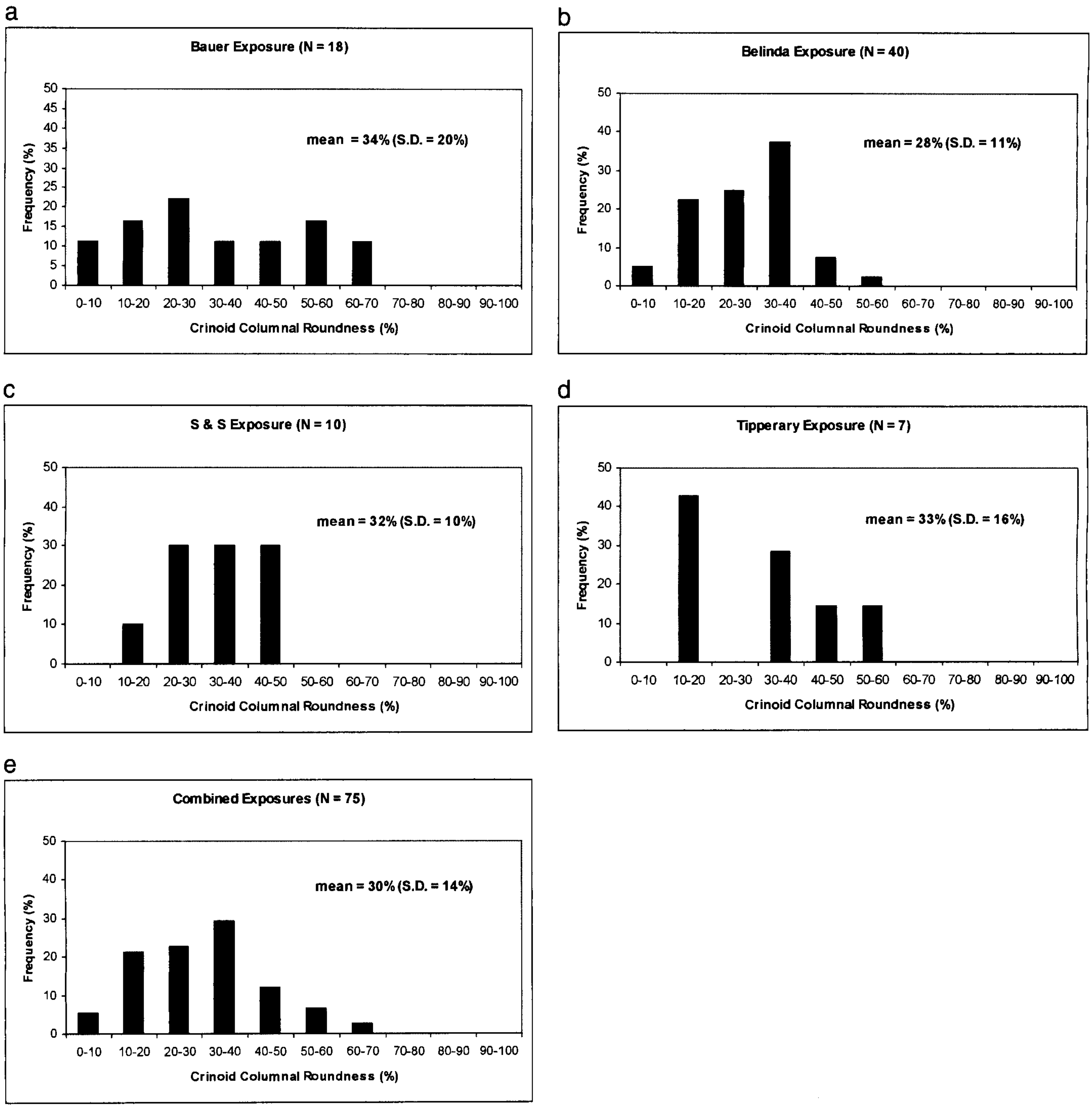

Fig. 8a. Frequency distribution of crinoid columnal roundness at the Bauer exposure.
Fig. 8b. Frequency distribution of crinoid columnal roundness at the Belinda exposure.
Fig. 8c. Frequency distribution of crinoid columnal roundness at the S & S exposure.
Fig. 8d. Frequency distribution of crinoid columnal roundness at the Tipperary exposure.
Fig. 8e. Combined frequency distribution of crinoid columnal roundness at all exposures.

direction plus or minus one standard deviation). It is clear that the wedge includes many sources of quartz clasts in Minnesota and Wisconsin. Therefore, the most likely origin for the Chariton Conglomerate is a hydraulic event that collected quartz clasts in Minnesota or Wisconsin, continued to collect limestone clasts and fossils in Minnesota, Wisconsin or Iowa, and deposited those materials in southern Iowa. The upper value of 700 km may be an overestimate as crinoid columnals may have experienced some rounding during a previous episode of fluvial transportation before they were incorporated into an indurated limestone,

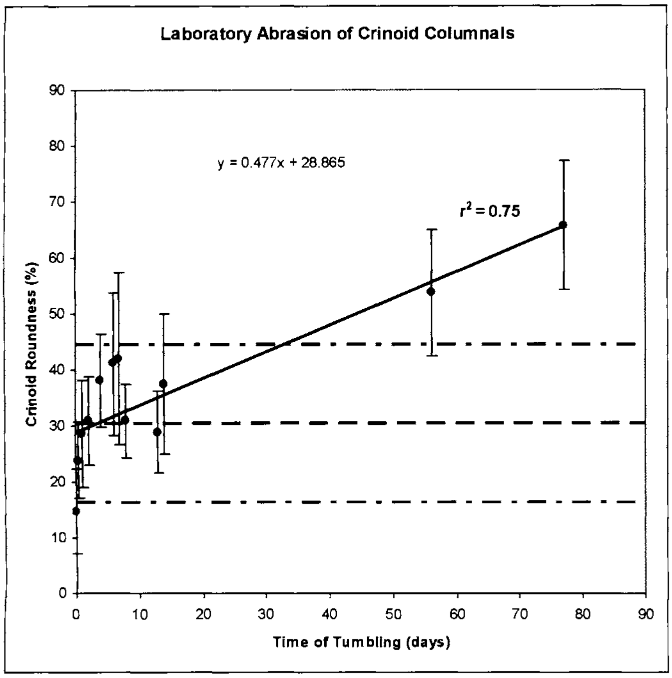

Fig. 9. Crinoid columnal roundness as a function of maximum distance traveled for laboratory abrasion of crinoid columnals. Error bars indicate one standard deviation above and below mean. Middle dashed line indicates mean crinoid columnal roundness for field data (see Fig. 8e). Upper and lower dashed and dotted lines indicate one standard deviation above and below mean, respectively, for field data.

weathered from the limestone, and re-incorporated into the Chariton Conglomerate. On the other hand, we are not aware of significantly rounded crinoid columnals anywhere in Iowa, Minnesota or Wisconsin besides the Chariton Conglomerate.

SUMMARY AND CONCLUSIONS

The main findings of this study can be summarized as follows:

1) The quartz granules found in the Chariton Conglomerate were derived from crystalline bedrock in Minnesota or Wisconsin.
2) The rounded crinoid columnals found in the Chariton Conglomerate could have been transported as far as 700 km prior to deposition.

The following questions remain:

1) What is the correct stratigraphic position of the Chariton Conglomerate? In particular, does the Chariton Conglomerate belong to the Marmaton Group or the Bronson Group?
2) Do the exposures in Missouri, which do not include quartz granules but do include unabraded crinoid columnals, belong to the Chariton Conglomerate?

The above questions could be addressed by detrital zircon geochronology, which would help to determine the provenances of the various exposures of the Chariton Conglomerate as well as other clastic rocks of the Marmaton and Bronson Groups.

To date no systematic survey or analysis of quartz limestone conglomerates has been carried out. Tindle (1978) showed an excellent photomicrograph of the Antrim Conglomerate in Northern Ireland, which includes rounded basalt fragments, angular quartz fragments and deformed crinoid columnals in a calcareous cement. Other examples of quartz limestone conglomerates are the Quiwi Formation in Tibet (Atchison and Davis 2001) and an unnamed unit in Kansas and Oklahoma (Yang 2007). We hope that comparison of field and laboratory measurements of crinoid columnal roundness may open a window of insight into these fascinating rock units.

ACKNOWLEDGEMENTS

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LITERATURE CITED

ADAMS, J. 1978. Data for New Zealand pebble abrasion studies. New Zealand Journal of Science 21:607–610.

ANDERSON, W. I. 1998. Iowa's geological past: Three billion years of change. University of Iowa Press, Iowa City, Iowa.

ARGAST, S., J. O. FARLOW, R. M. GABET, and D. L. BRINKMAN. 1987. Transport-induced abrasion of fossil reptilian teeth: Implications for the existence of Tertiary dinosaurs in the Hell Creek Formation, Montana (USA). Geology 15:927–930.

ATCHISON, J. C. and A. M. DAVIS. 2001. Orogenic conglomerates indicate the timing of collision in Tibet. Journal of Asian Earth Sciences 19:1–2.

BEAVINGTON-PENNEY, S. J. 2004. Analysis of the effects of abrasion on the test of *Paleonummilites venosus*: Implications for the origin of Nummulithoclastic sediments. Palaios 19:143–155.

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.

BIGELOW, G. E. 1984. Simulation of pebble abrasion on coastal benches by transgressive waves. Earth Surface Processes and Landforms 9:383–390.

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.

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.

HEARN, P., T. HARE, P. SCHRUBEN, D. SHERRILL, C. LAMAR, P. TSUSHIMA, C. KEANE, and M. J. ALFANO. 2003. Global GIS Database: Digital Atlas of North America. U.S. Geological Survey Digital Data Series DDS-62-F.

HECKEL, P. H. and J. P. POPE. 1992. Stratigraphic and cyclic sedimentation of Middle and Upper Pennsylvanian strata around Winterset, Iowa. Guidebook Series No. 14, Iowa Geological Survey, Iowa City, 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.

IOWA GEOLOGICAL SURVEY. 2008. Iowa stratigraphic column. http://www.igsb.uiowa.edu.

KODAMA, Y. 1994. Experimental study of abrasion and its role in producing downstream fining in gravel-bed rivers. Journal of Sedimentary Research A64:76–85.

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.

LEWIN, J. and P. A. BREWER. 2002. Laboratory simulation of clast abrasion. Earth Surface Processes and Landforms 27:145–164.

LEWIS, R. D., C. R. CHAMBERS, and M. W. PEEBLES. 1990. Grain morphologies and surface textures of Recent and Pleistocene crinoid ossicles, San Salvador, Bahamas. Palaios 5:570–579.

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.

MATTHEWS, E. R. 1983. Measurements of beach pebble attrition in Palliser Bay, southern North Island, New Zealand. Sedimentology 30:787–799.

MCKNIGHT, B. K. 1989. A tumbler experiment as introduction to scientific research. Journal of Geological Education 37:98–101.

POPE, J., B. WITZKE, G. LUDVIGSON, and R. ANDERSON. 2002. Bedrock geologic map of south-central Iowa. Iowa Geological Survey, Iowa City, Iowa.

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.

SPRINKLE, J. 1987. Phylum Echinodermata, Part 1. Pages 550–571. *In* Fossil Invertebrates. R. S. Boardman, A. H. Cheetham, and A. J. Rowell (eds.). Blackwell Scientific Publications, Oxford, U.K.

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.

TINDLE, A. G. 1978. Sedimentary rocks: Photomicrographs. Focal Point Filmstrips, Ltd., Southern Press, Horndean, U.K.

WALLACE, M. H. 1941. Chariton Conglomerate in Lucas and Marion Counties, Iowa. Transactions of the Kansas Academy of Science 44:322–326.

WENTWORTH, C. K. 1919. A laboratory and field study of cobble abrasion. Journal of Geology 27:507–521.

WILMARTH, W. G. 1938. Lexicon of geologic names of the Unites States (including Alaska). United States Geological Survey Bulletin 896, Washington, D. C.

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.

YANG, W. 2007. Transgressive wave ravinement on an epicontinental shelf as recorded by an Upper Pennsylvanian soil-nodule conglomerate-sandstone unit, Kansas and Oklahoma, U.S.A. Sedimentary Geology 197:189–205.