



Back on the horse: Recent developments in archaeological and palaeontological research in Alberta

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Beaver River Sandstone: A silicified toolstone from northeast Alberta, Canada

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ABSTRACT

This article is the third in the Alberta Lithic Reference Project series, the goal of which is to assist the identification of raw materials used for pre-contact stone tools in the province. Each article focuses on one raw material; the current article discusses a silicified orthoquartzite sedimentary rock that originates in northeast Alberta called Beaver River Sandstone (BRS). BRS appears in archaeological sites in northern and central Alberta and has been traced to a number of small outcrops or glacially-displaced surficial deposits and two major quarries north of Fort McMurray: the Beaver River Quarry (HgOv-29) and Quarry of the Ancestors (a complex of roughly 80 sites). Portable X-ray fluorescence (pXRF) indicates that BRS can be geochemically distinguished from macroscopically similar materials that outcrop in Montana and appear as artifacts in southern Alberta. We offer a description of BRS and comparable Montana materials, a photographic library for comparative purposes, a brief summary of BRS utilization in northeast Alberta, and pXRF data to facilitate the accurate identification of BRS in archaeological assemblages.

KEYWORDS

Beaver River Sandstone, silicified, Muskeg Valley Microquartzite, orthoquartzite, Tongue River Silicified Sediment, Alberta Lithic Reference Project, Quarry of the Ancestors, pXRF

1. The Alberta Lithic Reference Project

A lack of published references about pre-contact lithic materials (toolstones) in Alberta has led to inconsistent identifications. This article is one of a series of what will become chapters in a stand-alone Alberta toolstone guide. Each article focuses on a raw material used to make stone tools. A helpful, easy-to-use guide will amplify the utility of data generated by cultural resource management and academic projects; we hope this spurs new research agendas and helps answer questions about the province's past.

2. Introduction: Beaver River Sandstone

Early archaeological explorations of the oil sands region in northeast Alberta produced prehistoric lithic assemblages heavily dominated by a tan/gray fine-grained siliceous toolstone now known as Beaver River Sandstone (BRS). High concentrations of mainly early stage debitage suggested the potential presence of a nearby quarry. Forty years of additional survey have revealed a dense concentration of BRS-dominated sites centred on two major quarries along the Athabasca River, north of Fort McMurray (Figures 1 and 2).

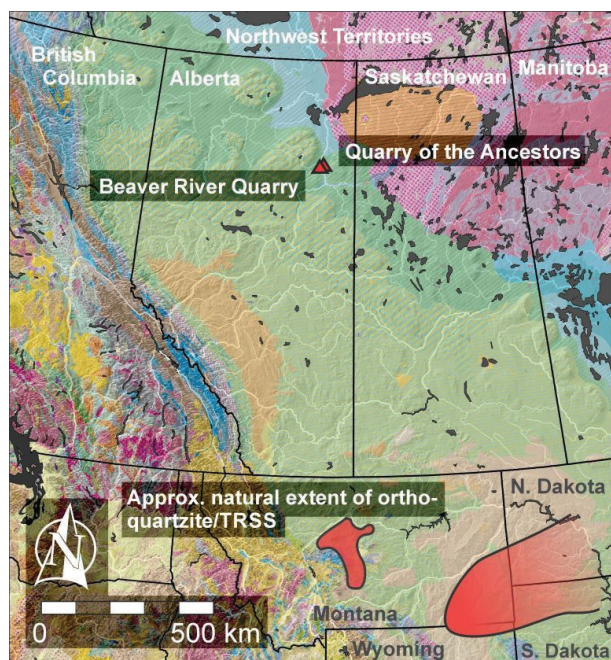


Figure 1. Outcrops of BRS in northeast Alberta and approximate location of cobble outcrops of orthoquartzite and Tongue River Silicified Sediment (background bedrock geology data from USGS 2014).

BRS was initially identified in sites on the west side of the Athabasca River near Mildred Lake and the Beaver River, and was referred to as grey chert or limestone (Syncrude 1973). Subsequent studies identified the material as quartzite (Syncrude 1974), silicified sandstone (Fenton and Ives 1982, 1984; Ives and Fenton 1983, 1985), orthoquartzitic microquartz-cemented siltstone (DePaoli 2005; Saxberg and Reeves 2005), and silicified limestone (Saxberg 2004). Because of these different petrographic classifications, several names have also been proposed for the material through time: Beaver Creek Quartzite (Syncrude 1974); Beaver River Sandstone (Fenton and Ives 1982, 1984; Ives and Fenton 1983, 1985), Beaver River Silicified Sandstone, Muskeg Valley Silicified Limestone (Saxberg 2004), and Muskeg Valley Microquartz (Saxberg and Reeves 2005).

This variation in nomenclature is tied to developments in the understanding of facies variation within BRS. The first bedrock outcrops of BRS were identified at Beaver River Quarry (HgOv-29), near the confluence of the Beaver and Athabasca Rivers. Early researchers at this site noted that archaeological samples from surrounding sites tended to be

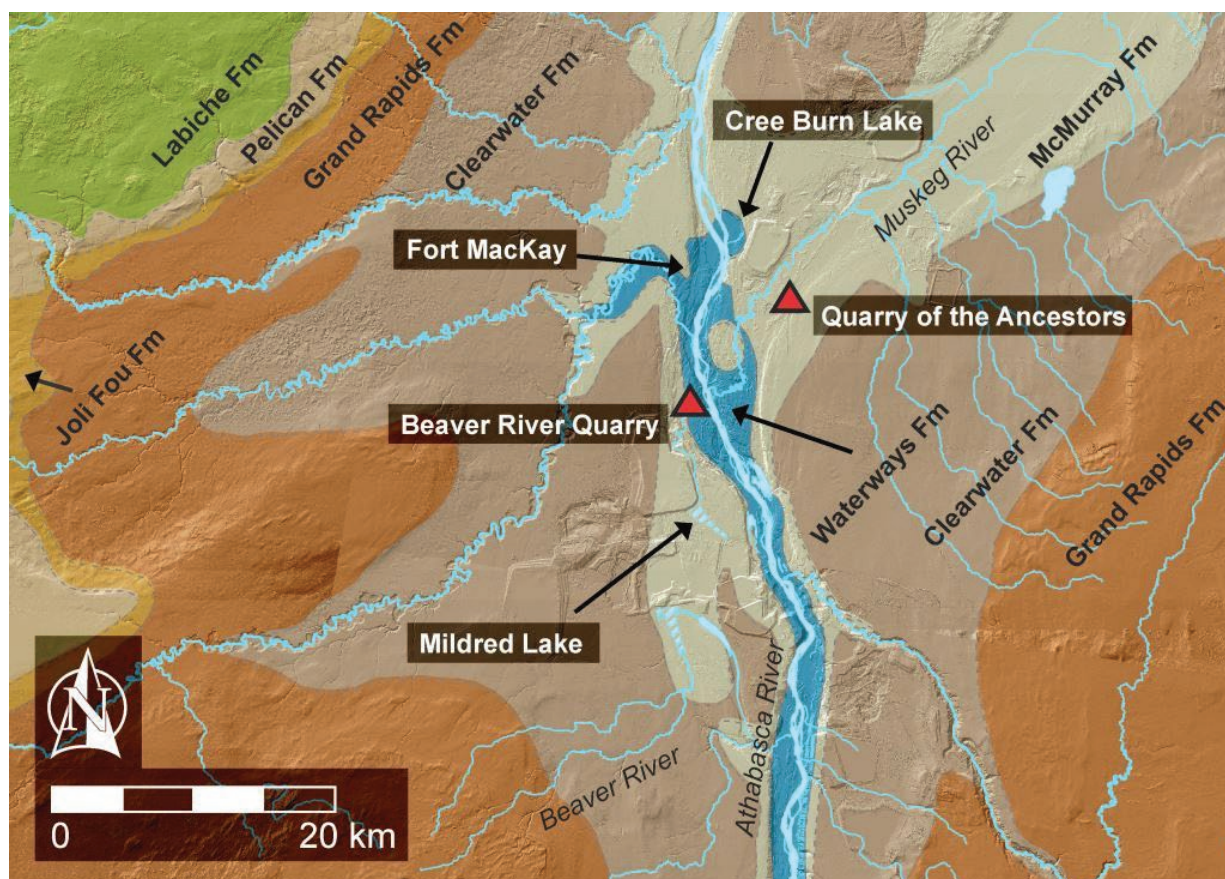


Figure 2. Major outcrops of Beaver River Sandstone (Quarry of the Ancestors and Beaver River Quarry) were likely exposed during large scale flooding along Athabasca River shortly after deglaciation (bedrock geology data from AGS 2015).

finer grained than material from the Beaver River Quarry outcrop and other outcrops identified along the Athabasca River (Donahue 1975, Reardon 1976, Fenton and Ives 1982, 1984; Ives and Fenton 1983, 1985). Reardon, Ives, and Fenton recognized that the source formation was likely characterized by substantial grain size variation, and that a finer textured source must be located in the region, possibly on the east side of the Athabasca River. However, because a fine-grained source was not then known, names that applied to coarser grained materials, like Beaver River Quartzite and Beaver River Sandstone, were adopted.

Cultural resource management work during the 1980s and 1990s resulted in the identification of hundreds of archaeological sites with BRS-dominated assemblages in the mineable oil sands region, mostly on the east side of the Athabasca River. The largest of these was the Cree Burn Lake site complex (HhOv-16), a series of surface and subsurface lithic scatters located on the east rim of the Athabasca River valley, overlooking an oxbow lake. Although not a source of BRS, the very large and diverse assemblages of fine grained BRS collected from the complex indicated that this area was significant in past seasonal rounds (Ives 1993), and added weight to the suspicion that another quarry of finer grained material was nearby. During this time, Saxberg and Reeves (2004) constructed a typological framework for the oil sands region based mainly upon BRS projectile points.

It was not until historic resource investigations were conducted for a limestone quarry across the Athabasca River from Fort MacKay in 2003 (Saxberg and Reeves 2004, 2005) that a bedrock source of the fine-grained variety was finally discovered. This initial work and subsequent investigations (Tischer and Fedirchuk 2006) led to the determination of the boundaries of a significant BRS quarry site complex called Quarry of the Ancestors, which has since been designated an archaeological preserve (Figures 2, 3, and 4). Petrographic work associated with finer grained material from the Quarry of the Ancestors led to the microquartzite and silicified limestone nomenclatures for the material (Saxberg and Reeves 2005). However, BRS remains the most commonly used name in the literature, and we support its continued use.

3. Geographic distribution of Beaver River Sandstone outcrops

Artificial exposures at Beaver River Quarry and natural exposures on the Athabasca River valley reveal flat-lying Beaver River Sandstone units in the top portion of the lower member of the Cretaceous-aged McMurray Formation (Fenton and Ives 1982, 1984, 1990; Ives and Fenton 1983, 1985). The lower McMurray directly overlies the Devonian



Figure 3. In-situ bed of BRS at Quarry of the Ancestors (photograph courtesy of Brian Ronaghan).



Figure 4. Outcrops of BRS at Quarry of the Ancestors (photograph courtesy of Brian Ronaghan).

Waterways Formation, and fills karst depressions on this surface. Natural outcrops are therefore expected along the Athabasca River and the lower reaches of its tributaries in the Fort MacKay area, where lower McMurray deposits have been exposed by erosion or where overlying deposits are thin or absent (Fenton and Ives 1990). Known BRS outcrops conform to this pattern. Beaver River Quarry is located in the lower reaches of Beaver River, while Quarry of the Ancestors is located in an area of thin overlying Quaternary sediment in the lower Muskeg River drainage. Both of these water courses are main tributaries of the Athabasca. HhOv-55 and other isolated outcrops have been observed within the Athabasca valley itself, where the modern river has eroded to the Devonian basement (Fenton and Ives 1982, 1984, 1990; Ives and Fenton 1983, 1985).

It is possible that smaller outcrops of BRS are glacially-displaced surficial or lag deposits that originated from near-surface occurrences of the McMurray Formation. Additional geomorphological work is required at these small outcrops to confirm or deny this possibility. Figure 5 shows that both Beaver River Quarry and Quarry of the Ancestors occur in areas near the subcrop transition between the Devonian deposits and the McMurray formation; this is a reflection of Beaver River Sandstone's position in the lower McMurray. Areas along this subcrop transition, where there is minimal overlying Quaternary sediment, may hold potential for additional quarry sites. The Clearwater River could also contain natural outcrops, but this area has not been systematically explored.

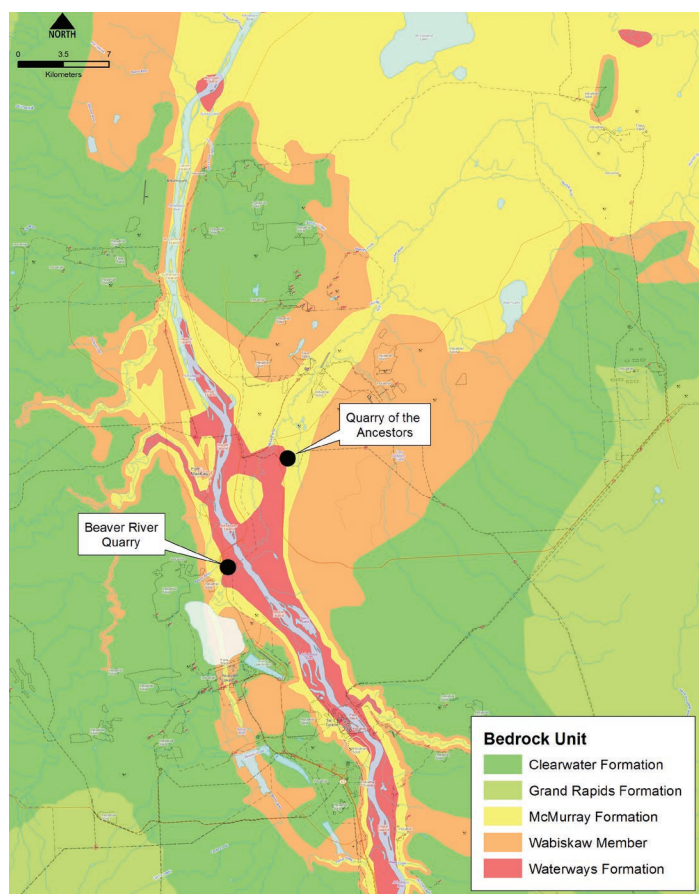


Figure 5. Beaver River Quarry and the Quarry of the Ancestors in relation to Devonian Deposits and the McMurray Formation.

Initial exposure of BRS along these valleys likely occurred during Late Pleistocene / Early Holocene outburst flooding from the northwestern arm of Glacial Lake Agassiz, the timing and nature of which (i.e., one flood vs. multiple outbursts) has been debated (Smith and Fisher 1993; Lowell et al. 2005; Fisher 2007; Murton et al. 2010). The outcome of one or more floods for BRS distribution is essentially the same: much of the Athabasca River valley downstream of

Fort McMurray was scoured during flood events, and this likely explains the near surface expressions of BRS (Figure 5). In the heart of the outburst zone, it appears that both scouring and displacement of large BRS float blocks took place, such that BRS is available at surface locations in the Quarry of the Ancestors area and as cobbles, plates, and large boulders extending toward the Bitumont area in outburst-related debris (Gryba, in press). These localities were all readily accessible to prehistoric knappers. Erosion and mass wasting along the Athabasca River valley may have also periodically exposed BRS throughout the Holocene.

4. Geological origins of Beaver River Sandstone

The McMurray Formation is a Cretaceous-aged sedimentary deposit, representing a generally fining upward sequence interpreted to be a marine transgression that occurred as the exposed pre-Cretaceous landscape of ridges and valleys was inundated by a rising sea from the north. The depositional environment of the McMurray Formation changed from a fluvial to an estuarine environment, and later to a marine embayment. Carrigy (1959) informally distinguished these depositional environments as the lower, middle, and upper Members, respectively. Fenton and Ives (1990:130-131) and Flach (1984) posited that Beaver River Sandstone is part of the Lower McMurray Formation (Figure 6); this was supported by stratigraphic and petrographic work by Tsang (1998). Hein et al. (2001) also agreed, based on the unit's stratigraphic position, preliminary palynological dates, and lithologic characteristics. However, BRS is lithologically distinct from the bulk of the lower McMurray, and given the poor age constraints available, its lithostratigraphic affinity warrants further research.

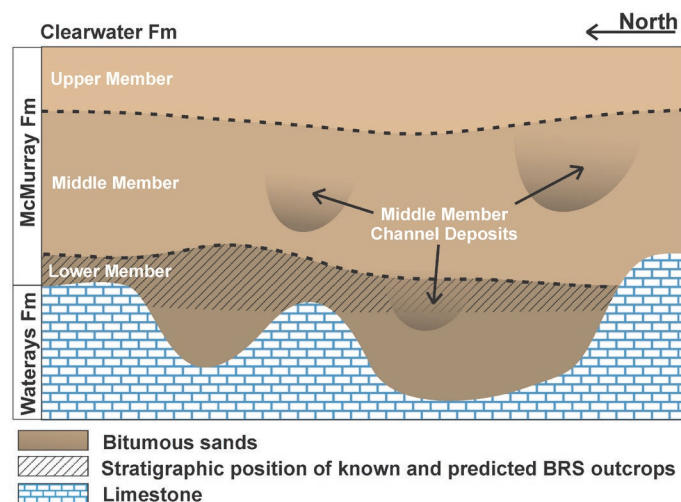


Figure 6. A north-south schematic reflecting the discontinuous nature of potential Beaver River Sandstone outcrops in the lower member of the Cretaceous McMurray Formation as it overlies the Waterways Formation Devonian deposits (adapted from Fenton and Ives 1990).

McMurray Formation sands are poorly compacted and friable, generally uncemented, and bound by bitumen. The sands can be cemented with calcite or siderite, but this is uncommon. Silica cement makes the BRS a unique facies in the McMurray Formation. The cement is composed of euhedral to subhedral microcrystalline quartz crystals, which in turn are further in-filled with a secondary anhedral quartz cement (Tsang 1998). Detrital grains include angular to subrounded quartz with < 4% hematite, tourmaline, mica, and unidentified opaque minerals (Figure 7). Locations mentioned in Figure 7 are depicted in Figure 8.

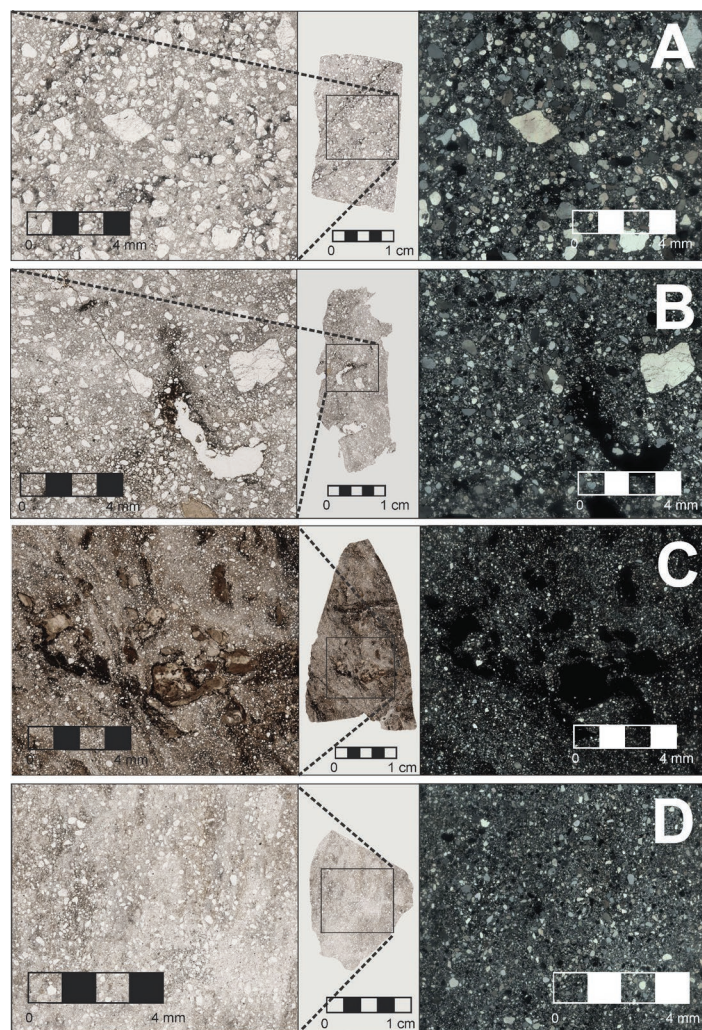


Figure 7. Thin sections (A through D) under normal (left) and cross polarized light (right). A: BRS from Quarry of Ancestors (HhOv-319). Coarse sandstone with subangular to rounded grains, poorly sorted with a fine cemented matrix. Dark grey streaks may represent organic-enriched zones, possibly plant-root traces. B: BRS from Beaver River Quarry (HhOv-29). Dominantly medium grain sandstone with outsize granules, poorly sorted with a fine cemented matrix. Organic enriched zone accompanied by variations in grain-size and sorting interpreted as a plant-root trace. C: TRSS sample from Montana (Montana Group One). Potentially bioturbated and plant-root modified sedimentary fabric with amorphous silica cement following some of those fabrics. D: Upper fine to medium grained orthoquartzite from Carter County, Montana (Montana Group Four). Admixed sedimentary fabric is ascribed to bioturbation.

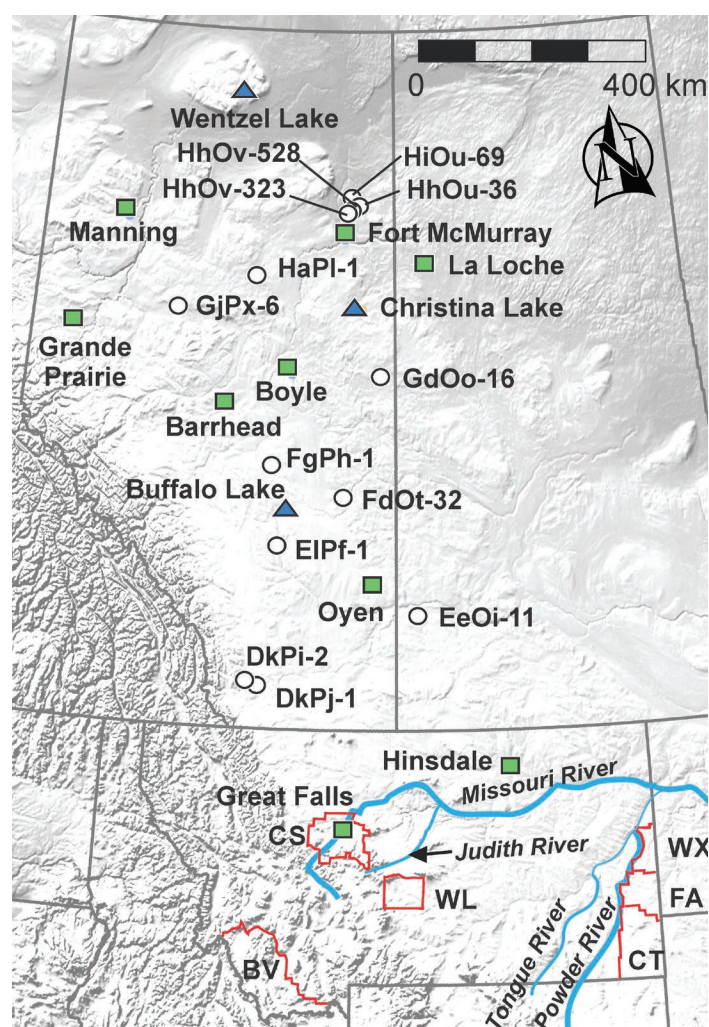


Figure 8. Place names mentioned in text. BV: Beaverhead County, CS: Cascade County, WL: Wheatland County, WX: Wisaux County, FA: Fallon County, CT: Carter County.

The detrital grain size is variable, ranging from coarse siltstone to coarse sandstone. Some meniscate trace fossils (e.g., *Taenidium*) and open trace fossils (e.g., *Scoyenia*) occur; these trace fossils are ascribed to the activities of burrowing insects and insect larvae. Plant root traces are also visible (Figure 7).

Tsang (1998) suggested that silicification of the proto-BRS sediments occurred within a karst feature associated with silica-saturated connate water. Based on rhenium-osmium radiometric dating, Selby and Creaser (2005) suggested an age of 112 ± 5.3 Ma (million years ago) for the age of hydrocarbon emplacement in the McMurray Formation. In this scenario, placement of the hydrocarbon occurred not long after deposition of the McMurray sediments. Hence, silicification of the McMurray Formation as the origin of the BRS must have occurred close to the age of deposition of the McMurray sands and prior to hydrocarbon placement. Considering the presence of insect-associated trace fossils

and root traces, we further suggest that cementation occurred in these topographic lows as an evaporative silcrete. That is, when silica-rich water evaporated, the remnant silica cemented the interstices of siltstone and sandstone matrices.

5. Identification of Beaver River Sandstone

In order to identify BRS, it is necessary to not only determine its specific features but also examine how it differs from similar materials.

5.1 Distinguishing macroscopic features of Beaver River Sandstone

BRS is an opaque dull grey to mottled tan or buff stone that varies from medium to fine grained in texture (Figures 9-11). The material often has a faint sheen when viewed with a hand lens or microscope. Most specimens of BRS contain noticeably large angular quartz crystal inclusions in an otherwise uniformly fine-grained matrix. This is less noticeable in BRS from Beaver River Quarry than it is in BRS from Quarry of the Ancestors. The visible crystal inclusions generally range from 0.1 to 1 millimetre in diameter. Faint colour banding is visible in some specimens as is occasional orange iron staining (Fenton and Ives 1982). Some specimens also have black bitumen staining/colouration. Heat-treated varieties are noticeably reddened. As mentioned, BRS from Beaver River Quarry is coarser grained than from Quarry of the Ancestors but exhibits a similar range of colour and mottling.

For those interested in raw material comparisons, current repositories of BRS include the Royal Alberta Museum (Edmonton), the Archaeological Survey of Alberta (Edmonton), the Prince of Wales Northern Heritage Centre (Yellowknife), the Yukon Cultural Services Branch (Whitehorse), and the Manitoba Museum (Winnipeg).

5.2 Similar Materials to Beaver River Sandstone

BRS can resemble tan or grey cherts (Figures 12 to 16) and rhyolites (Figure 17). Coarse-grained varieties of BRS can be easily mistaken for other orthoquartzites including a particular group of materials variously called Montana Silicified Sediment, Tongue River Silicified Sediment (TRSS), Montana orthoquartzites, and Dakota Sandstone (Gryba, in press). Figures 12 to 18 depict BRS and similar-looking raw materials with captions to explain discriminating features.

The visual overlap between BRS and Montana materials is uncanny and has led to misidentification. Figure 19 compares microscopic structures of BRS from Beaver River Quarry and Quarry of the Ancestors with Montana TRSS

and orthoquartzite. We initiated PXRF analyses to assess geochemical differences between BRS and Montana raw materials. An introduction to Montana toolstones is provided below followed by a summary of the pXRF program.

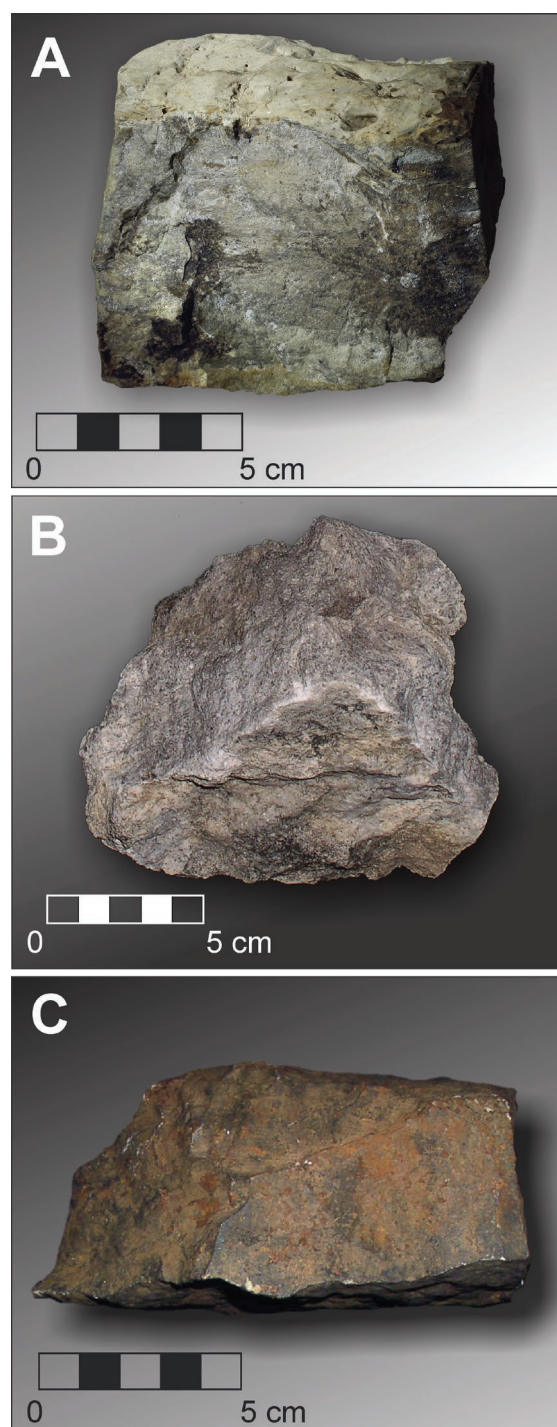


Figure 9. Outcrop cobbles from Beaver River Quarry (A) (Royal Alberta Museum, Edmonton, Alberta) coarse-grained BRS from Quarry of the Ancestors (B) (Department of Archaeology and Anthropology, University of Saskatchewan, Saskatoon, Saskatchewan), and fine grained BRS from Quarry of the Ancestors (C) (Department of Archaeology and Anthropology, University of Saskatchewan, Saskatoon, Saskatchewan).

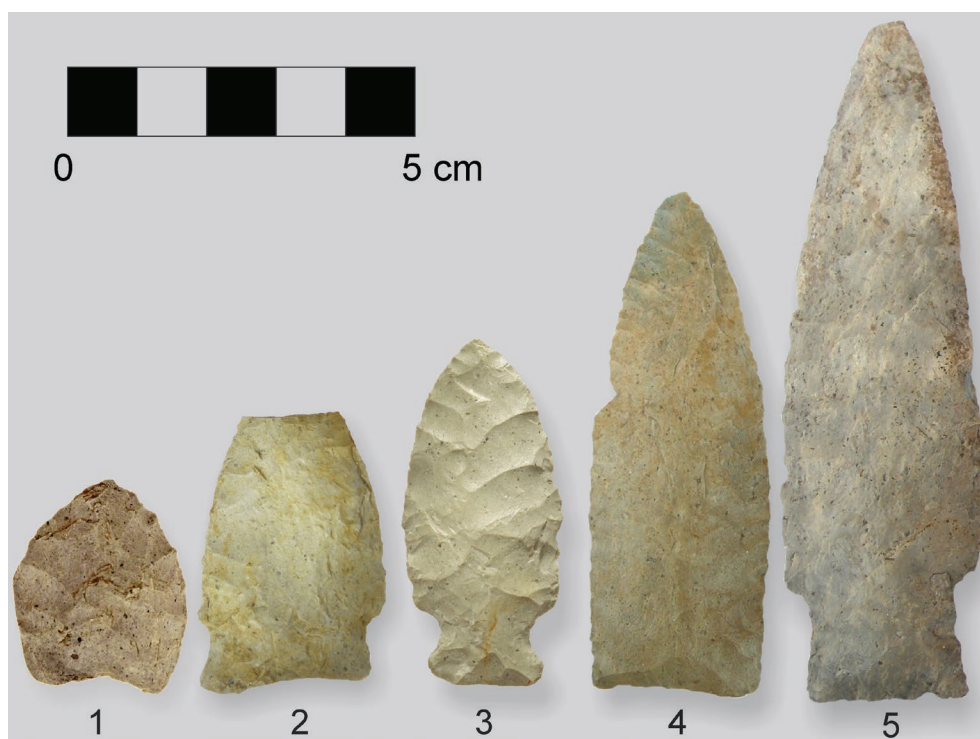


Figure 10. Artifacts of BRS. 1: GdOo-16:1 (possible fluted point from the Duckett Collection, Cold Lake area, eastern Alberta); 2: HiOu-69:1 (Royal Alberta Museum, Edmonton, Alberta, photograph courtesy of the Royal Alberta Museum); 3: HhOv-528:409722 (Royal Alberta Museum, Edmonton, Alberta, photograph courtesy of Karen Giering); 4: HhOv-323 (Broad bladed Eden point, Royal Alberta Museum, Edmonton, Alberta, photograph courtesy of Nancy Saxberg); 5: HhOu-36:150 (Scottsbluff II point, Royal Alberta Museum, Edmonton, Alberta, photograph courtesy of Nancy Saxberg). Projectile point type labels for artifact numbers 3, 4, and 5 taken from Reeves et al. 2015.



Figure 11. BRS points with mottling and large quartz crystal inclusions (visible as light and dark grey specks). The point at left is from the Alexander collection found on Flat Lake near Boyle, north central Alberta. The point at right is from the Stettler Town and Country Museum, and was found near Buffalo Lake, South Central Alberta (no catalogue numbers). Microscopic analysis and pXRF confirm that both points are within the variability of BRS from QoA/BRQ.

5.2.1 Montana TRSS/orthoquartzite

Until recently, the primary source area for arenaceous silicified sediment (composed of fine to medium-grained sand cemented by silica) was believed to be southeast Montana, southwest North Dakota, and northwest South Dakota. This distinctive gray to tan colored, high quality lithic raw material was originally designated as Tongue River Silicified Sediment (TRSS) in reference to the geologic formation in which it occurs (Keyser and Fagan 1987). Specific to Montana, TRSS is largely restricted to Carter (CT), Fallon (FA), and Wibaux (WX) Counties (Figure 8) and does not extend west to either the Powder or Tongue River Basins (Clark and Fraley 1985; Deaver and Deaver 1988). It does, however, extend east as far as central Minnesota and north-central Iowa (Bakken 1993).

TRSS in primary geological context has not been identified in southeastern Montana. Instead, most of this material occurs in the form of eroded and intermittent lag deposits where pebbles, cobbles, boulders, and subangular blocky pieces are scattered throughout the local sediments over a fairly large geographic area. Thus, most or all of the TRSS from southeastern Montana utilized in stone tool manufacture was probably opportunistically collected as the material was randomly encountered.



Figure 12. BRS point from the Alexander collection (no catalogue number), found on Flat Lake near Boyle in north central Alberta. This point geochemically lies within the variability of group QoA/BRQ.

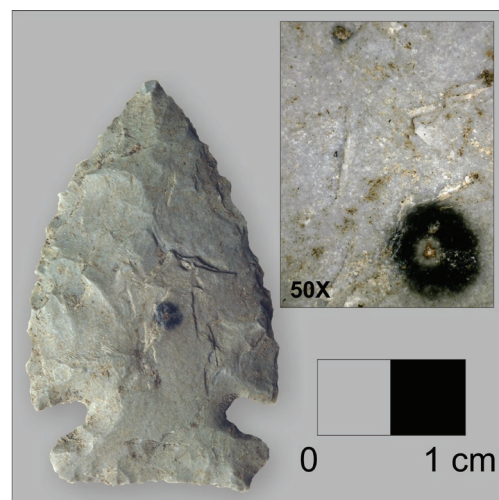


Figure 15. Grey cherts can resemble BRS but are often uniform, fine-grained, and lack large crystals, although cherts may contain microfossils as above (DkPi-2:4535, Royal Alberta Museum, Edmonton, Alberta).



Figure 13. BRS point from the Johnston collection (no catalogue number) found near Oyen, southeast Alberta. This point geochemically lies within the variability of group QoA/BRQ.



Figure 16. This point is likely of Potters Chert from Texas, which can resemble the mottling of BRS. It is generally fine-grained and lacks large crystals, although it can contain dark microfossils (collected in Texas and housed in the Sodbusters Archives and Museum, Strome, Alberta).

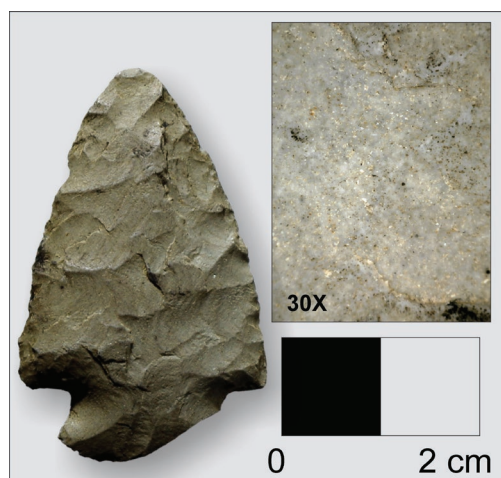


Figure 14. Tan cherts can resemble BRS but they are generally uniform, fine-grained, and lack large crystals, although cherts may contain microfossils (no catalogue number, Johnston collection).

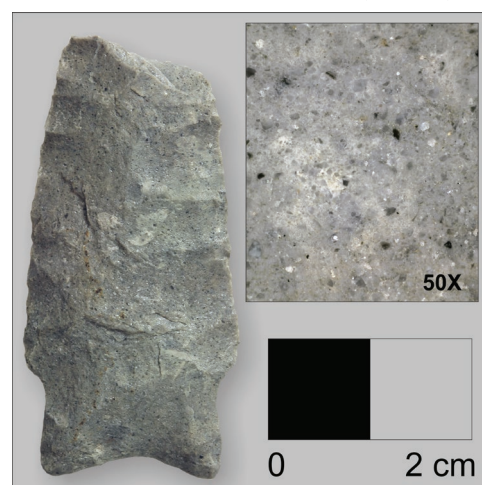


Figure 17. Glassy rhyolite can superficially resemble BRS but is generally coarse-grained with abundant variable-sized phenocrysts (FgPh-1, no catalogue number, Royal Alberta Museum, Edmonton, Alberta).

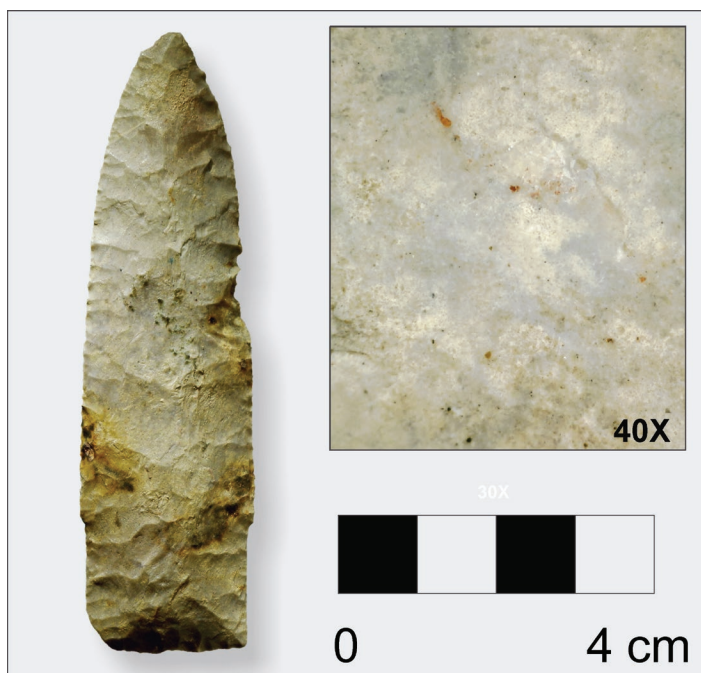


Figure 18. TRSS can strongly resemble BRS both macroscopically and microscopically. Geochemical analyses such as pXRF may be the only means to distinguish some varieties of TRSS from BRS (artifact from the Heron-Eden site, EeOi-11, southwest Saskatchewan). This point geochemically lies within Montana Group One.

Over the past three decades, additional source areas of TRSS-like material (here called Montana orthoquartzites) have been identified in the central portion of Montana (Aaberg 1992). As is the case for southeastern Montana, the central Montana sources are largely eroded deposits scattered over sizeable areas. However, at least three primary bedrock exposures have been reported. One is southeast of Great Falls in the Stockett/Centerville locality. The other is adjacent to the Missouri River northeast of Great Falls. A third is in the Beaver Creek headwaters of the Little Rocky Mountains north of Missouri River and west of Hinsdale.

The frequency with which this material occurs in archaeological contexts in Montana is not well established. The primary reason for this is because researchers have used a variety of descriptors including “orthoquartzite” (Brumley 1990), “silcrete” (Murphy 2014), “silicified sediment” (Greiser 1988), and “Kootenai Silicified Sediment” (Aaberg 1992). Based on a limited review of central and northern Montana artifact collections, and the available literature, TRSS-like lithic raw material was more heavily utilized by Avonlea groups (Figure 20) from the greater Judith Basin area north and east as far as Saco/Hinsdale (Figure 19) than by all other archaeological cultures combined (Rennie and Taylor 2015).

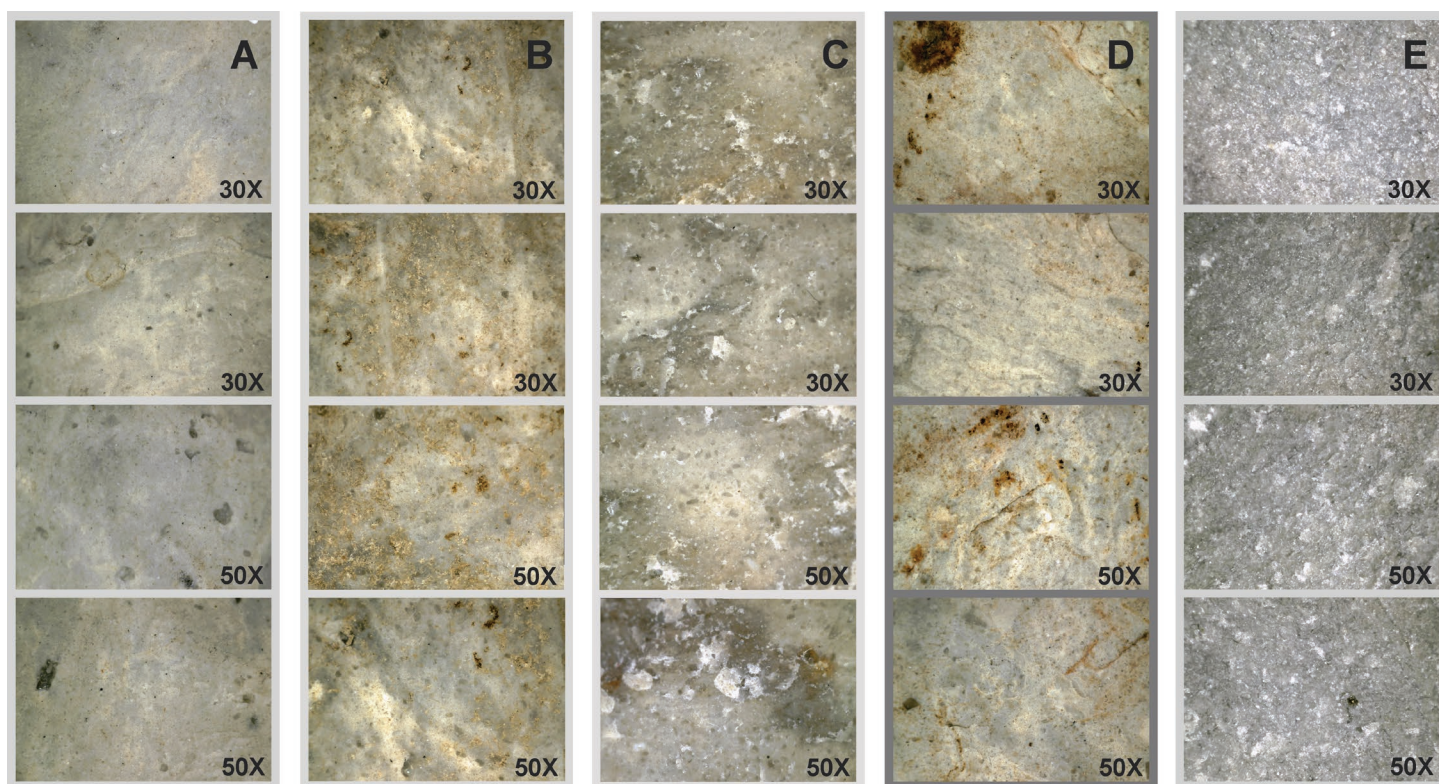


Figure 19. Microscope images of fine grained Beaver River Sandstone from: A: Quarry of the Ancestors; B: coarse grained Beaver River Sandstone from Beaver River Quarry; C: Carter County orthoquartzite (Montana Group 3); D: Tongue River Silicified Sediment (Montana Group 1); and E: Carter County orthoquartzite (Montana Group 4).

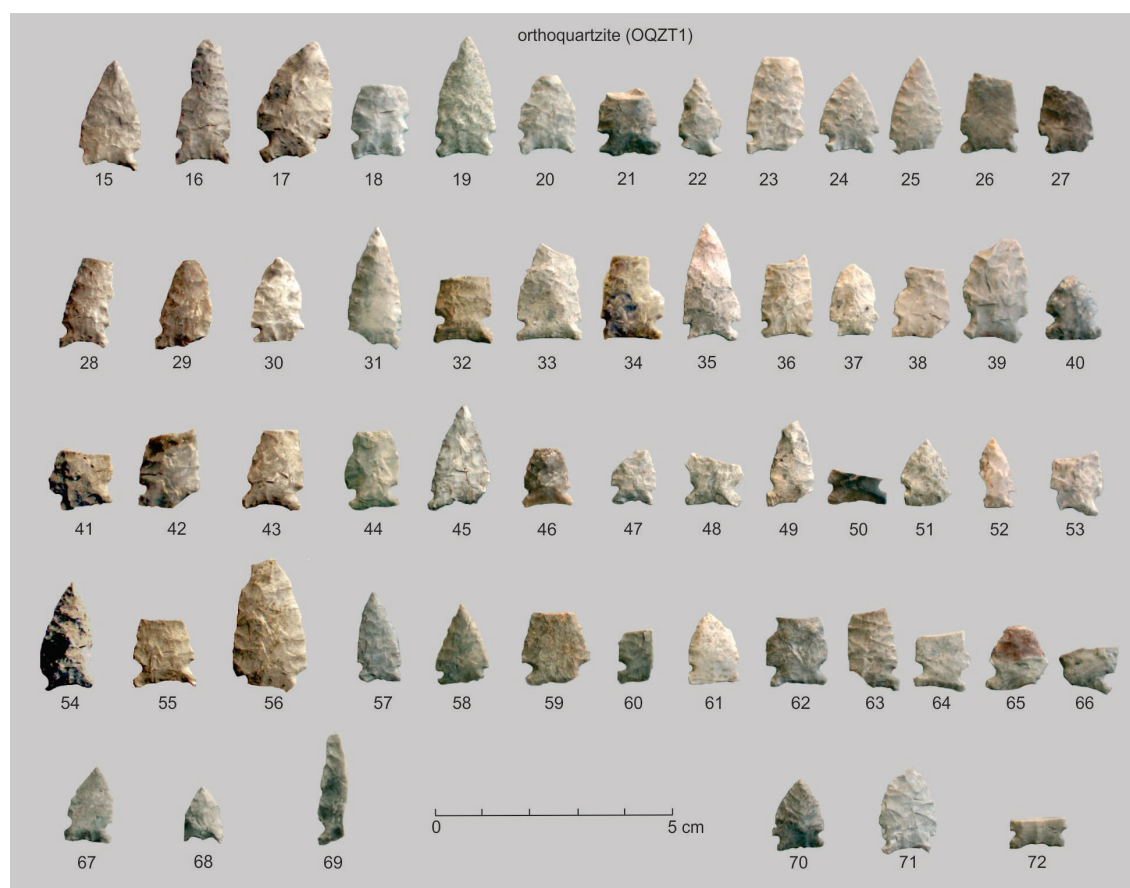


Figure 20. Orthoquartzite projectile points from site 24BL101 in Montana.

Of interest, Keyser and Fagan (1987) noted that the dominant period of TRSS procurement at the ESP site in northwestern South Dakota occurred ca. A.D. 1000—thus showing possible coeval preference for this silicified sediment in two distinct geographic localities.

5.3 Portable X-ray fluorescence program

Non-destructive pXRF analyses were conducted on 36 samples of Beaver River Sandstone from Quarry of the Ancestors, three samples from Beaver River Quarry, 29 samples of orthoquartzites, rhyolite, and TRSS from Montana: six orthoquartzite samples from Wheatland County, nine orthoquartzite samples from Cascade County, four rhyolite samples from Beaverhead County, six orthoquartzite samples from Carter County, and four samples of “Montana Silicified Sediment” and TRSS from across Montana (Table 1). An additional 14 artifacts of BRS-looking material from across Alberta, Saskatchewan, and Montana, were analysed in this pilot project.

5.3.1 Methods

Analyses were conducted at the University of Georgia’s Center for Applied Isotope Studies (CAIS). A Bruker Tracer

Series III, portable X-ray fluorescence spectrometer (pXRF) was used for the analyses. The instrument is equipped with an X-ray tube consisting of a rhodium (Rh) target and a beryllium (Be) window. The tube is capable of reaching 40kV at 30μA, an energy more than adequate to exceed the ionization potentials required to measure the trace elements of interest in this study. The instrument uses a silicon drift detector (SDD) with a resolution of ca. 145 eV.

Prior to analysis, samples with flat, smooth areas were chosen as the low angle and lack of surface variation would produce the least amount of surface scatter upon contact with the X-ray beam. If a sample did not have an acceptable surface and/or minimum size, it was not analyzed.

Analytical protocols employed at CAIS are summarized in Table 2. Each sample was analyzed for 100 seconds at 40kV and 30μA. A primary filter (0.006” Cu, 0.001” Ti, 0.012” Al filter) designed to reduce background radiation within the mid-Z elemental range was placed in-line between the tube and sample. Elements measured in the study include manganese (Mn), iron (Fe), zinc (Zn), gallium (Ga), rubidium (Rb), strontium (Sr), yttrium (Y), zirconium (Zr), niobium (Nb), and thorium (Th).

Table 1. Summary of pXRF results. QoA/BRQ : Quarry of the Ancestors and Beaver River Quarry. Montana Group 1: Cascade and Wheatland Counties, Montana Group 2: Beaverhead County, Montana Group 3: Carter County sample A, Montana Group 4: Carter County sample B.

Sample #	Nature of Sample	Comments	Fe	Ga	Rb	Sr	Y	Zr	Nb	Geochemical group based on pXRF results
1	Artifact	EeDI-11, projectile point, Eden-Heron site, SK	1504	10	6	61	24	457	37	Montana Group 1
2	Artifact	EeDI-11, projectile point, Eden-Heron site, SK	1336	10	6	67	17	281	28	Montana Group 1
3	Artifact	HgOv-29, Beaver River Quarry, NE AB	3189	10	8	8	18	433	21	QoA/BRQ
4	Artifact	HhOv-66, NE AB	1259	7	6	7	14	362	16	Unassigned
5	Artifact	No site #, near Beaver River Quarry, NE AB	925	8	5	6	14	361	15	Unassigned
6	Artifact	No site #, near Beaver River Quarry, NE AB	908	10	5	6	14	371	15	Unassigned
7	Artifact	HhOv-319, Quarry of the Ancestors, NE AB	1133	9	5	12	24	471	24	QoA/BRQ
8	Artifact	HhOv-319, Quarry of the Ancestors, NE AB	1632	7	7	13	17	375	19	QoA/BRQ
9	Artifact	HhOv-319, Quarry of the Ancestors, NE AB	2486	8	6	12	28	490	29	QoA/BRQ
10	Artifact	HhOv-319, Quarry of the Ancestors, NE AB	1844	10	6	16	28	480	31	QoA/BRQ
11	Artifact	HhOv-319, Quarry of the Ancestors, NE AB	1882	8	6	12	23	502	26	QoA/BRQ
12	Artifact	HhOv-319, Quarry of the Ancestors, NE AB	1128	12	7	12	25	522	24	QoA/BRQ
13	Artifact	HhOv-319, Quarry of the Ancestors, NE AB	2209	10	7	8	25	458	26	QoA/BRQ
14	Artifact	HhOv-319, Quarry of the Ancestors, NE AB	2235	11	7	8	21	517	23	QoA/BRQ
15	Artifact	HhOv-319, Quarry of the Ancestors, NE AB	1288	8	5	12	26	472	28	QoA/BRQ
16	Artifact	HhOv-319, Quarry of the Ancestors, NE AB	1998	11	6	8	25	514	27	QoA/BRQ
17	Artifact	HhOv-319, Quarry of the Ancestors, NE AB	1136	10	6	8	20	539	23	QoA/BRQ
18	Artifact	HhOv-319, Quarry of the Ancestors, NE AB	1303	9	6	8	20	534	27	QoA/BRQ
19	Artifact	HhOv-319, Quarry of the Ancestors, NE AB	1171	11	6	10	21	518	27	QoA/BRQ
20	Artifact	No site number, Montana	1111	9	6	74	21	356	18	Montana Group 1
21	Artifact	HhOv-319, Quarry of the Ancestors, NE AB	1604	9	5	11	28	503	29	QoA/BRQ
22	Artifact	HhOv-319, Quarry of the Ancestors, NE AB	1305	10	7	12	27	501	30	QoA/BRQ
23	Artifact	HhOv-319, Quarry of the Ancestors, NE AB	1976	9	6	19	27	443	35	QoA/BRQ
24	Artifact	HhOv-319, Quarry of the Ancestors, NE AB	1423	10	7	14	26	422	28	QoA/BRQ
25	Artifact	HhOv-319, Quarry of the Ancestors, NE AB	1495	14	6	8	23	558	27	QoA/BRQ
26	Artifact	HhOv-319, Quarry of the Ancestors, NE AB	1730	8	6	7	22	506	25	QoA/BRQ
27	Artifact	HhOv-319, Quarry of the Ancestors, NE AB	1170	11	5	9	23	562	27	QoA/BRQ
28	Artifact	HhOv-319, Quarry of the Ancestors, NE AB	1395	9	6	7	21	547	23	QoA/BRQ
29	Artifact	HhOv-319, Quarry of the Ancestors, NE AB	1479	12	5	9	24	584	26	QoA/BRQ
30	Artifact	HhOv-319, Quarry of the Ancestors, NE AB	1857	13	4	12	24	502	30	QoA/BRQ
31	Artifact	HhOv-319, Quarry of the Ancestors, NE AB	1108	11	6	8	20	544	23	QoA/BRQ
32	Artifact	No site #, Johnston collection, Oyen, SE AB	37537	23	125	78	34	170	15	Chert
33	Artifact	HhOv-319, Quarry of the Ancestors, NE AB	6715	13	7	18	28	497	33	QoA/BRQ
34	Artifact	HhOv-319, Quarry of the Ancestors, NE AB	1154	10	4	8	17	306	20	Unassigned
35	Artifact	No site #, Stettler Museum, C AB	1090	12	5	7	23	485	27	QoA/BRQ
36	Artifact	No site #, Alexander collection, Boyle, N AB	1629	10	6	8	20	404	28	QoA/BRQ
37	Artifact	No site #, Alexander collection, Boyle, N AB	1424	11	6	10	30	571	35	QoA/BRQ
38	Artifact	Quarry of the Ancestors h:97.69.933, NE AB	1206	10	6	18	26	413	27	QoA/BRQ
39	Artifact	HhOv-319, Quarry of the Ancestors, NE AB	1326	13	5	6	18	502	21	QoA/BRQ
40	Artifact	HhOv-319, Quarry of the Ancestors, NE AB	1904	15	7	10	25	594	30	QoA/BRQ
41	Artifact	HhOv-319, Quarry of the Ancestors, NE AB	1210	12	6	7	21	617	20	QoA/BRQ
42	Artifact	HhOv-319, Quarry of the Ancestors, NE AB	1184	13	5	7	21	549	23	QoA/BRQ
43	Artifact	HhOv-319, Quarry of the Ancestors, NE AB	2693	11	6	18	31	472	35	QoA/BRQ
44	Artifact	HhOv-319, Quarry of the Ancestors, NE AB	1471	16	5	15	30	602	35	QoA/BRQ
45	Artifact	HhOv-319, Quarry of the Ancestors, NE AB	2686	15	6	15	30	591	31	QoA/BRQ

Table 1. (continued)

Sample #	Nature of Sample	Comments	Fe	Ga	Rb	Sr	Y	Zr	Nb	Geochemical group based on pXRF results
46	Artifact	HhOv-319, Quarry of the Ancestors, NE AB	2305	9	6	8	21	484	21	QoA/BRQ
47	Artifact	HhOv-319, Quarry of the Ancestors, NE AB	1264	16	6	9	22	538	28	QoA/BRQ
48	Geological	Wheatland County, Montana	1473	13	6	91	22	435	25	Montana Group 1
49	Geological	Wheatland County, Montana	1155	15	6	80	24	487	28	Montana Group 1
50	Geological	Wheatland County, Montana	3041	10	6	47	20	447	23	Montana Group 1
51	Geological	Wheatland County, Montana	3029	14	7	55	22	487	23	Montana Group 1
52	Geological	Wheatland County, Montana	1086	11	6	38	17	428	19	Montana Group 1
53	Geological	Wheatland County, Montana	1006	9	6	44	21	429	22	Montana Group 1
54	Geological	Carter County, Montana	9648	15	98	26	33	217	27	Montana Group 3
55	Geological	Carter County, Montana	1557	12	7	18	19	513	15	Montana Group 4
56	Geological	Carter County, Montana	936	8	4	8	17	449	12	Montana Group 4
57	Geological	Carter County, Montana	8343	18	92	22	29	192	22	Montana Group 3
58	Geological	Carter County, Montana	8915	14	85	21	29	182	21	Montana Group 3
59	Geological	Carter County, Montana	1028	8	5	9	18	445	16	Montana Group 4
60	Geological	Cascade County, Montana	1142	16	6	53	8	112	13	Montana Group 1
61	Geological	Cascade County, Montana	1182	12	6	75	7	81	11	Montana Group 1
62	Geological	Cascade County, Montana	980	9	5	49	8	95	12	Montana Group 1
63	Geological	Cascade County, Montana	37624	16	8	119	9	100	12	Unassigned (cortex contamination)
64	Geological	Cascade County, Montana	1187	10	5	60	8	91	11	Montana Group 1
65	Geological	Cascade County, Montana	1003	11	5	67	8	89	10	Montana Group 1
66	Geological	Cascade County, Montana	1123	15	7	61	18	446	22	Montana Group 1
67	Geological	Cascade County, Montana	999	11	6	58	13	281	14	Montana Group 1
68	Geological	Cascade County, Montana	1340	14	7	86	27	490	32	Montana Group 1
69	Geological	Cascade County, Montana	1019	9	6	74	17	368	17	Montana Group 1
70	Geological	Beaverhead County, Montana	1459	21	193	16	41	350	38	Montana Group 2
71	Geological	Beaverhead County, Montana	1398	21	167	17	35	329	52	Montana Group 2
72	Geological	Beaverhead County, Montana	1387	23	188	16	40	341	37	Montana Group 2
73	Geological	Beaverhead County, Montana	1442	19	179	18	38	322	35	Montana Group 2
74	Geological	Montana	1567	14	8	75	31	424	36	Montana Group 1
75	Geological	Montana	1744	15	5	49	23	543	23	Montana Group 1
76	Geological	Montana	1564	14	7	50	23	504	18	Montana Group 1
77	Artifact	No site #, Johnston collection, Oyen, SE AB	1775	12	7	19	34	528	28	QoA/BRQ
78	Artifact	No site #, Johnston collection, Oyen, SE AB	1212	6	5	7	26	452	31	QoA/BRQ
79	Artifact	Montana	1161	11	7	83	25	458	24	Montana Group 1
80	Artifact	FdOt-32, flake, Hardisty, E AB	2107	11	6	9	23	409	26	QoA/BRQ
81	Artifact	No site #, Renynolds collection, C AB	1439	9	6	12	17	295	14	Rhyolite
82	Artifact	No site #, Alexander collection, Boyle, N AB	1458	9	6	11	24	447	24	QoA/BRQ

The calibration used here was originally developed for analysis of obsidians and other silicate rocks. The calibration was created using a set of obsidian standards commissioned from the University of Missouri Research Reactor (MURR) (see Speakman and Shackley 2013). These reference materials consist of 40 pieces of obsidian that characterize a suitable range of elemental variation for most rhyolitic obsidians as well as the samples in this study.

Following analysis, data were tabulated in Excel. Initial examination of the data determined that values for Mn, Zn, and Th were at or below detection limits in most samples. Consequently, these elements were removed from the dataset. The elemental results were compared using Mahalanobis distance probabilities and posterior classifications, and visualized through principal component analysis.

Table 2. CAIS protocols for analyzing trace elements in rhyolitic obsidians.

Bruker Tracer III	
Filter:	12mil. Al: 1mil. Ti: 6mil. Cu (Green Filter)
Energy and Current:	40kV/30µA
Environment:	Open air, no vacuum
Calibration:	40 MURR RM's
Live Time (seconds):	100s
Elements Measured:	Mn, Fe, Zn, Ga, Rb, Sr, Y, Zr, Nb, Th

5.3.2 Geochemical results and significance

Comparisons of trace element concentrations, including rubidium (Rb), strontium (Sr), yttrium (Y), niobium (Nb), and zirconium (Zr), are useful for differentiating BRS from similar-looking materials (Figures 21-24). Sample sizes are admittedly small but preliminary results depict generally distinct geochemical clusters: Montana Group 1 consists of samples from Cascade and Wheatland Counties as well as several samples of Tongue River Silicified Sediment (TRSS) whose provenience in Montana was not known; Montana Group 2 includes samples from Beaverhead County; Montana Group 3 consists of three samples from Carter County; Montana Group 4 contains three additional samples from Carter County; and the final geochemical cluster encompasses samples from Quarry of the Ancestors (QoA) and Beaver River Quarry (BRQ). Three orthoquartzite samples from Carter County (Montana Group 4) lie partially within the geochemical variability of BRS (e.g., when comparing rubidium and strontium). However, these Carter County samples can be distinguished geochemically through a comparison of niobium and zirconium (Figure 24) and do not visually overlap with BRS (macroscopically or microscopically).

The most macroscopically and microscopically similar materials to BRS (i.e., TRSS) can be clearly distinguished through geochemical comparisons via pXRF; all samples of TRSS were found to lie within Montana Group 1. The current study indicates that Eden points from Saskatchewan that had been previously labeled as BRS (Linnamae and Johnson 1999) were in fact TRSS. A Clovis point from the Duckett site (GdOo-16; Figure 10) that has been called BRS may be made of TRSS from Montana or the Dakotas and should be analysed via pXRF.

As noted above, a sample of orthoquartzite from Carter County (Montana Group 4) is more difficult to discern geochemically from BRS, but is macroscopically and microscopically distinct. The Carter County orthoquartzites are of a more vitreous lustre than BRS with coarse texture and foliation planes typical of quartzites (Figure 19).

The matrix of the most common BRS artifacts appears macroscopically uniform in texture, like chert, while the matrix of Carter County materials appears irregular like common metaquartzites. Lastly, the orthoquartzite samples that compose Montana Group 4 are uniform grey and lack the mottling of BRS and TRSS.

The current pXRF pilot study also found that artifacts previously assumed to be TRSS from southern Alberta are BRS (including an Eden point from the Oyen area depicted in Figure 14). The widespread movement of BRS to southern Alberta should not be surprising. What is thought to be Knife River Flint Scottsbluff material has been recovered near Fort McMurray and Manning, while obsidian from the Grande Prairie and Fort McMurray areas has been sourced to Idaho and Wyoming.

Materials variously called Montana Silicified Sediment, Tongue River Silicified Sediment, and some material labeled as Montana orthoquartzites (those from Cascade and Wheatland Counties) all cluster geochemically within Montana Group 1 (see Figure 23). This suggests either that there are distinct Montana materials that are not distinguishable geochemically or that materials once thought of as distinct are actually the same material (or at least related in terms of geological formation).

In summary, we suggest that pXRF can verify if a BRS-looking material is from northeast Alberta or Montana/Dakotas area. To date, pXRF cannot easily distinguish between materials from northeast Alberta and some orthoquartzites from Carter County, Montana; however, if pXRF analyses narrow down the material in question to these two sources, basic macroscopic and microscopic work can lead to successful differentiation. This small geochemical study highlights the need for further work and the need to exercise caution concerning macroscopic identification of raw materials in Alberta regardless of their geographic proximity to presumed sources.

6. Archaeological significance of Beaver River Sandstone

BRS is one of the few raw materials in archaeological assemblages in Alberta with a known origin north of the Great Plains and outside of the Rocky Mountains. Tracing the use of this material through space and time can therefore serve as a proxy for cultural relationships between inhabitants of northeastern Alberta and other regions. The material is also useful for studying the full breadth of the lithic reduction sequence from procurement to retouch, and for gaining understanding of lithic technologies such as heat treatment.

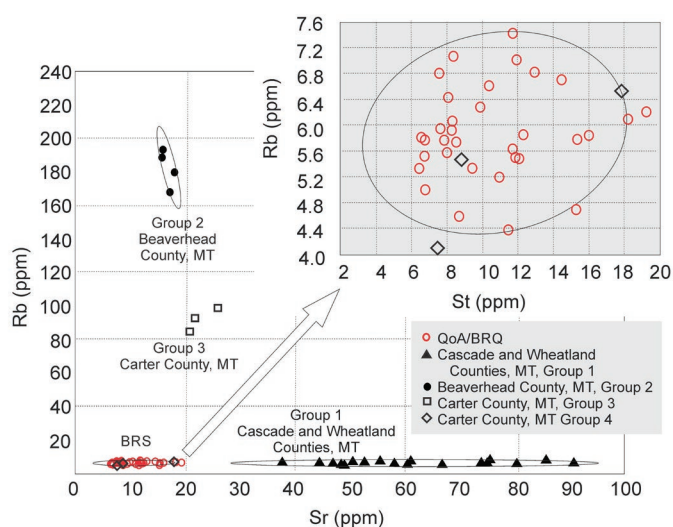


Figure 21. Bivariate plot of pXRF results showing cluster of BRS material with inset depicting overlap of Group 4 Carter County samples (of rubidium and strontium levels with 95% confidence ellipses). Note the clear separation of BRS/Carter County Group 4 from the three remaining sample groups. All specimens are raw materials.

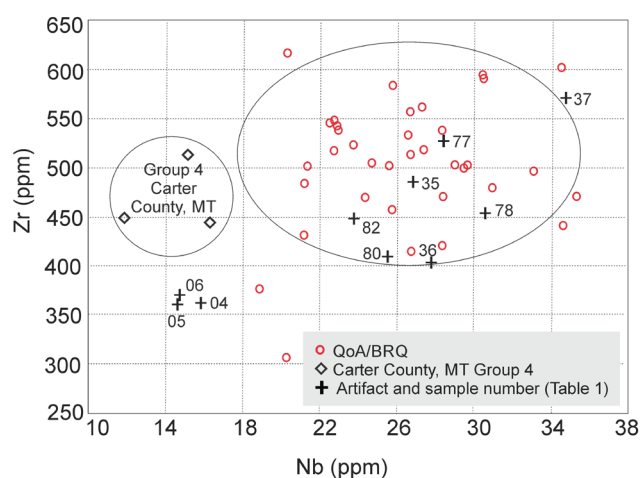


Figure 22. Bivariate plot of pXRF results displaying distinction between Group 4 Carter County samples and BRS (with 95% confidence ellipses).

6.1 Geographic distribution

BRS is one of the most archaeologically well-known and most heavily utilized toolstones in northern Alberta. Only limited attempts have been made to systematically map BRS artifact distribution (Blower 2008; Martindale 2014), but they are found over a large area across northeast Alberta and Saskatchewan (Figure 25). As of 2016, 956 archaeological sites in Alberta have reported BRS artifacts. An ongoing project has identified over 3.8 million BRS artifacts recovered from these sites with a combined weight of over 8000 kg. Although concentrated most densely around Quarry of the Ancestors and the Fort Hills, BRS is also common in the Birch Mountains, along Clearwater River, and at La Loche in northwest Saskatchewan (Figure

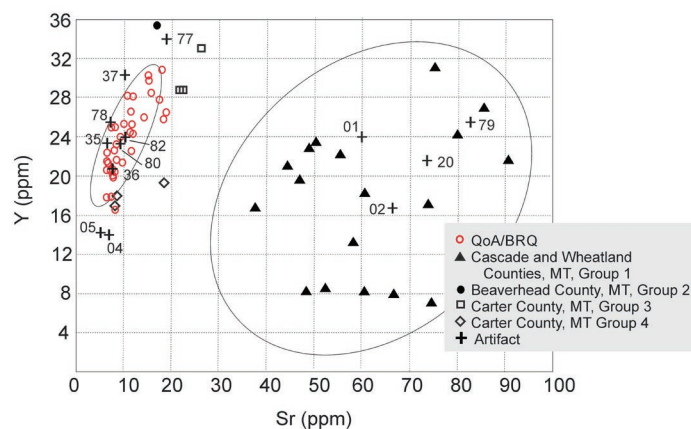


Figure 23. Bivariate plot depicting distinction of BRS and Group 1 Cascade and Carter County samples in relation to Carter County Groups 3 and 4 (in a comparison of yttrium and strontium with 95% confidence ellipses).

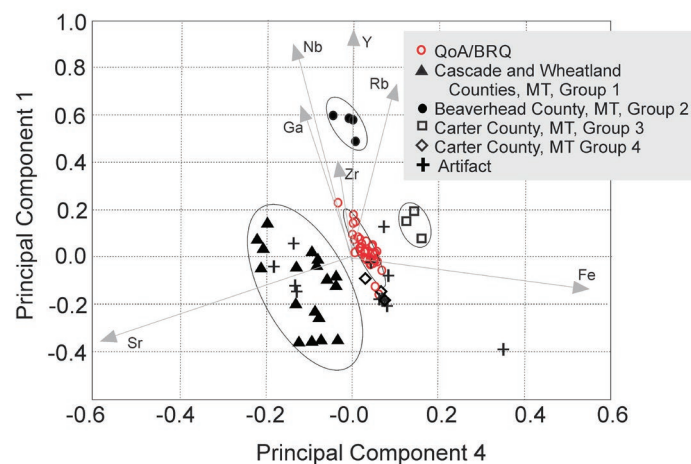


Figure 24. Principle Component Analysis depicting segregation of geochemical data from raw material groups.

8) (Fenton and Ives 1990; Korejbo 2011; Martindale 2014). Further afield, BRS toolstone has also been visually identified in the archaeological assemblages of Wentzel Lake (Conaty 1977), Slave River (Reeves et al., in press), the Alook site (HaPl-1) on North Wabasca Lake (Sims 1981), Christina Lake, the Duckett site and neighbouring areas near Cold Lake (GdOo-16) (Fedirchuk and McCullough 1986), Barrhead (Fenton and Ives 1990), Hardisty (FdOt-32), the Grande Prairie area, the Thickwood Hills, Boyle, Dry Island Buffalo Jump (EIPf-1), Head-Smashed-In Buffalo Jump (DkPj-1), and Fort Macleod (DkP-2) (Ronaghan 1981) (see Figure 25). Preliminary scanning electron microscopy with energy dispersive X-ray spectroscopy (SEM/EDX) conducted in 2002 suggest that the specimen reported at Dry Island buffalo jump, which is a small triangular point that was found associated with Avonlea materials, is not BRS.

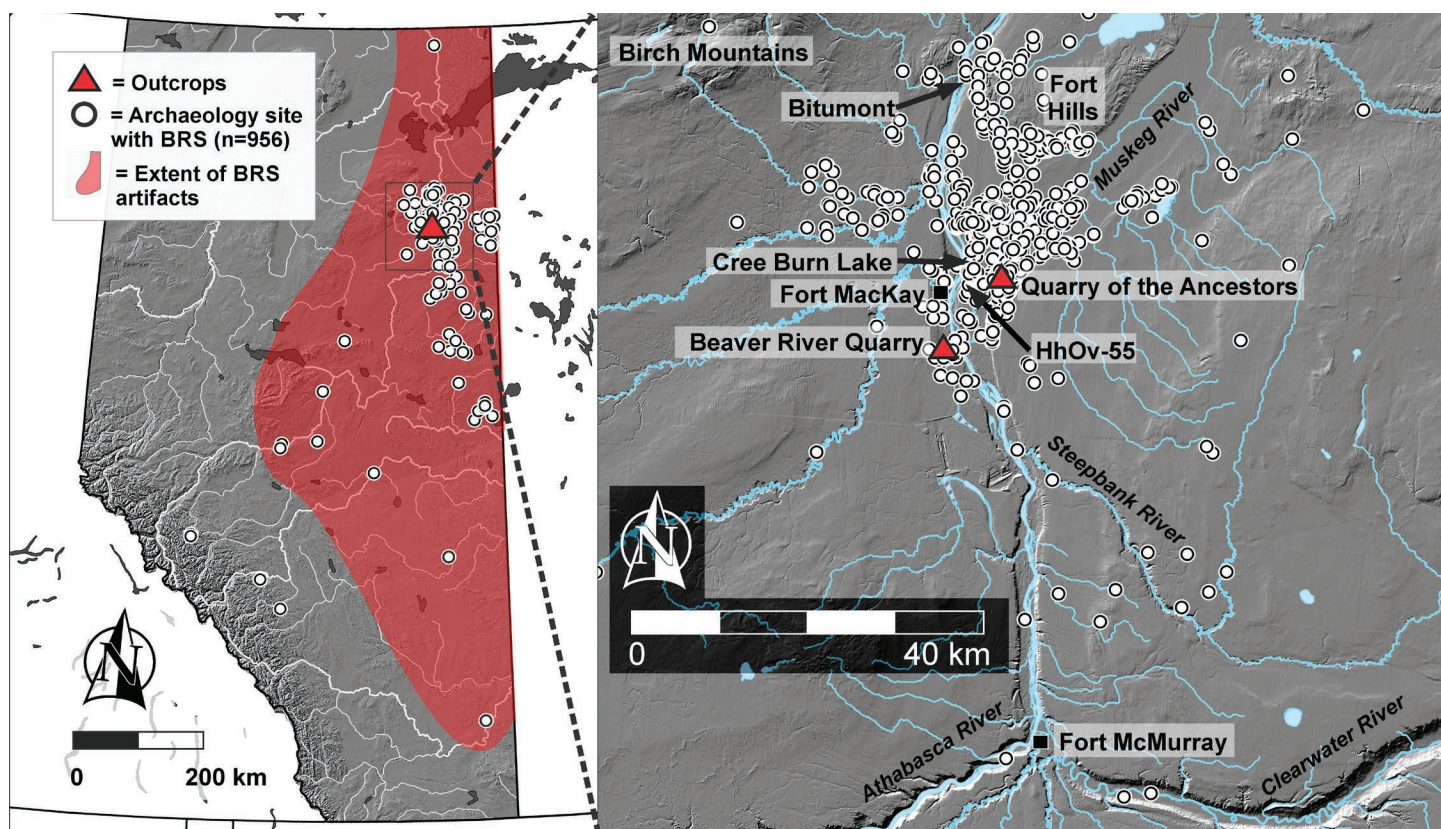


Figure 25. Estimated distribution of Beaver River Sandstone and locations of archaeological sites with recorded Beaver River Sandstone. These sites were retrieved by searching Alberta site forms (as of 2015) for the terms Beaver River Sandstone, Beaver River Silicified Sandstone, Muskeg Valley Silicified Limestone, Muskeg Valley Metamorphosed Quartzite, and their acronyms. Records of BRS in the Eastern Slopes and in Southern Alberta should be treated as tentative until geochemical confirmation.

As noted above, geochemical testing will help verify whether or not other reported examples from sites across the province are actually BRS. This is particularly important for sites in central and southern Alberta. Samples of BRS have been sent to archaeologists in northeast British Columbia, the Prince of Wales Northern Heritage Centre in Northwest Territories and the Cultural Services Branch in Yukon but BRS artifacts have not yet been identified north or west of Alberta's border.

6.2 Temporal distribution

BRS appears to have been used throughout the Holocene. Assuming the quarry sources were initially exposed by the Agassiz flood, use may extend back to the Late Pleistocene. Infrared stimulated luminescence (IRSL) ages on eolian sediments that contain archaeological deposits at Quarry of the Ancestors indicate that the landscape was stabilized by about 10,000 cal yr BP, and that human occupation may have occurred around this time (Woywitka et al. 2013). Accelerated mass spectrometry (AMS) ages are available for 28 sites that have BRS in their assemblage (Woywitka, this volume). Most of these dates are from calcined bone found in association with lithic artifacts. The dates range in age from ca. 8100 to 500 cal yr BP, with the most prominent

concentration between 3000 and 1500 cal yr BP (Woywitka, this volume).

Reeves et al. (in press) have proposed a typological framework for northeastern Alberta, largely based on diagnostic artifacts fashioned from BRS. In this classification, items that bear resemblance to well-dated diagnostic artifacts from adjacent regions (mainly the Great Plains) are assigned similar age ranges in the oil sands region. Thus, lanceolate spear points and Cody knives are assigned early Holocene ages, side notched dart points are attributed middle to late Holocene ages, and notched arrow points have late Holocene ages. Although exhaustive, this framework is not based on direct dates from archaeological sites in northeastern Alberta. Only one site has yielded a date in association with a diagnostic tool; a lanceolate point was recovered in association with calcined bone at HhOv-113 that yielded an age of 7220 ± 40 ^{14}C yr BP (Roskowski-Nuttall 2015; Beta-333309). Given the uncertainty of using typological form as a proxy for age in northern Canada (Hare et al. 2004), the Reeves et al. (in press) framework remains speculative. It does, however, provide an early classification system against which future chronological studies can be tested.

6.3 Heat treatment

Reddish to orange discoloration rinds on BRS artifacts appear on cortex, fractures, and planes of weakness. In some instances, this discoloration has been credited to iron staining in the burial environment. This argument is consistent with the known mobility of iron ions in highly acidic soils of the oil sands region, a phenomenon that often leads to distinctive orange B horizons similar to the hue observed on BRS artifacts. However, it has also been argued that the reddish to orange rinds may reflect deliberate efforts to improve working properties of this raw material through controlled exposure to fire.

This hypothesis has been explored through a series of BRS heat treatment experiments conducted by Gryba (in press) and Robertson and Kevinsen (2013). Gryba used fine and coarse grained BRS samples collected from Beaver River Quarry, Quarry of the Ancestors and from Fort Hills gravel deposits. Robertson and Kevinsen concentrated on fine grained samples from Quarry of the Ancestors, but experimented with coarser varieties. Both sets of experiments involved heating BRS for up to a full day at up to 500 to 600 degrees Celsius. These conditions produced reddish rinds comparable to archaeological examples, as well as a general trend to improved workability. Gryba noted visible recrystallization and suggested that precontact BRS users may have changed coarse grained to fine grained varieties through heat treatment. Robertson and Kevinsen did not note this effect but observed that some samples underwent substantial improvements in fracture characteristics. A lack of texture change meant that some samples still had no utility for the production of edged implements. Regardless, both sets of experiments suggest that heat treatment of BRS would have improved working characteristics and that the reddish discoloration seen in many archaeological examples is likely the result of this process.

7. Conclusion

Beaver River Sandstone (BRS) is a silicified sedimentary rock from northeast Alberta that appears in archaeological assemblages across the province and into Saskatchewan. Preliminary results of pXRF on BRS suggest that it can be geochemically differentiated from very similar-looking materials from Montana including orthoquartzites and Tongue River Silicified Sediment. Through the combination of pXRF analysis and its relatively distinct macroscopic and microscopic qualities (uniform textured, dull grey or tan matrix with large crystal inclusions) BRS can be readily identified in Alberta assemblages. This toolstone can be a valuable indicator of relationships and movement patterns of Alberta's northern pre-contact people.

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