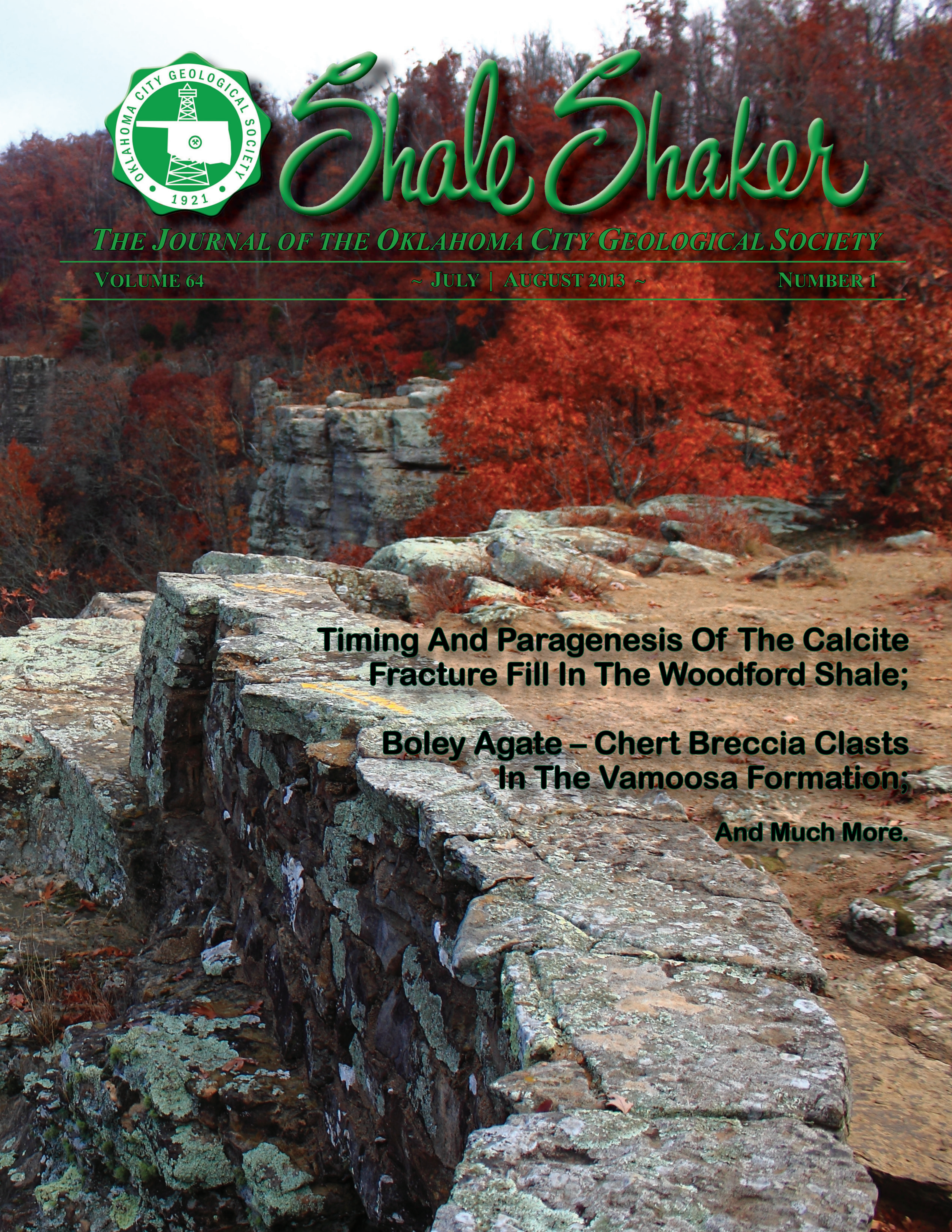


Shale Shaker

THE JOURNAL OF THE OKLAHOMA CITY GEOLOGICAL SOCIETY

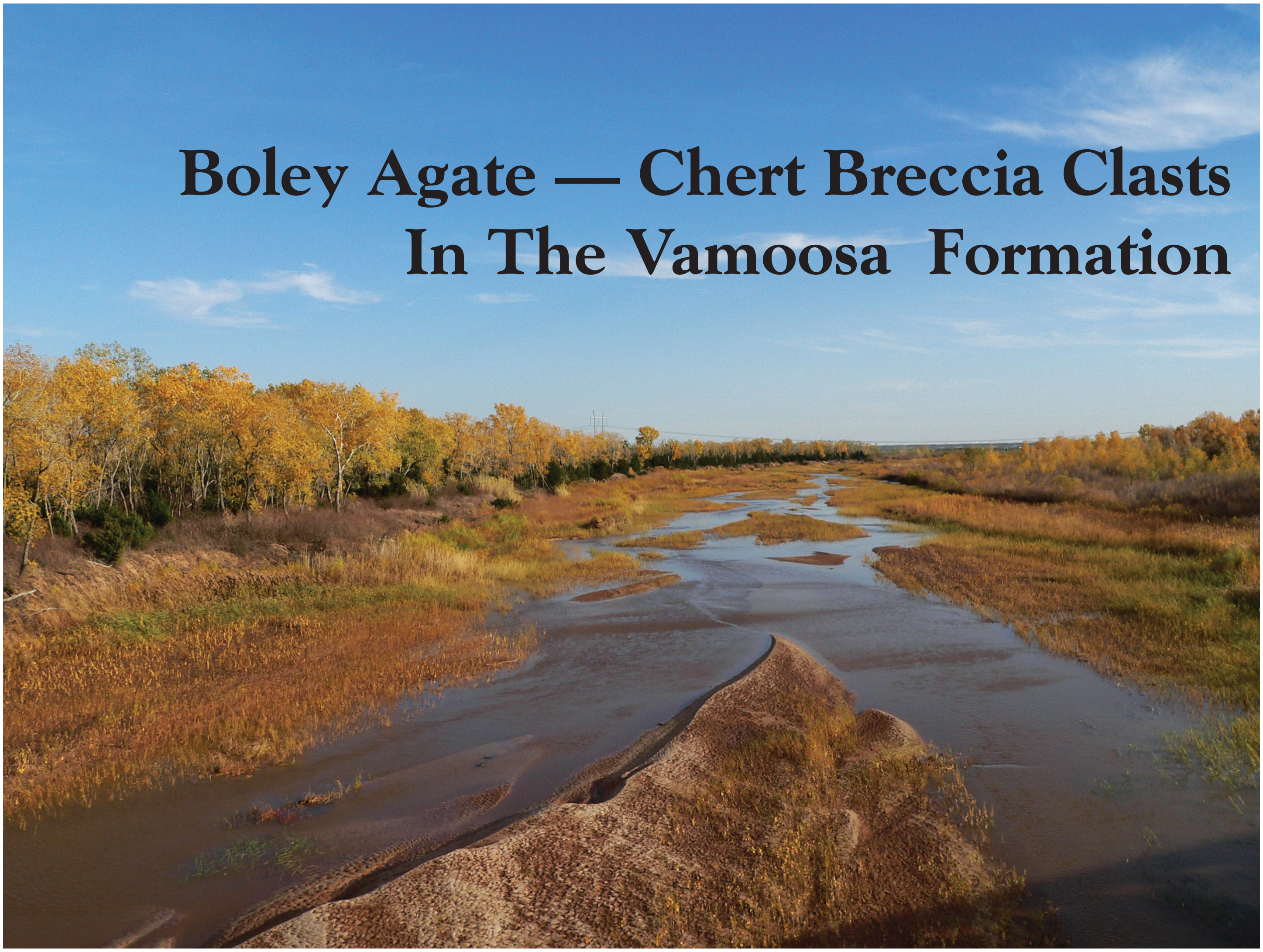
VOLUME 64 ~ JULY | AUGUST 2013 ~ NUMBER 1

Timing And Paragenesis Of The Calcite Fracture Fill In The Woodford Shale;

Boley Agate – Chert Breccia Clasts In The Vamoosa Formation;

And Much More.

By: Neil H. Suneson, Oklahoma Geological Survey, Mewbourne College of Earth and Energy, University of Oklahoma, Norman, Oklahoma | (405) 325-7315 | nsuneson@ou.edu;
William G. Lyon, Department of Cartography and Geography, East Central University, Ada, Oklahoma;
David Goza, School of Music, University of Oklahoma, Norman, Oklahoma



Boley Agate — Chert Breccia Clasts In The Vamoosa Formation

Introduction

Agates are among of the most popular collectible "stones" throughout the world, and many books – both scientific and nontechnical – have been written about agates. Oklahoma is not known for its agates, but two localities stand out. One is the "agate bed" in the Morrison Formation (Upper Jurassic). Although not mentioned in either of the Cimarron County geologic reports (Rothrock, 1925; Schoff, 1943), a persistent bed characterized by agate nodules in the lower part of the Morrison is present in Union County, New Mexico (Baldwin and Muehlberger, 1959) and is locally present in the Morrison in Cimarron County. A second agate occurrence in Oklahoma is in the central part of the state and is in the Boley Conglomerate Member of the Vamoosa Formation. This agate – appropriately named Boley agate – not only is beautiful as lapidary material but has an interesting, albeit poorly known, geological history. Both are the subject of this brief report.

Location of Outcrop

A popular and easily accessible outcrop of the Boley Conglomerate is located in southern Seminole County just north of OK Hwy 56 about two miles east of the intersection with US 377/OK 99 and seven miles west of Sasakwa. The outcrop (W/2 SW/4 sec. 35, T. 6 N., R. 6 E.) is an abandoned gravel pit known locally as the Donald Stover Quarry (Figure 1). However, the Boley Conglomerate is widely exposed and is commonly used as road gravel in this part of the state, and additional exposures and collecting sites, mostly to the north, are present.

Stratigraphy

The Boley Conglomerate was named by Ries (1954) for exposures near the town

Figure 1. Outcrop of Boley Conglomerate (basal member of Vamoosa Formation) at Donald Stover Quarry along Oklahoma Highway 56 between Konawa and Sasakwa.

of Boley[1] in Okfuskee County and identified as the basal member of the Vamoosa Formation. Ries (1954) credited Morgan (1924) with having first described the conglomerate, but disagreed with him regarding the nomenclature of the units. Ries (1954) correctly described a significant unconformity at the base of the Boley Conglomerate separating older to younger (south to north) Missourian strata below from Virgillian strata above (Figure 2). Thus, the Boley Conglomerate is about 302 Ma old.

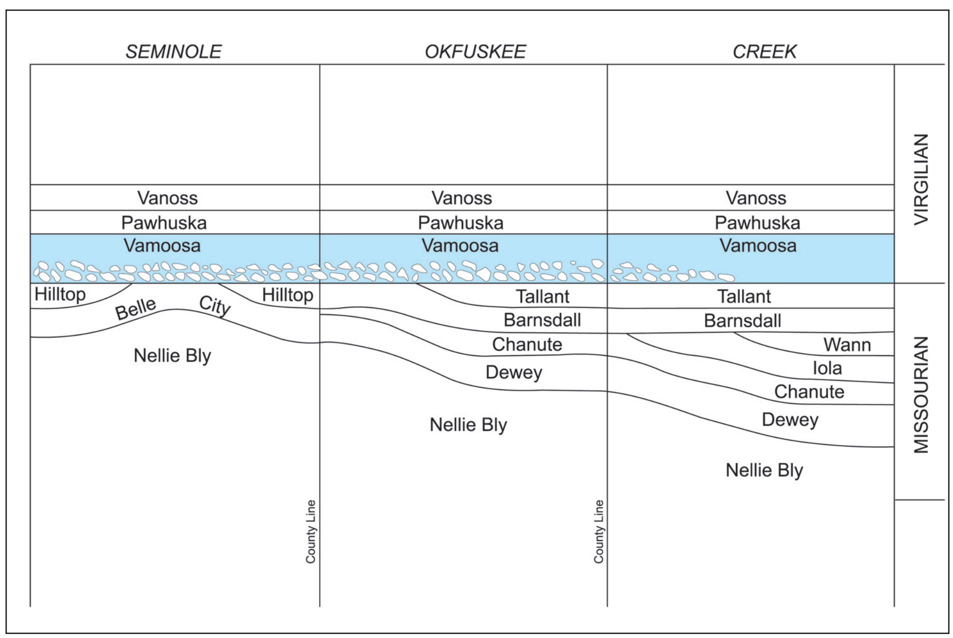


Figure 2. Stratigraphic column showing general stratigraphic relations of Boley Conglomerate to underlying strata in Seminole, Okfuskee, and Creek Counties.

The Vamoosa Formation extends from about three miles north of Ada to the Oklahoma-Kansas state line (Miser, 1954) (Figure 3). The type section as identified by Morgan (1924) is in secs. 25 and 26, T. 6 N., R. 6 E. on OK Hwy 56 between Konawa and Sasakwa. This probably is close to the abandoned gravel pit noted above and shown in Figure 1. The

[1] The town of Boley, Oklahoma, was founded in 1903 by Creek Freedmen, the ancestors of slaves held by Creek Indians prior to the Civil War. In the early 1900's it was one of the most prosperous all-Black towns in the country but, like many Oklahoma towns, it failed in 1939 during the Depression.

Boley Conglomerate is widespread and well-recognized in Seminole and Okfuskee Counties (Tanner, 1956; Ries, 1954). How far south the Boley Conglomerate occurs is not reported; it is present, however, in northern Pontotoc County. It extends northward into the southern part of Creek County where Oakes (1959, fig. 10) shows it, but does not name it, at the base of the Vamoosa. Farther to the north in Pawnee County, the Boley is absent and the base of the Vamoosa Formation is the fine-grained Cheshewalla Sandstone (Greig, 1959).

Only two of the authors listed above suggested a depositional environment for the conglomerate; Ries (1954) suggested much of the Vamoosa was deposited in a delta and Tanner (1956) referred to "channels." Perhaps the first proposed origin of the Boley Conglomerate was in an unpublished master's thesis – Jones (1922, p. 20) suggested the conglomerate (which he called the Little River Conglomerate) and interbedded shales have a "terrestrial or lake origin." Undoubtedly the most unusual interpretation of the conglomerate is that it was deposited by "Chert River," which Oakes (1947) suggested deposited pebbles in the Atoka to Garber Formations, a period lasting from the Atokan to Leonardian, or about 40 million years.

Chert Pebbles and Cobbles

Many of the Middle to Upper Pennsylvanian formations in east-central Oklahoma contain chert clasts, but the Boley Conglomerate contains some particular varieties that have long been of interest to geologists. (Other conglomerate beds above the Vamoosa contain chert clasts similar to those in the Boley, in particular, those at the Aztec Quarry in the NE¼ sec. 10, T. 6 N., R. 4 E., about three miles northeast of Asher, but these beds do not appear to be as widespread or as well mapped.) Jones (1922, p. 11) noted a "peculiar type of pebble" that consists of chert fragments in a coarsely crystalline quartz matrix. Ries (1954, p. 83) described pebbles of silica-replaced fossiliferous (crinoids, bryozoa) limestones and "exotic pebbles [of] silicified tectonic breccias and second and even third generation conglomerates." Tanner (1956, p. 93-94) divided the cherts into four lithologic types: 1. Buff, uncommon faint banding; 2. Banded buff and green or solid green; 3. Multiple-cycled tectonic breccias; 4. Other, including chalcedony, quartzite, and quartz. He suggested that the type 1 cherts formed as a result of silica replacement of limestone, but did not propose an origin for the others.

The source terrane of the chert clasts is unknown but is important for paleogeographic reconstructions. No paleocurrent studies have been done on the Boley Conglomerate or the overlying part of the Vamoosa Formation, and matching chert lithologies to modern potential source-terrane exposures is difficult. Despite noting that H.D. Miser recognized Arkansas Novaculite (exposed only in the Ouachita Mountains) pebbles among the Boley pebbles, Tanner (1956, p. 95) largely discounted a Ouachita source. W.E. Ham (in Tanner, 1956, p. 94) suggested that one of the chert breccias (no. 3, above) was similar to those found in the Boggy(?) Formation in the Mill Creek Syncline in the Arbuckle Mountains (sec. 8, T. 2 S., R. 5 E.), but Ham et al. (1954) did not map any Boggy in that area. Tanner's (1956) question mark following Boggy is noteworthy. Tanner (1956) summarizes by stating that a number of Ordovician to Pennsylvanian formations in the Arbuckle Mountains – Hunton Anticline area could be the source of the cherts, but is not specific, and discounts the Ouachita Mountains as a source.

Most of the cherts in the Boley Conglomerate probably are silicified limestone, but how the limestones were silicified and where they occur or occurred are unknown. Ries' observation made in 1954 (p. 83) is still true: "The origin of these (chert) pebbles in the Boley Conglomerate Member of the Vamoosa Formation would form an intriguing study."

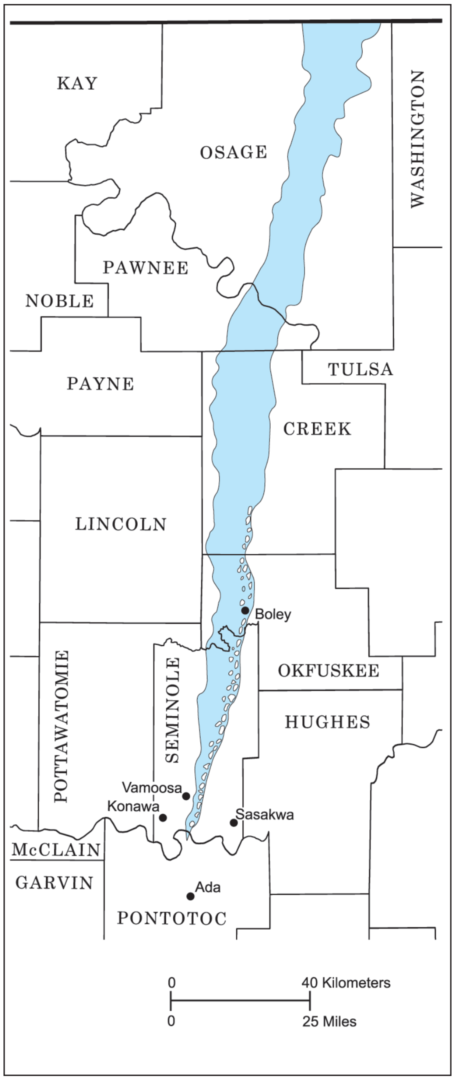


Figure 3. Map showing extent of Vamoosa Formation and Boley Conglomerate in central Oklahoma.

Boley Agate – True Agate?

The formal nomenclature of the many varieties of cryptocrystalline quartz is based on microscopic and crystallographic characteristics, but the terms have been used casually by collectors based on hand-specimen features. Thus, terms such as flint, chert, agate, onyx, carnelian, and jasper are often used interchangeably. Pabian et al. (2006) recognize "chalcedony" as an overarching term, its subsets (flint, chert, etc.) all exhibiting twisted microscopic fibers of SiO_2 and further define "agate" as "banded chalcedony." This definition of chalcedony is similar to that in the Glossary of Geology (Neuendorf et al., 2005) – a) "a cryptocrystalline variety of quartz …; b) "a general name for crystalline silica that forms concretionary masses with radial-fibrous and concentric structure." The Glossary defines agate as "a translucent cryptocrystalline variety of quartz, being a variegated chalcedony frequently mixed or alternating with opal, and characterized by colors … ." Thus, the Glossary includes opal as a possible constituent of agate. Opal is a mineral or mineral gel ($SiO_2 \cdot nH_2O$) and includes both opal-A (amorphous, noncrystalline) and opal-CT (crystalline, containing the microscopic quartz polymorphs cristobalite and tridymite). The cryptocrystalline character of chalcedony, presence of water in opal, and the microscopic cristobalite and tridymite require laboratory analyses to determine. However, it is the "field" or macroscopic characteristics of agate – the banding and translucence – that are commonly used, and it is these bands and the patterns they create that have caught the eye of collectors for centuries and account for the popularity of agates among the frequenters of rock shops.

Figure 4. Tumbled and polished Boley agate showing banded character, "eyes," and "fortification" structures. Longest dimension is 1.2 inches. (David Goza collection)

If we accept Pabian et al.'s (2006) and the Glossary of Geology (Neuendorf et al., 2005) "field" and/or macroscopic characteristics, any rock deserving of the name agate should exhibit both banding and translucence. Based on this, some of the material known to collectors as "Boley agate" qualifies as such – the banding is pronounced, and other structures associated with the category "agate" are present, such as "fortification" structures and those hemispheres often described as "eyes" (Figure 4). The chert clasts that are bound together in a banded matrix of chalcedony cement account for the peculiar quality of Boley agates, widely recognized as unique or very nearly so.

The popular use of the term "Boley agate" has, however, extended well beyond the formal description above. In its most generous use, it includes all of the chert breccias found in the Boley Conglomerate. This includes a great deal of material that, were it collected from any other location, would surely never have attracted the label "agate" based on almost anyone's understanding of the term. Some of that material is described in the sections below. The Glossary (Neuendorf et al., 2005) defines chert as "a hard, extremely dense or compact, dull to semivitreous, microcrystalline or cryptocrystalline sedimentary rock, consisting dominantly of interlocking crystals of quartz less than about 30 µm in diameter; it may contain amorphous silica (opal). It sometimes contains impurities such as calcite, iron oxide, and the remains of siliceous and other organisms. It has a tough, splintery to conchoidal fracture, and may be white or variously colored gray, green, blue, pink, red, yellow, brown, and black. …. [It] may be an original organic or inorganic precipitate or a replacement product." Like chalcedony and agate, there are microscopic and macroscopic characteristics of chert; whereas many "field" cherts may appear to be similar, laboratory analyses may show them to be very different.

It might be useful to formalize the term "Boley agate" with a set of minimum requirements. To that end, we might regard any chert breccia cemented with either translucent or banded chalcedony or both, to be Boley agate. This definition covers a broad descriptive territory, and would probably be satisfactory to most collectors. Alternatively, we might want to include all of the chert breccias found as clasts in the Boley Conglomerate, whether cemented with chalcedony or not, as Boley agate.

Boley Agate

We have revised Tanner's (1956) classification of chert pebbles and cobbles found in the Boley Conglomerate. These are based on collections from the Donald Stover Quarry and nearby exposures and from outcrops near Boley, Oklahoma. Tanner (1956, p. 93-94) divided the clasts into four groups:

1. Buff, in some instances faintly banded, subangular chert.
2. Banded buff-and-green, or solid green, subangular chert.
3. Brecciated (tectonic) second or third generation chert.
4. Miscellaneous; including chalcedony, quartzite, quartz granules, and clay plates.

(Note: Throughout the following discussion we refer to the individual clasts, that when cemented together make up the pebbles and cobbles in the Boley Conglomerate, as subclasts.)

1. Chert Breccia (similar to Tanner's (1956) #3)

A. Subclasts are unconnected and appear to be unrelated to each other (Figure 5). Subclasts vary from subrounded to angular, and they vary from pebble- to granule-sized. In a sedimentary sense, these would be considered "distally" transported and thoroughly mixed. In a tectonic sense, the subclasts are moved far enough away from each other and separated by enough cement and/or thick fractures that they

Figure 5. Rough specimen of chert breccia clast type 1A. Subclasts appear to have no relation to each other and cannot be reconstructed. This clast is probably sedimentary in origin. Longest dimension is 4.7 inches. (Bill Lyon collection)

Figure 6. Tumbled and polished chert breccia clast, var. "Boley barfstone." This clast appears to be sedimentary in origin. Longest dimension is 1.7 inches. (Bill Lyon collection)

Figure 7. Cut surface of chert breccia clast in which subclasts can be reconstructed. The subclasts in this specimen are tectonic in origin and separated by fractures. Longest dimension 2.7 inches. (Bill Lyon collection)

cannot be reconnected. A popular term for a type in which the subclasts are granule-size or smaller is "oatmeal" or "Boley barfstone" (Figure 6).

B. Subclasts can be reconstructed into larger fragments (Figure 7). Subclasts typically are angular, and their size varies greatly. In a sedimentary sense, these would be considered "autoclastic" breccias. In a tectonic sense, these might indicate little movement along a fault or fracture zone. Subclasts typically are jasper, indicating the presence of iron. Colors are red, brown, ocher, and green.

C. Slightly delaminated stratified breccias. A type of autoclastic breccia in which the original rock clearly is sedimentary and the subclasts have delaminated largely along bedding planes.

2. Stratified Chert (similar to Tanner's (1956) #1 and #2)

A. Massive or unstratified chert. Clasts (typically pebble-size) in the Boley Conglomerate that likely originated as a thickly stratified sedimentary rock. Stratification may be extremely faint or detectable only using specialized techniques such as cathodoluminescence.

B. Stratified chert in which no delamination or brecciation has occurred. This type grades into 1C. Small fossil fragments are present in some specimens; sponge spicules appear to be the most common. An unusual variety of this type is a very finely wavy laminated chert known as "polygraphic" chert (Figure 9).

3. Banded Chert (not the same as stratified chert)

Rare specimens with fracture-fills or void-space fillings in which the silica is banded like agate (Figure 10). The banded silica filling can constitute either a very minor portion of the rock or most of it. The bands are not related to original stratification, rather, represent repeated precipitation

Figure 8. Slightly delaminated chert. Longest dimension about 3 inches. (Neil Suneson collection)

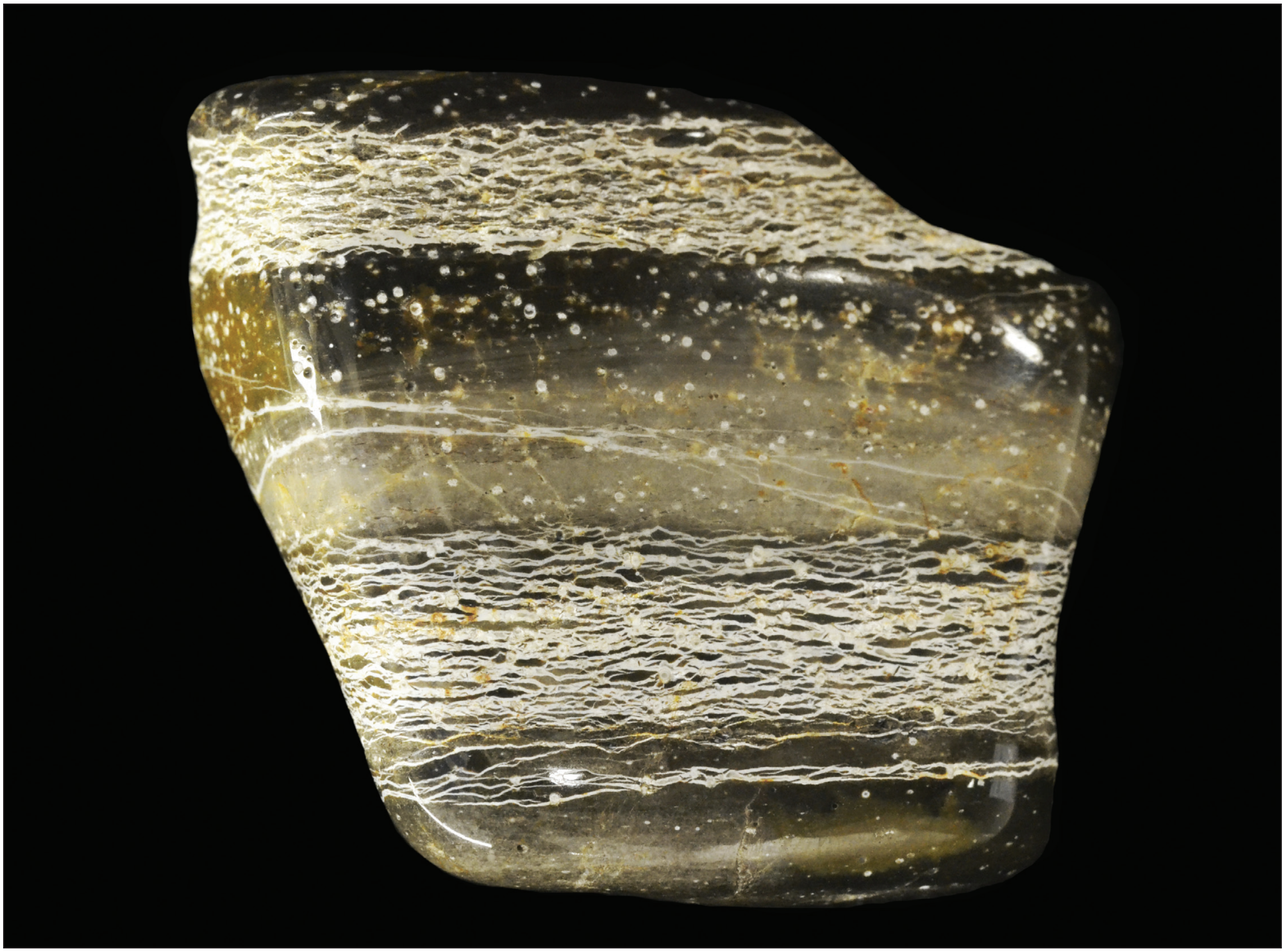


Figure 9. Tumbled and polished stratified chert, var. "polygraphic." The origin of the small white specks, which are present in the poorly laminated gray chert and the wavy laminated "polygraphic", is unknown. Longest dimension 2.3 inches. (Bill Lyon collection)

episodes of silica with slight variations in chemistry. These banded fracture-fills may occur in either 1 or 2 above.

We do not consider silica-cemented sandstones (included in Tanner's (1956) #4) to be Boley agate, although these are fairly common in Boley Conglomerate outcrops; however, these may be related to the stratified cherts in the original source area.

Texture and Formation Processes

Texture alone, although suggestive, is fairly slender evidence upon which to base hypotheses concerning the origin of the chert and chert breccia clasts within the Boley Conglomerate. Nevertheless, it is possible that each category of clast may have undergone quite different geochemical histories before their final deposition within the Vamoosa Formation. Thus, one key to determining the origin of the different cherts in the Boley Conglomerate is identifying the source formation of the clasts and/or subclasts. As noted above, this remains unknown and will be the subject of continued exploration by us.

In the following discussion, we describe some of the issues that require further studies for their resolution and those techniques that might be expected to yield some of the data that will ultimately provide answers. These studies may be applicable to the Boley Conglomerate clasts and subclasts and an as-yet-undiscovered source. (As above, we continue to refer to the pebbles and cobbles within the Boley Conglomerate as clasts and to the individual fragments that make up the breccia pebbles and cobbles as subclasts.)

1. Timing and mechanism of brecciation. Several types of "Boley agates" involve brecciation. What is the exact nature of the brecciation and to what categories of sub-

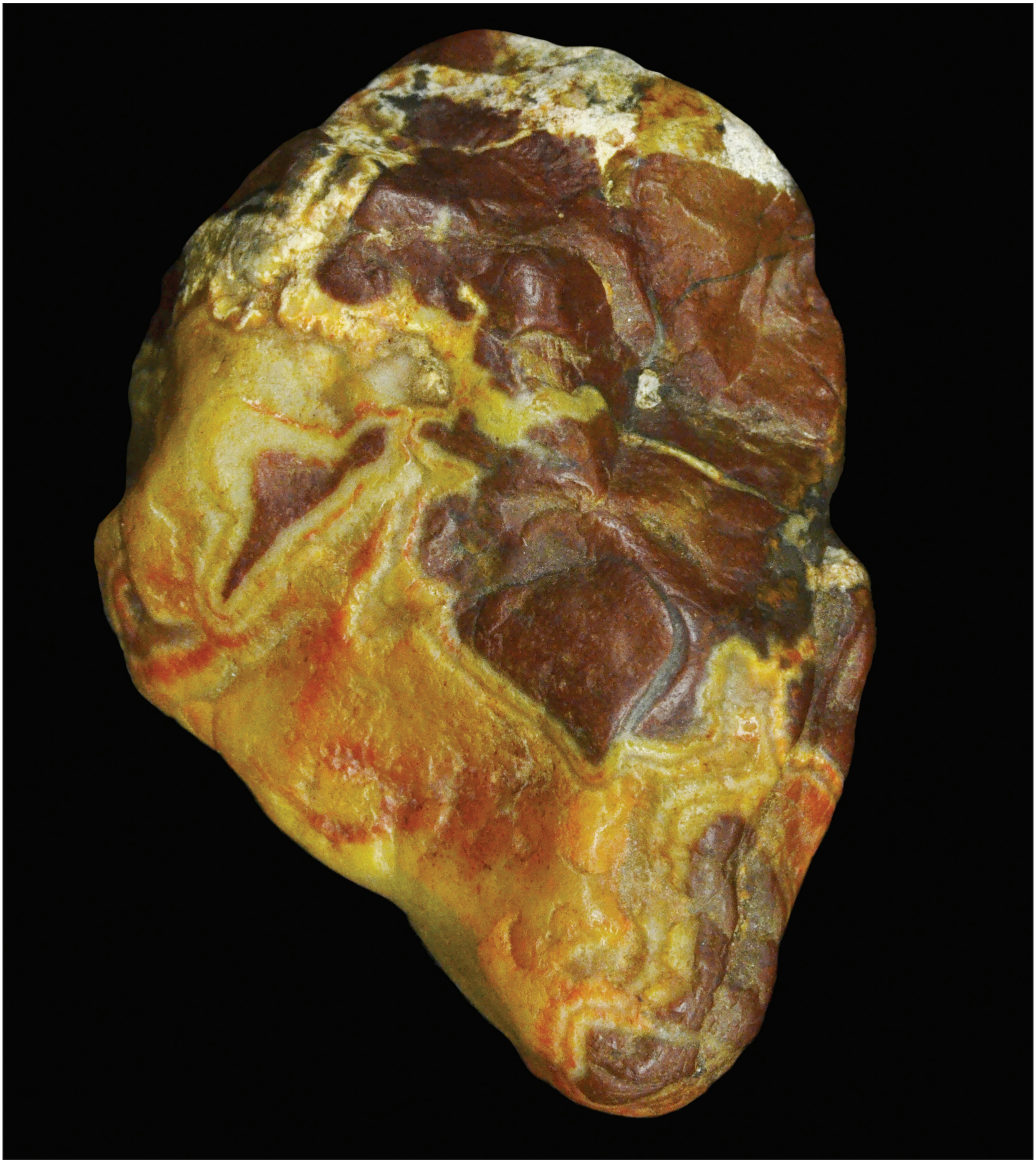


Figure 10A. Partly tumbled and polished banded chert showing agate-like banding. Note that the clasts are jasper. Longest dimension 2.8 inches. (David Goza collection)

Figure 10B. Tumbled and polished banded chert. The fracture- or vug-filling silica varies widely across the specimen from very little (lower right) to over 50% (top). Longest dimension 2.5 inches. (David Goza collection)

Figure 10C. Tumbled and polished banded chert. Note that some banding is truncated by "later" banding. Longest dimension 1.9 inches. (David Goza collection)

clast do these mechanisms apply? Various mechanisms of brecciation that may apply include erosion by water (e.g., rip-up clasts), simple fracturing, tectonic brecciation, karstic brecciation, desiccation (*sensu stricto*), and osmotic desiccation (syneresis). Several of these fall under the subheading of autoclastic brecciation, that is, the brecciation occurred *in situ* with very little transport of the subclasts before cementation.

2. Timing and mechanism of silica replacement of the subclasts in the breccias. The silica replacement may have occurred before or after brecciation. Tectonic brecciation may be more probable in connection with a relatively competent rock such as limestone, the fragments of which would be replaced by silica to form chert subclasts and then cemented.

3. Timing and mechanism of silica precipitation and cementation. It is not clear whether cementation uniformly occurred after silica replacement of the subclasts or whether it may have occurred more or less simultaneously with a replacement process.

4. Some chert clasts within the Boley Conglomerate bear a marked resemblance to some subclasts within the chert breccias. Are there petrographic or geochemi-

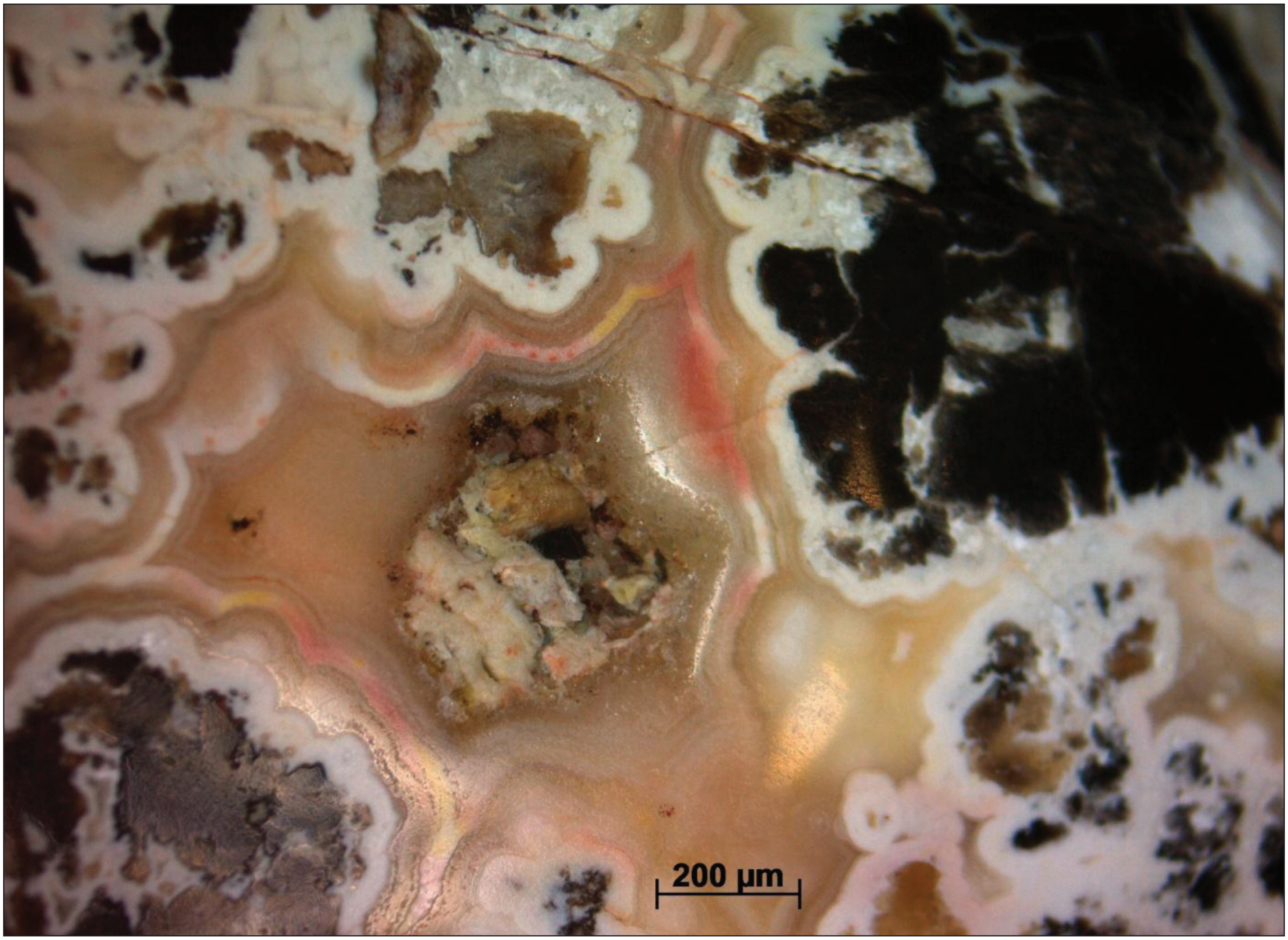


Figure 10D. Close-up view of agate texture and open vug with quartz crystals. Scale bar shown. (David Goza collection)

cal data that support this qualitative observation?

5. Some of the chert clasts within the Boley Conglomerate appear to be jasper. Do these iron-rich, opaque forms of chert have a distinctly different provenance than the more common pale-colored or faintly striped chert clasts? (Kostov (2010) (citing Yakovleva and Putolova, 1971) gives a table of mineral inclusions thought to be responsible for various jasper colors. Red, brown, and yellow jasper typically are caused by various mixtures of hematite and goethite. Green may be caused by a wider range of mineral including chlorite, pumpellyite, epidote, actinolite, clinozoisite, and celadonite.) The same question applies to the subclasts within brecciated clasts.

Investigative Techniques for Analysis of the Microcrystalline Silicas

Progress in understanding the origin of Boley agates and other chert clasts in the Vamoosa will require that data from many geochemical and mineralogical techniques be integrated. These have been used in many investigations of the origin of microcrystalline cherts by geologists (any and all methods) and archaeologists (especially the non-destructive methods). Many of these studies require comparison of data patterns, and therefore, often call upon statistical methodology that permits examination of large numbers of complex patterns (e.g., discriminant analysis, cluster analysis, Q-mode factor analysis, etc.). We do not address these in this paper.

We divide the various investigative techniques into the following five main categories: petrographic analysis, isotopic analysis, elemental analysis, X-ray diffraction analysis, and spectroscopic analysis. Where possible, we cite examples from the literature describing the use of these methods to characterize materials containing microcrystalline silica.

Petrographic Analysis. Various kinds of information concerning the microtextures of cherts can be derived from microscopic examination of thick and thin sections; this includes such features as the morphology of mineral and fossil inclusions and their identification. Petrographic analyses may perhaps be used in concert with X-ray microspectroscopy (e.g., SEM-EDAX) and cathodoluminescence techniques. The latter is widely used in the petroleum industry for studying episodes of cementation or dissolution in reservoir rock fabrics. Prothero and Lavin (1990) extensively review the applications of chert petrography to archaeology, and Götze et al. (1998) have combined cathodoluminescence with micro-Raman studies.

Isotopic Analysis. Isotopes of hydrogen, oxygen and boron have been usefully applied to the study of chert breccia by Kolodny et al. (2005). In particular, oxygen isotopic studies seem to provide information on the isotopic composition of water during the crystallization process of whatever microcrystalline phases are present. Deuterium seems to be preferentially excluded from the hydroxyl groups in certain microcrystalline silica phases during their formation. Boron isotopes may give some insight into the salinity of formation waters, which might prove useful with respect to the process of syneresis of silica gel. Boron isotopes may also be useful for determining the diagenetic history of the silica clasts and the silica matrix.

Elemental Analysis. The texture of the chert clasts ranges from very coarse to very fine, and that limits the usefulness of bulk elemental analyses to those subclasts or cements sufficiently large to be sampled separately and then prepared for techniques such as bulk X-ray fluorescence (XRF) or dissolution and then analysis by inductively coupled plasma emission (ICP-AES). Certain X-ray-based techniques such as XRF or SEM-EDAX are limited in their analytical sensitivity to very light elements, and other macro methods, when applicable, have an advantage for elements lighter than sodium.

X-ray Diffraction Analysis. Many of the defining studies of microcrystalline phases of silica involve some form of X-ray analysis. Unfortunately, these techniques are typically difficult to apply on a massive scale when thousands of samples may need to be analyzed to achieve statistical significance. Nevertheless, these methods are definitive when the objective is to supply quality control samples for other types of spectroscopic study. These methods are often limited with respect to sensitivity for detecting minor phases in a complex sample (see Wenk and Kolodny, 1968; Pretola, 2001).

Other Spectroscopic Methods. Raman spectroscopy has proven to be an extraordinarily powerful tool for the rapid identification of microcrystalline phases of silica. Kingma and Hemley (1994) show an impressive ability to discriminate diverse silica phases including α-quartz, α-cristobalite, α-tridymite, coesite, and moganite. The ability of this technique to rapidly provide digitized spectra that can form the basis of a statistical analysis strongly recommends it for study of these chert clasts and subclasts.

Fourier transform infrared spectroscopy (FTIR) has been applied to the study of siliceous sediments (Rice et al., 1995) and their diagenetic transformations. Unfortunately, except for IR microscopy, this is difficult to apply except to homogeneous bulk samples.

Many of the subclasts within Boley agate specimens appear to be jasper. For our purposes here we define jasper as an opaque, iron-rich form of chert recognized in the field by the colors red, brown, ocher, green, and more rarely black. These colors suggest that the iron content might be sufficiently large to allow study by ^{57}Fe-Mössbauer spectroscopy. The iron content of the jasper subclasts within Boley agate specimens is probably contained within microscopic inclusions of such minerals as hematite, goethite, and lepidocrocite, and certain iron-rich clay minerals such as nontronite, glauconite, celadonite, etc. Mössbauer spectra can provide information on the mineralogical identity of the iron-rich phases and in the case of the clay fraction, allow estimation of the extent of reduction to Fe^{2+} within these minerals.

Summary

Boley agates are among the most interesting and beautiful lapidary materials in Oklahoma. In addition, Boley agates and the unit they are found in – the Boley Conglomerate – present a number of geological questions for which we have no, or only the vaguest of, answers. Individuals interested in the origin of chert and chert breccias, including those petroleum geologists exploring and developing the Mississippian chat in north-central Oklahoma, will recognize some of the questions.

1. The Boley Conglomerate was probably derived from south of its current outcrop area, probably in the Lawrence Uplift or Hunton Anticline areas. But exactly where are the cherts and chert breccias present in the conglomerate exposed today, if indeed, they are, and from what formation were they eroded?

2. What is the origin of the brecciation? Among the possibilities are sedimentary processes such as erosion, tectonic fracturing, karst (collapse) processes, desiccation, and syneresis.

3. Is there more than one generation of brecciation?

4. When did the silicification occur in relation to the brecciation? What is the origin of the silica-rich fluids?

5. When did the silicification of the subclasts occur in relation to the silicification of the matrix?

6. Were all the different types of chert clasts and Boley agates silicified by the

same process?

7. What is the significance of the jasper (iron-rich) subclasts? In addition to the "typical" brick-red jasper, other colors occur including brown, ocher, green, and black. What is the origin of these different colors?

Acknowledgements

NHS would like to thank OGS geologist Brittany Pritchett for having made many useful comments on the manuscript and for taking many photographs of the Boley specimens, including Figure 10D. He also thanks Gene Kulmann, manager of the OGS Oklahoma Petroleum Information Center, for allowing me to use the photographic facilities there, and Rick Andrews, for his photographic expertise..

References Cited

Baldwin, B.; and Muehlberger, W.R., 1959, Geologic studies of Union County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 63, 171p.

Greig, P.B., 1959, Geology of Pawnee County, Oklahoma: Oklahoma Geological Survey Bulletin 83, 188p.

Götze, J.; Nasdala, L.; Kleeberg, R.; and Wenzel, M., 1998, Occurrence and distribution of "moganite" in agate/chalcedony: a combined micro-Raman, Rietveld, and cathodoluminescence study: Contributions to Mineralogy and Petrology, v. 133, p. 96-105.
\

Ham, W.E.; McKinley, M.E.; et al., 1954, Geologic map and sections of the Arbuckle Mountains, Oklahoma, in Ham, W.E., 1955, Field conference on geology of the Arbuckle Mountain region: Oklahoma Geological Survey Guidebook 3, 61p, scale 1:72,000. (republished with revisions by K.S. Johnson, 1990, as Oklahoma Geological Survey Map GM-31, scale 1:100,000)

Jones, B., 1922, The geology of the Wewoka area: unpub. M.A. thesis, University of Oklahoma, Norman, 29p.

Kingma, K.J.; and Hemley, R.J., 1994, Raman spectroscopic study of microcrystalline silica: American Mineralogist, v. 79, p. 269-273.

Kolodny, Y.; Chaussidon, M.; and Katz, A., 2005. Geochemistry of a chert breccia: Geochimica et Cosmochimica Acta, v. 69, p. 427–439.

Kostov, R.I., 2010, Review of the mineralogical systematics of jasper and related rocks: Geology and Mineral Resources, v. 13, no. 9, p. 8-12.

Miser, H.D., 1954, Geologic map of Oklahoma: U.S. Geological Survey and Oklahoma Geological Survey, scale 1:500,000.

Morgan, G.D., 1924, Geology of the Stonewall Quadrangle, Oklahoma: Oklahoma Bureau of Geology Bulletin 2, 248p.

Neuendorf, K.K.E.; J.P. Mehl, Jr.; and J.A. Jackson, 2005, Glossary of Geology, 5th ed.: Alexandria, Virginia, American Geological Institute, 779p.

Oakes, M.C., 1947, Chert River, an inferred Carboniferous stream of southeastern Oklahoma: Proceedings of the Oklahoma Academy of Science, v. 28, p. 70-71.

Oakes, M.C., 1959, Geology and mineral resources of Creek County, Oklahoma: Oklahoma Geological Survey Bulletin 81, 134p.

Pabian, R.; with Jackson, B.; Tandy, P.; and Cromartie, J., 2006, Agates: Treasures of the Earth: Buffalo, New York, Firefly Books Inc., 192p.

Pretola, J.P., 2001, A feasibility study using silica polymorph ratios for sourcing chert and chalcedony lithic materials: Journal of Archaeological Science, v. 28, p. 721-739.

Prothero, D.R.; and Lavin, L., 1990. Chert petrography and its potential as an analytical tool in archaeology, in Lasca, N.P.; and Donahue, J., eds., Archaeological geology of North America: Boulder, Colorado, Geological Society of America, Centennial Special Volume 4, p. 561-584.

Rice, S.B.; Freund, H.; Huang, W.-L.; Clouse, J. A., and Isaacs, C.M., 1995, Application of Fourier transform infrared spectroscopy to silica diagenesis: the opal-A to opal-CT transformation: Journal of Sedimentary Research, v. A65, p. 639 - 647.

Ries, E.R., 1954, Geology and mineral resources of Okfuskee County, Oklahoma: Oklahoma Geological Survey Bulletin 71, 120p.

Rothrock, E.P., 1925, Geology of Cimarron County, Oklahoma: Oklahoma Geological Survey Bulletin 34, 107p.

Schoff, S.L., 1943, Geology and ground water resources of Cimarron County, Oklahoma: Oklahoma Geological Survey Bulletin 64, 317p.

Tanner, W.F., 1956, Geology of Seminole County, Oklahoma: Oklahoma Geological Survey Bulletin 74, 175p.

Wenk, H.-R., and Kolodny, Y., 1968, Preferred orientation of quartz in a chert breccia: Proceedings of the National Academy of Science, v. 59, p. 1061-1066.

Yakovleva, M.E, and Putolova, L.S., 1971, On the mineralogical composition of some jaspers and the cause of their colour: New Data on Minerals from the USSR, v. 20, p. 172 – 179 [in Russian].

Biographical Sketch

Neil Suneson has worked for the Oklahoma Geological Survey since 1986, when he and some colleagues started mapping the frontal belt of the Ouachita Mountains and the southern part of the Arkoma Basin as part of the USGS-sponsored COGEOMAP and later STATEMAP programs. After working in the Ouachitas, he did some reconnaissance mapping in northwestern Oklahoma and more detailed mapping in the Oklahoma City metro area.

Neil Suneson
Oklahoma Geological Survey

When the Survey became part of the Mewbourne College of Earth and Energy at OU, more of Neil's time was devoted to teaching (including the School of Geology's summer field camp outside of Cañon City, Colorado) and advising students on their theses. His interests range from the Late Tertiary geology of the Oklahoma Panhandle to the Early Paleozoic geology of the Broken Bow uplift in southeastern Oklahoma and everything in between. He even likes (some) igneous rocks.

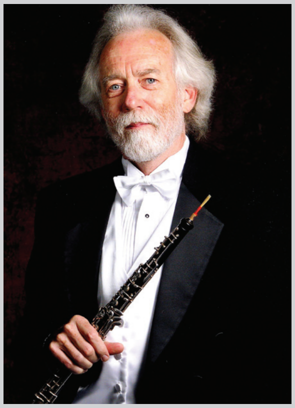
Prior to working for the Survey, Neil was a petroleum development geologist with Chevron USA where he worked on the Lost Hills Oilfield. He also worked with Chevron Resources Company in geothermal exploration throughout the western U.S. All his college degrees are in geology. He received at B.A. from Amherst College in 1972, an M.S. from Arizona State University in 1976, and a Ph.D. from the University of California – Santa Barbara in 1980. His dissertation, largely funded by the U.S. Geological Survey, was based on mapping in the highly extended terrane of west-central Arizona.

Dr. Lyon

Biographical Sketch

Dr. Lyon is a broadly trained research scientist with over 27 years research experience in applied geochemistry including extensive work with clay and iron minerals, and subsurface organic matter involving X-ray diffraction, Mössbauer spectroscopy, FTIR and other spectroscopic methods of characterization. His most recent work includes 15 years research experience as a contractor at The Robert S. Kerr Environmental Research Center (U.S. EPA) in environmental geochemistry comprising work on virus transport in the subsurface, and research on interactions of groundwater and pollutants with subsurface organic particles,coatings and biogenic minerals. Previously in the petroleum industry, Dr. Lyon spent 12 years in exploration related research. Prior to working in the petroleum industry, Dr. Lyon was involved in energy research, which included research on materials associated with nuclear reactors.

Biographical Sketch



David Gozza

David Goza is an oboist and orchestral conductor whose playing appointments have included orchestras and opera companies in Memphis, Charlottesville, Tulsa and Springfield, MO. He has filled podium assignments in Memphis, Charlottesville and Springfield, and academic positions at The University of Virginia, Missouri State University, Drury College and The University of Arkansas. He currently teaches World Music at OU. He holds Master of Music degrees in both oboe performance and composition, and the DMA in instrumental conducting from UMKC. His interest in geology and his knowledge of the field are those of a rank, eager and perhaps educable amateur.

Shale Shaker

120 North Robinson, Suite 900 Center
Oklahoma City, OK 73102