Comparative Analysis of the Souris Gravel and Sand Deposit, a Precontact Lithic Resource in Southwestern Manitoba

by

Sharon L. Thomson

A Thesis
submitted to the University of Manitoba
in partial fulfillment of the
requirements for the degree of
Master of Arts
in the

Department of Anthropology

Faculty of Graduate Studies
The University of Manitoba
Winnipeg, Manitoba

ISBN 0-612-16334-2

Canada

COMPARATIVE ANALYSIS OF THE SOURIS GRAVEL AND SAND DEPOSIT, A PRECONTACT LITHIC RESOURCE IN SOUTHWESTERN MANITOBA

BY

SHARON L. THOMSON

A Thesis submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements for the degree of

MASTER OF ARTS

Abstract

Gravel deposits in the vicinity of Souris, Manitoba, contain various types of siliceous rock, including chert, agate, quartzite, silicified wood, silicified lignite, and fused shale or porcellanite. These gravels are derived from early Tertiary erosion of the Rocky Mountains. In the absence of better-quality outcrops of material suitable for knapping, the Souris gravel exposure was likely utilized by local Native groups as a precontact source of stone for tool manufacture.

Visually-similar silicates are found both on archaeological sites throughout southwestern Manitoba and in deposits in Wyoming, Montana, South Dakota and North Dakota. In order to both compare the Souris material with similar material to the south and to test the reliability of macroscopic visual identification, samples from Souris and the United States were tested and compared with archaeological material using thin sections, x-ray diffraction, instrumental neutron activation analysis, and oxygen isotopic analysis.

Results indicate that visually-similar silicates can be differentiated from each other by petrographic analysis. Examination reveals that some flakes from the Treleaven and Snyder II North sites identified as "petrified wood" are actually silicified lignite. Similarly, based upon very high U levels, two very small translucent flakes previously identified as agate have been re-identified with some confidence as silicified wood/silicified lignite. Four flakes of silicified lignite from the archaeological sources are virtually indistinguishable microscopically from North Dakota Knife River Flint.

Usage of the term "Knife River Flint", which implies a specific source area, should be tempered by the knowledge that silicified lignite is found in secondary gravel deposits

over a wide geographic area. Outcrops of such gravel at Souris, Manitoba contain silicified lignite that is generally of poorer quality than silicified lignite from aboriginal quarries in North Dakota.

Comparative Analysis of the Souris Gravel and Sand Deposit, a Precontact Lithic Resource in Southwestern Manitoba

List of Figures

List of Tables

Acknowledgements

I would like to thank the many people who devoted time and effort to making this thesis possible: Dr. Fred Longstaffe for conducting the Oxygen Isotopic Analyses, Dr. Ron Hancock for conducting the INAA, Dr. Nancy Chow for allowing the use of photomicrograph facilities, Drs. Jennifer Shay and Mike Sumner for providing plant identifications, and Dr. Greg Monks for acting on my committee. Test samples of Souris gravel and sand were graciously supplied by Dr. Harvey Young of Brandon University, while comparative lithic samples were provided by Drs. Lynn and Dale Fredlund and the Manitoba Museum of Man and Nature. Most of all, my heartfelt thanks go to Drs. Leigh Syms and Barbara Sherriff, who spent many hours in sometimes frustrating -- but ultimately fruitful! -- discussion and review. Without their constant support and encouragement, the road would have been a much rockier one.

On a more personal note, I'd like to thank the friends and family who were sympathetic to the cause: my parents, who always told me that I could do anything I wanted to, and made me believe it; Andrea Klymasz, whose faith in me kept me going when I felt the most unfocused, and especially my husband Andrew, for the many meals he brought me at the computer and for putting up with me when the writing wasn't going so well!

Partial funding for this research was provided by grants from the Manitoba Heritage Federation and the Natural Science and Engineering Research Council, who provided financial support for the X-ray diffraction and oxygen-isotope analyses (NSERC A7387 to Fred J. Longstaffe) and a University Research Fellowship and operating grant to Barbara Sherriff.

Chapter 1: Introduction

Archaeology and geology have a long association. The development of the geological law of superposition in 1669 by Nicolaus Steno and the principle of uniformitarianism in 1785 by James Hutton gave archaeologists the scientific means by which to demonstrate the antiquity of humanity and to interpret cultural evolution. In recent decades, archaeology's theoretical orientation has shifted from an emphasis upon historical reconstruction to a more multi-faceted approach in which all aspects of a culture's interaction with its environment are considered. One of the first and most extensive treatments to make use of this ecological orientation was Carl Butzer's *Environment and Archaeology* (1964). Reprinted in 1971 with extensive additions, Butzer's work emphasized humanity's relationship with and development within its natural environment. A similar recognition of the value of geological principles to archaeological analysis has resulted in the definition of the term *geoarchaeology* by Gladfelter (1977:519) as "the contribution of earth sciences, particularly geomorphology and sedimentary petrography, to the interpretation of archaeological contexts." Since then, an increasing number of books have been published dealing with the application of scientific knowledge to archaeology; three notable examples are *Geoarchaeology: Earth Science and the Past* (Davidson and Shackley 1976), *Archaeological Chemistry: A Sourcebook on the Applications of Chemistry to Archaeology* (Goffer 1980) and *The Petrology of Archaeological Artifacts* (Kempe and Harvey 1983).

In Canada, early archaeological research conducted by the Saskatchewan Museum of Natural History (Wettlaufer 1956; Wettlaufer and Mayer-Oakes 1960) incorporated both

geological and pedological components, while Johnston (1946) and MacNeish (1958) examined the geology of southern Manitoba and the significance of Glacial Lake Agassiz to post-glacial human settlement. The publication of *Life, Land and Water* (Mayer-Oakes 1967), marked the first instance in which papers on Manitoba archaeology were presented in a single volume with papers on geology and geography.

Conversely, geologists are also recognizing the common thread in geological and archaeological research. The Geological Society of America has established a division of Archaeological Geology, and the number of papers presented at GSA symposia dealing with geoarchaeological research is increasing yearly. This factor, perhaps more than any other, illustrates the recognition of the mutual contributions of archaeologists and geologists to an understanding of the archaeological past (Hassan 1979:267). The scope of geoarchaeology has expanded rapidly to include such diverse topics as the location of sites by geochemical analysis, geomorphological analysis of archaeological sites, site stratigraphic studies, sedimentological analysis of archaeological deposits, paleoenvironmental analysis, sourcing of raw materials, the spatial range of site catchment areas, dating of archaeological remains, the conservation and preservation of "wet site" archaeological resources, and modelling of the dynamic relationship between man and his environment (Hassan 1979:268).

One such geoarchaeological topic -- the study of lithic raw material sources -- draws heavily from the field of petrology, or the study of rocks. Petrological analysis can be applied to any aggregate of mineral particles, from rigid stone to soft, unconsolidated clays. Its most common archaeological application has traditionally been in the

examination of fired clay pots and the coarse particles or *temper* added to strengthen the clay matrix. However, despite the relatively early discovery in 1656 that stone tools could be distinguished from local outcrops of similar material, the petrological analysis of stone tools has only gained acceptance within the past five decades (Shotton and Hendry 1979:76).

Siliceous stone is an excellent material for study because, unlike ceramic or organic artifacts, it is not readily subject to weathering. Similarly, its hardness and flaking qualities make it ideal for tool manufacturing and a natural medium for individual stylistic expression. Few archaeologists, however, are aware of the full range of geological techniques available to help them extricate information from their lithic artifacts. Perhaps for these reasons, most lithic studies have focused upon *stylistic* change over time and between cultural groups, ignoring the wealth of information that can be obtained by studying the composition of the stone rather than the final form taken by the tool. The vast majority of site reports contain only the most superficial of lithic analyses, giving very basic information such as tool form and type of raw material. Furthermore, analysis rarely consists of more than a macroscopic visual inspection. This "laundry list" type of analysis is not only insufficient, but becomes dangerous when one considers the difficulty in differentiating between two or more visually-similar stone types. It is all too easy to formulate erroneous hypotheses regarding trade networks based upon a subjective identification.

A survey of monographs produced by the Archaeological Survey of Canada to date reveals only one focusing entirely upon petrographic analysis. This indicates the

inadequate treatment this important subject has traditionally received. In general, however, the need for more precise definition of regional lithic resources is gaining recognition, and in recent years, significant attempts have been made to define more precisely the various raw materials used prehistorically in southern Manitoba, Saskatchewan and southern Ontario.

Petrological analysis provides information on the texture, mineralogy and chemistry of samples -- the "characterization" of raw materials. Typically, characterization studies have concentrated on raw material from primary sources, i.e., *in situ* outcrops which show evidence of prehistoric quarrying activity. Such studies are a good test of the analytical techniques being used, as some portion of the lithic artifacts found on nearby archaeological sites could be expected to include material from the quarry site. In Manitoba, however, the limitations of this focus are obvious: there are few known outcrops from which lithic raw material has been quarried. With the exception of Selkirk chert, which outcrops in a fairly small area along the Red River, and porphyritic or Bird Lake rhyolite, which seems to be limited to sites along the Winnipeg River, known sources of finely-grained silicates are rare. Swan River Chert, ubiquitous in glacial tills throughout west-central Manitoba, Saskatchewan and east-central Alberta, appears in significant quantities on sites in southwestern Manitoba, but no primary outcrops have ever been identified. In addition, it is usually of poor to medium quality, with vugs and impurities which make its knapping behaviour unpredictable, so that it would not likely have been a raw material of choice.

Secondary gravel deposits, however, are extensive and outcrop in various locales throughout the southwestern portion of the province. Given the apparent paucity of primary siliceous outcrops, it seems plausible that, if raw material of moderate knapping quality occurs within these gravel deposits, they may well have been utilized as a precontact source of stone. However, the difficulties inherent in sourcing of secondary deposits are considerable. Glacial and fluvial processes are capable of depositing a wide range of materials derived from numerous sources over a wide geographic area; in southwestern Manitoba, these processes have produced a complex arrangement of tills overlying bedrock. A commonly-held archaeological belief is that these secondary materials cannot be distinguished from the parent source, making the characterization of secondary sources useless. The truth or fallacy of such a belief can only be proven by continued studies such as this.

This thesis will attempt to characterize deposits of gravel and sand occurring in and near Souris, Manitoba. Current theories regarding the geological origins and depositional history of this poorly-understood deposit are summarized. Siliceous raw materials within the deposit will be examined using a number of petrological techniques, including macroscopic description, thin sections, X-ray diffraction patterns, neutron activation analysis and oxygen isotope analysis. Comparisons are made with visually-similar raw materials from sources in North Dakota, South Dakota, Wyoming and Montana and with archaeological material from two sites in southwestern Manitoba. These comparisons will address a number of questions regarding the Souris gravel and sand deposit:

1. Can siliceous raw materials be distinguished from each other petrographically and geochemically?

2. Can raw material from the deposit at Souris be distinguished petrographically and/or geochemically from macroscopically-similar material from locations in the United States?

3. Do the results of this analysis support current opinions regarding the origins of the deposit?

4. Is the material from either Souris or the United States petrographically or geochemically similar to archaeological samples from two southwestern Manitoba sites?

5. Which analytical techniques produce the most definitive results for individual rock types?

The implications of detailed petrographic study are obvious. With comparative data from a variety of sources, archaeological materials which have thus far been identified only by lithic type could potentially be assigned to specific sources. Furthermore, by providing a variety of techniques to correct misidentifications, petrographic analyses reduce the likelihood of incorrect interpretations. Ultimately, by laying the groundwork for comparison of archaeological lithics with both local and non-local sources, we provide the means to refine our understanding of pre-contact trade and movement patterns.

Chapter 2: Previous Research

2.1 Introduction

Although people have been interested in the examination of archaeological artifacts for centuries, as recently as the late 19th century archaeology was generally conducted with a less than rigorous regard for sampling methods or scientific methodology, and a wealth of information was routinely lost each time artifacts were removed from the ground without their provenance recorded. In the past six decades, however, archaeology has developed into a much more precise discipline with great concern for accuracy and a willingness to adopt relevant concepts and techniques from other fields of research. The popularization in the 18th and 19th centuries of the geological principles of uniformitarianism and superposition had a tremendous impact upon archaeology, as they led to the general acceptance of the concepts of human antiquity and the development of culture (Hassan 1979:267). More recently, the theoretical shift in archaeology from a concern with typology and historical reconstruction to an emphasis on the actual lifeways of the people being studied has only served to increase the potential of geological applications to archaeology (Hassan 1979:267). Archaeologists can now obtain information on precontact diet, exchange networks, environment, site settlement and formation processes, and interaction between cultural groups using a variety of geological and paleontological techniques.

2.2 Development of the Physical and Chemical Analyses Used

The earliest attempts to examine the nature of archaeological artifacts focused on their physical properties. In what was possibly the first attempt to study raw material

sources, Halley and Stukely endeavoured in the 19th century to establish the provenance of the limestone used to construct Stonehenge (Gale 1981:41). The development of thin section microscopy in the 19th century allowed archaeologists new insight into the physical composition and microscopic texture of archaeological materials. Since then, thin sections have become a standard means of archaeological analysis. They are relatively cheap to manufacture and versatile, lending themselves not only to the microscopic examination of rocks but of ceramics as well (for a review and discussion of physical and chemical techniques applied to the analysis of ceramics, see Hanna 1982).

Although early thin sections produced at the end of the 19th century lacked refinement and were difficult to manufacture from very friable or highly metamorphosed rocks, advancements in equipment and materials over the past decades have made it possible to prepare thin sections from even the most difficult of rock types. They enable the researcher to examine texture and mineralogy, and provide an excellent way of determining the basic nature of the material before more detailed analysis is undertaken (Kempe and Templeman 1983:30). Depending on the complexity of the questions being addressed, examination of thin sections may preclude the necessity for more detailed analysis.

Although thin section construction requires removal of material from an artifact -- making it by definition a destructive technique -- advances in cutting equipment have greatly reduced the amount of material which must be removed. Slices less than 1 mm thick can be removed using a thin wire saw impregnated with diamond or carborundum

(Bishop and Woolley 1973). The very small slot left in the artifact can then be filled with putty so that no alteration is visible.

Staining of thin sections to enhance the appearance of diagnostic internal features was introduced in 1887 by Lemberg; since then, the technique has been refined by Warne (1962) and applied to alternate media such as acetate peels (Buehler 1948; Bissell 1957; Dickson 1965; Katz and Friedman 1965; Stewart and Taylor 1965; Price 1975; Young and Syms 1980), which effectively record an impression of the ground surface of a rock without incurring the expense of making an actual thin section.

Although thin sections have been used with much success in the study of igneous and metamorphic rocks, it is more difficult to extract information from homogeneous siliceous rocks such as chert (Tite 1972). Despite these difficulties, examination of the physical properties of siliceous rocks using thin sections has been used with varying degrees of success by a number of researchers (for example, Ingham and Dunikowska-Koniuszy 1965; Clayton *et al.* 1970; Broughton 1976; Parkins 1977; Thomas 1983; Scurfield and Segnit 1984; Janusas 1984; Eley and von Bitter 1989; Prothero and Lavin 1990; Lavin and Prothero 1992), and it remains a relatively inexpensive and quick way of obtaining information on composition and texture. Petrographic analysis should not, however, be relied upon as a sole means of assigning silicates to a source, as sedimentary rocks deposited in different time periods will appear microscopically identical if the original sediments were of very similar composition (Eley and von Bitter 1989:3). Therefore, thin sections are best used in conjunction with other methods of characterization.

X-rays, a continuation of the electromagnetic spectrum, were discovered by Roentgen in 1895. The way in which an x-ray is diffracted when it strikes crystalline material has led to the development of a relatively quick, accurate way to determine the major components of an object. The primary drawback to the technique is that it requires a very small, powdered sample of the material to be studied, rendering it a partially destructive method. Obviously, if the archaeologist or curator is unwilling to have a sample removed from the artifact, x-ray diffraction (XRD) may be considered unacceptable. However, this technique remains one of the most sensitive ways to detect the mineral composition of lithic material -- an important factor to consider given the complicated composition of many archaeological artifacts (Stos-Fertner *et al.* 1979:187). For this reason, if removal of a small fragment from an artifact is permissible, XRD is a promising means of analysis.

X-ray diffraction has been applied to the analysis of both clay and stone vessels. In 1975, Francaviglia, Minardi and Palmieri used XRD, in combination with other x-ray methods, to study the techniques used in the manufacture of Etruscan bucchero ceramics. The unique black coloration of this pottery had previously been attributed to the reduction during firing of red Fe_2O_3 to black FeO and the presence of additives such as manganese dioxide (MnO_2) or carbonaceous material. XRD affirmed that the colouration resulted, not from the reduction of Fe_2O_3 or the presence of MnO_2, but from the presence of carbonaceous material which had been used as a colorative agent. Further XRD of samples indicated a unique composition to the pot clays, suggesting that the Etruscan potters may

have selectively obtained weathered tuffs from certain non-local deposits as a non-plastic additive.

Later analysis of Norwegian ceramics (Stout and Hurst 1985) used XRD to characterize clay cups produced between *ca.* A.D. 300 to 500, in an attempt to identify the degree of firing and possible sources of the clays used. In addition, there was some question as to whether the black coloration on the vessels was produced by burnishing followed by firing in a reducing atmosphere, or whether it was the result of a previously undetected slip applied to the vessel surface. XRD patterns of samples taken from both the surface and the core of the cups indicated almost identical mineral composition, precluding the possibility that a slip had been applied. Results also indicated that the clays used to manufacture the cups may have come from a single source near one of the sites, based upon the presence of chlorite in all the vessel fragments studied and in clay deposits in that locale.

XRD studies have also been used to address issues such as the heat treatment of chert. Although numerous experiments have shown that heat treatment improves the knapping qualities of certain quartzitic materials (see, for example, Crabtree and Butler 1964; Behm and Faulkner 1974; Mandeville and Flenniken 1974; Bleed and Meier 1980), some dispute remains as to the degree of heating required and the kind of changes heating produces in the rock. Weymouth and Mandeville (1975) attempted to measure the internal changes which occur when chert is heated, in order to establish objective criteria for the identification of heat treatment in archaeological lithics. They observed that the diffraction lines in heat-treated chert were broader than those in unheated chert. This indicates that,

as suggested by previous microscopic study, the size of the constituent crystals decreased with heating. Rather than being the result of recrystallization, however, they hypothesized that existing crystals split along micro-cracks or at local points of strain, and that this process could be initiated by heating and loss of water during the heating process. They also determined that for certain chert types of known source, heat treatment could be determined by comparison with treated and untreated source rocks.

Other x-ray diffraction analyses of lithic materials have focused on their mineral composition rather than their crystalline form. Kohl *et al.* (1979) used XRD to examine the composition of soft stone vessels from southwestern Asia. Routine x-ray diffraction aimed at identifying variability within the stone led to the discovery that all the stone vessels from a major archaeological site at Tepe Yahya in southeastern Iran -- identified long ago as steatite and never questioned -- were actually chlorite. Accordingly, Kohl *et al.* applied XRD to 375 samples of soft stone from a number of sites and local sources in order to determine their mineral composition prior to further analysis. Not only was the technique successful in identifying several broad groups for further analysis, it was sufficient alone to differentiate between vessel fragments from two different archaeological sites and to suggest a strong correlation between another site and a distant source of raw stone.

Aside from descriptive accounts based upon macroscopic and microscopic qualities, extensive research has been directed at lithic characterization by geochemical analyses. Chemical examination of archaeological materials began as early as the 18th century, with studies of the composition of Greek and Roman coins and glass (Klaproth 1796, cited in

Goffer 1980:3). In 1853, a volume was published listing various archaeological discoveries and the results of their chemical analyses. This is the first real evidence of the recognition by archaeologists of the potential value of chemical analysis of artifacts (Goffer 1980:3). In the same year, Wocel suggested that the chemical analysis of archaeological artifacts might aid in determining the provenance or source of the materials from which they were constructed, and that the age of ancient metal artifacts could be estimated in the same way (cited in Goffer 1980:3). By the end of the 19th century, the chemical analysis of bone had been attempted, as had the application of chemical techniques to the preservation of archaeological remains (Goffer 1980:4). Throughout the 20th century, interest in the application of physical and chemical analyses to archaeological problems has increased steadily, and advanced instrumentation and nuclear and radioactive methods in the past five decades have spurred a revolution in archaeological analysis.

The most common means of characterizing inorganic archaeological materials involve the measurement of trace elements. Lithic analyses have tended to focus upon materials such as obsidian, steatite and marble rather than other rocks of siliceous origin suitable for stone tool manufacture. This is due largely to the suitability of these materials for study; they are found in relatively few source locations and chemical variation between formations is generally much greater than variation within a single source. On the other hand, siliceous rocks such as chert and chalcedony are notoriously difficult to characterize. Being of sedimentary origin, they tend to be extremely variable in trace element levels, not only between sources but also within a single source (Luedtke 1978, 1979). This variability is so pronounced that multiple tests on different portions of the same sample

will often yield widely variable results. In addition, chert is ubiquitous in its presence in both primary and secondary deposits throughout the world, making it impossible to sample every known source for comparison.

Several techniques are available; those most commonly used have been instrumental neutron activation analysis (INAA), x-ray fluorescence (XRF), and, more recently, proton-induced x-ray emission (PIXE). Each of these techniques uses some agent, whether neutrons, protons or x-rays, to bombard a sample. This induces excitation of the atoms and a characteristic, measurable signal of some sort which can be translated into absolute quantities of trace elements.

Instrumental neutron activation analysis (INAA) was initially conceived of and applied in 1936 by Hevesy and Levi, but it was greatly restricted by the equipment available until the development of nuclear reactors in the 1940s and 1950s (Goles 1977:344). One of the first attempts to identify the geological source of archaeological artifacts by INAA was initiated by Gordus *et al.* (1967, 1968), who recognized that earlier attempts to apply INAA to gold coins and ceramics had not employed the necessary statistical analyses to complete the work. Gordus *et al.* chose obsidian artifacts for study because the elements sodium (Na) and manganese (Mn) tend to vary significantly between obsidian sources but very little within a given source, and are therefore excellent elements to use in characterization. More than 1900 obsidian samples were examined from a number of American sources, including Obsidian Cliff in Yellowstone National Park; Mono Lake, California; Montana, Wyoming, Idaho and Mexico. Sodium and manganese levels were measured and the results tested for goodness-of-fit. Each source tended to

produce discrete clusters of values when the two elements were plotted against each other. Hopewellian projectile points of unknown geological origin were then examined, and it was found that Na and Mn values corresponded with the sources at Obsidian Cliff and in Idaho and Mexico. Further INAA of the elements Fe, Sm, La, Sc and Rb compared favourably with Obsidian Cliff. Other successful INAA studies of obsidian have been conducted by Frison *et al.* (1968), Cann, Dixon and Renfrew (1969), and Nelson *et al.* (1977), Stross *et al.* (1977), Asaro *et al.* (1978); Nelson and Voorhies (1980), Wright and Chaya (1985) and Wright, Chaya and McDonald (1990).

In examining Mesoamerican turquoise sources, Wiegand *et al.* (1977:24) coined the term "Provenience Postulate" to describe the theory that chemical variation between sources of raw material will exceed any variation within the source itself. They obtained turquoise samples from approximately 200 mines, outcrops and archaeological sites in the United States and Mexico. They discovered that variation both between sources and within each source was much greater than anticipated and suggested that the correlation of artifacts with a single source would have to be based upon a range of values for each trace element present, rather than anticipating an "exact" match. Results also indicated that trace element measurements of artifacts from individual sites clustered closely, suggesting that each site tended to obtain turquoise from a single source. In some cases, these values clustered so closely that the authors hypothesized a common origin in a single vein of turquoise.

In a similar earlier study, Allen *et al.* (1975) used INAA to successfully correlate steatite artifacts from five archaeological sites in the eastern United States with known

eastern steatite sources. Later work by Gale (1981) found that characterization of Mediterranean marbles could be accomplished by a comparison of strontium (Sr) and rubidium (Rb).

In some of the first characterization studies of Ontario chert artifacts, Luedtke (1978, 1979) found macroscopic identification insufficient in correlating chert artifacts with their source and applied INAA to a wide range of cherts, using discriminant analysis to evaluate the results. Like Wiegand *et al.* (1977), Luedtke recognized intra-formational variability but felt that variation between formations was much greater and would allow for differentiation if a sufficiently large number of samples was taken from each source to establish a representative range of trace elements for that formation. She further cautioned that it was equally important to measure a large number of elements.

In a study of Kettle Point chert in Ontario, Janusas (1984) concluded that macroscopic physical properties such as colour, fracture, surface texture, hardness, refractive index, translucency and degree of vug contribute little to the macroscopic characterization of chert and are best used in conjunction with other forms of analysis. She employed thin sections, INAA and oxygen isotopic composition analysis to examine samples of Kettle Point chert from a primary outcrop on Lake Superior and archaeological artifacts. All were then compared with similar cherts from elsewhere in Ontario, Michigan and Ohio. Results showed, perhaps predictably, that Kettle Point chert varies tremendously chemically and that INAA was insufficient by itself to differentiate between sources. Despite the apparent limitations of INAA in distinguishing between different sources of some raw materials, subsequent applications of the technique to chert from the

Great Lakes region (Julig, Pavlish and Hancock 1989, 1991a,b; Julig *et al.* 1992) have also achieved a measure of success. INAA of Knife River Flint, agate, and chert from the Cummins Site and several other sources of these lithics indicated that most material types could be clearly separated from each other (Julig, Pavlish and Hancock 1989, 1991b). The same study strongly suggested that the majority of the brown silicates found on the site which closely resembled Knife River Flint were actually a mixture of Hudson Bay Lowland chert and agate, and that quartzite present at the Cummins Site may have been transported from Hixton, Wisconsin. INAA of material from six other sites in the Great Lakes region identified as Knife River Flint also indicated that misidentification had occurred, and that several artifacts were in fact Hudson Bay Lowland chert or agate (Julig, Pavlish and Hancock 1991a). Attempts to characterize Hudson Bay Lowland chert by INAA (Julig, Pavlish and Hancock 1991b) were slightly less definitive, but generally successful. This analysis had the added benefit of utilizing a newly-developed non-destructive method of INAA which allowed the testing of entire specimens. Coupled with the fact that the radioactivity produced in the specimens by the low-flux SLOWPOKE reactor is short-lived, this method is especially advantageous, because the artifacts may then be returned to their source collections after analysis.

When trace element variation is as great within a single outcrop as between divergent outcrops, INAA may not provide fully satisfactory results. Craig and Craig (1972) were the first to suggest that a different method of analysis, using oxygen and carbon isotopes, could be used to characterize marble. These elements were considered promising because concentrations appeared to be uniform throughout both individual

artifacts and throughout individual quarries. When a small number of quarry samples and artifacts were tested, it was found that the quarry samples clustered in well-defined groups. Half of the 10 artifacts tested fell within these clusters; although the other five remained ambiguous, it is likely that a larger sample of source rocks would have provided more comprehensive results.

Isotopic composition analysis has traditionally been used by geochemists and geologists in the determination of past climates, specifically temperature (for example, Knauth and Lowe 1978). Marine organisms which secrete a protective calcium carbonate ($CaCO_3$) shell are excellent objects for study, as the $^{18}O/^{16}O$ isotopic composition of the sea water (and therefore, temperature) at the time during which they lived is reflected in the composition of their shells. If the source regions have markedly different temperature regimes or the water bodies differ in isotopic composition, the potential exists to identify the source of any shells which appear in archaeological context (Shackleton and Renfrew 1970:1062).

Shackleton and Renfrew (1970) examined *Spondylus* shells found on Neolithic sites near the Black and Aegean Seas. $^{18}O/^{16}O$ isotope ratios were measured and compared with the known isotopic composition of the Black and Mediterranean Seas. Although they expected that isotope values of shells taken from sites near the Black Sea would closely approximate the composition of the Black Sea waters, they were surprised to find that they were a much closer match to the Aegean. Further tests on recent Black Sea *Spondylus* shells supported these results, as did carbon isotope ratios. The authors therefore hypothesized the prehistoric existence of a "prestige type" of exchange network, whereby

trade goods are distributed over considerable distances and occur in high concentrations in remote locations (1970:1064).

Further tests of the isotopic composition of lithic artifacts were conducted by Coleman and Walker (1979), who removed fragments from a number of marble sarcophagi in the British Museum in an attempt to compare carbon and oxygen isotope ratios with source data previously gathered by Craig and Craig (1972) and Manfra *et al.* (1975). They found little variation within individual sarcophagi, but were able to positively associate the sarcophagi examined with specific Pentellic and Marmaran marble sources. Later research included experiments by Herz (1987), who examined carbon and oxygen isotopes in 11 known marble sources and 61 artifacts. He was able to assign all but six of the artifacts to sources.

Although Janusas (1984) found instrumental neutron activation analysis of Kettle Point chert to be inconclusive, oxygen isotopic composition analysis using $^{18}O/^{16}O$ ratios showed a significant difference between Kettle Point chert and other similar cherts of known, different geological time periods, leading her to conclude that isotopic composition analysis had potential in differentiating between different types of visually-similar materials and may one day be used to differentiate between different outcrops of the same material.

Although outside the scope of this thesis, other methods of geochemical analysis have also been used successfully. X-ray fluorescence has been applied to artifact studies by Hall (1960); Hall, Banks and Stern (1964); Stevenson, Stross and Heizer (1971); Hester (1975); Nelson, D'Auria and Bennett (1975), Nelson *et al.* (1977), Fladmark (1984) and Hughes and Nelson (1987). Fission track analysis has been applied (Durrani

et al. 1971) in cases where obsidian from different flows (sources) is very similar chemically, and proton-induced x-ray emission spectroscopy (PIXE) has been applied by Ahlbert *et al.* (1976); Nielson *et al.* (1976) and Nelson *et al.* (1977).

2.3 Tertiary Gravels on the Northern Plains

Long before the Souris gravel and sand deposit was identified, geologists were documenting gravel deposits in the Cypress Hills area of Alberta and Saskatchewan. McConnell (1886) was the first to describe the quartzose sands and gravels in this region, and hypothesized that they were derived from the Rocky Mountains. He suggested a Miocene (which at that time, included what is now called the Oligocene) age for the deposits on the basis of vertebrate remains present, and identified similar, but distinctive, gravels covering low level valley floors, which he named "Saskatchewan gravels". McConnell also identified rocks in the glacial till covering the Cypress Hills which could only have come from the Precambrian Shield to the northeast. He believed that the gravel conglomerate capping the Cypress Hills was deposited in a former depression and that this conglomerate afforded a natural protection against erosive forces, preventing the underlying strata from being eroded as quickly as the surrounding terrain and leading to the eventual formation of the Cypress Hills.

In 1918, Collier and Thom studied the physiography of northeastern Montana and identified several erosional surfaces at a lower level than the Cypress Hills. Gravel deposits capping these plateaux were designated the Flaxville gravels, after the type locality near the town of Flaxville, Montana. The Flaxville gravels were identified as

Miocene or early Pliocene in age on the basis of vertebrate remains. Collier and Thom also recognized a number of gravel deposits at an even lower level, which they hypothesized were late Pliocene to later Pleistocene in age. These deposits were the equivalent of McConnell's "Saskatchewan gravels".

Alden (1924) identified both Tertiary and Pleistocene erosional surfaces or "benches" on the Northern Plains, citing the Cypress Hills as the type locality for the Tertiary surface. He built upon this work in a later (1932) publication, in which he examined the physiography and glacial geology of eastern Montana, describing the composition and physiographic location of the Cypress Hills and their relation to gravels capping other high-level plateaux, including the Flaxville. Alden concurred with Collier and Thom's Flaxville erosional surfaces and expanded upon their work by postulating a series of equivalent benches over much of the Northern Plains. Somewhat contrary to McConnell's hypothesis, Alden believed that the Cypress Hills conglomerate was deposited over a broad, gently sloping plain composed of alluvial fans heading at the points where the streams emerged from the mountains.

In a related study, Williams (1929) also discussed the physiography of the Cypress Hills, their probable origins and their relation to the lower Flaxville plateaux in Montana and northern Wyoming. Williams and Dyer (1930) later expanded on this work, discussing drainage and topographic features south of the Cypress Hills. They also recognized equivalents of Alden's erosional benches and described glacial landforms in the area. Their study was the first to formally designate the hard, gravel-bearing conglomerate capping the Cypress Hills as the Cypress Hills Formation.

In 1930, Wickenden discovered Eocene vertebrate remains in hard, conglomeratic sandstone east of Swift Current, Saskatchewan. Subsequent research (Russell and Wickenden 1933) indicated that this Eocene Swift Current sandstone was situated 285 m lower than the younger (Oligocene) Cypress Hills Formation. Stratigraphic evidence proved that this was not due to stratigraphic deformation, as the younger and higher Cypress Hills deposits lay directly atop Paleocene Ravenscrag deposits and the older Swift Current beds on top of Cretaceous Bearpaw shales. Russell and Wickenden concluded that, far from being deposited in a depression, as hypothesized by McConnell, the Oligocene Cypress Hills conglomerate was deposited first on the flanks of, and later on top of, existing hills. As the Laramide Revolution came to an end, erosive forces overcame the forces of aggradation and the Cypress Hills were once again isolated as an upland. The authors were unable, however, to resolve the question of how the Eocene Cypress Hills came into being.

Russell (1934, 1938, 1940, 1950) undertook a series of studies of fauna from the Cypress Hills Formation. In 1934, he compared his own identifications with those initially assigned by Lambe in 1908 and continued to make revisions through the years as more fossil vertebrate remains were collected. Russell's identifications confirmed the Oligocene age of the Cypress Hills Formation. In 1940, he mapped the bedrock geology of the Foremost-Cypress Hills area; in the same year, Russell and Landes described the structure and stratigraphic succession of much of southern Alberta. Similar studies of the bedrock geology of the Cypress Hills in Saskatchewan were conducted by Fraser *et al.* (1935), Russell (1948) and Kupsch (1956), while in 1946, Furnival added to the still incomplete

knowledge of the geological structure of the Cypress Hills by re-mapping the Cypress Lake area of southwestern Saskatchewan. Using well-logs and by studying stratigraphic succession of the surrounding areas, he described surficial feature and subsurface stratigraphy.

In 1937, Rutherford described McConnell's "Saskatchewan gravels" and identified exposures in central Alberta. Although at that time the relationship of the Saskatchewan gravels to the older Cypress Hills conglomerate had not yet been established, Rutherford was of the opinion that these gravels were somehow derived from the Cypress Hills deposits.

Warren (1939) felt the Wood Mountain gravels of Saskatchewan were the equivalent of the Flaxville deposits in Montana. He also correlated the Hand Hills of Alberta with the Flaxville Gravels, rather than the Cypress Hills, as had previously been assumed on the basis of elevation.

Stalker (1963) examined Quaternary deposits along river valleys in southern Alberta. He identified Saskatchewan gravel and sand along the floors of preglacial rivers below glacial till, noting that these deposits were typified by an absence of granite, gneiss, schist, gabbro and pegmatite of northeasterly (Precambrian Shield) origin. Similarly, Westgate (1968) described Saskatchewan gravel deposits occurring as channel fill in preglacial valleys in the Foremost-Cypress Hills area. He dated them as mid- to late Pleistocene, saying that they accumulated, in part, in a cold climate (1968:106). Westgate also described all Upper Cretaceous rocks and Tertiary conglomerate in the map area, including the Cypress Hills Formation and the Flaxville deposits.

Although it had been hypothesized for some time that the Rocky Mountains were the initial source of the Cypress Hills sediments, Vonhof (1965a,b), by studying lithology and sedimentary structures in the Cypress Hills Formation, attempted to identify a definite source locality for the material. By examining variables such as stream gradient, direction of cross-bedding, gravel fabrics and the lithology and distribution of the sands and gravels, Vonhof verified that the headwaters of the streams which deposited the Cypress Hills sediments originated in the Rocky Mountains of northwestern Montana.

Storer (1978) confirmed the ages assigned to the Oligocene Cypress Hills, Wood Mountain and upper Miocene Flaxville deposits. He suggested that the Wood Mountain gravels are in fact slightly younger than the Flaxville, and should be dated to the upper Miocene. He also suggested ages for the lower-level Hand Hills and Wintering Hills in Alberta.

Elson (1956, 1958) was the first to mention the occurrence of quartzose gravel near Souris, Manitoba and hypothesized an early Pleistocene age based upon the presence of granitic material of glacial origin. Elson also noted that this gravel was likely deposited by early Pleistocene rivers carrying material of Rocky Mountain provenance (1958:63).

However, the first study to examine sub-surface deposits in southwestern Manitoba in any detail (and in the Souris vicinity in particular) was conducted by Klassen (1969), who was the first to designate the gravel and sand deposits overlying bedrock in buried preglacial valleys the 'Souris gravel and sand' (1969:2). Based on a non-quantitative shovel sample, he identified a much higher percentage of chert and quartzite pebbles in these gravels than in typical glacial gravels of the region, and designated a large

commercial gravel pit exposed approximately 1.2 km east of the town of Souris as the reference section for his newly-defined unit, hypothesizing a possible interglacial origin for the deposit.

Klassen and Wyder (1970) conducted further borehole testing of subsurface sediments in the Virden map area, including Souris, in an attempt to refine knowledge of the preglacial drainage valleys in which Souris gravel and sand deposits occurred. They summarized the current knowledge regarding the preglacial Missouri River and noted the presence of gravels similar to the Souris gravel and sand in earlier boreholes drilled across the preglacial Missouri Valley near Frobisher, Saskatchewan (Wyder 1968). The same gravels were also identified by the authors in a buried valley south of Pierson, Manitoba.

Klassen later summarized the stratigraphy of southwestern Manitoba in a Special Paper published by the Geological Association of Canada (1971). In discussing the Souris basin, Klassen elaborated on his earlier hypothesis that the Souris gravel and sand was deposited during an interglacial stage, assigning it tentatively to the Aftonian (1971:261).

An appraisal of sand and gravel resources in the Brandon region conducted by Underwood McLellan and Associates (1977) supported Klassen's (1969, 1971) statements regarding the unique composition of the Souris gravel and sand deposit. The writers contrasted its composition with that of "average" glacial gravels in the region, finding evidence to support the claim that the deposit may be Tertiary or early Pleistocene in age (1977:79).

2.4 Descriptive Lithic Studies on the Northeastern Plains

One of the first detailed examinations of a lithic raw material which occurs in archaeological sites on the Northern Plains was Clayton *et al.*'s (1970) petrological analysis of Knife River Flint (KRF). In addition to a thorough discussion of the extent and nature of the deposit, the authors also examined thin sections of KRF, described its macroscopic and microscopic characteristics, suggested possible geological origins in the Eocene Golden Valley Formation and compared it with visually-similar material types which occur in the same geographic region. In that same year, Leonoff (1970) addressed the identification and distribution of lithic raw material on archaeological sites in Manitoba. Leonoff used thin sections to examine several of these materials in detail, tabulated frequencies of occurrence on eight sites in different areas of the province and developed distribution hypotheses. Ahler (1977) performed a similar study on raw material in the Middle Missouri subarea, subdividing it into stone of non-local and local origin. Gregg (1987), elaborating on Clayton *et al*'s (1970) work, discussed the distribution of Knife River Flint on the Northeastern Plains and the former extent of the Golden Valley Formation. The distribution and characteristics of Knife River Flint have since been studied extensively (see for example Clark 1984; VanNest 1985; Ahler 1986). Descriptive accounts of other siliceous rocks found on archaeological sites covering a wide geographic area have been directed at silicified lignite (Broughton 1976), silicified wood (Scurfield and Segnit 1984), Swan River chert (Campling 1980) Tongue River Silicified Sediment (Ahler 1977; Anderson 1978; Keyser and Fagan 1987), Rainy Buttes Silicified Wood (Loendorf *et al.* 1984) and fused shale or porcellanite (Fredlund 1976). Additional

studies of materials found on sites in southern Manitoba and southern Saskatchewan have been undertaken by Syms (1980), Thomas (1983) and Johnson (1986). Other comprehensive studies of non-local material (Porter 1960; Eley and von Bitter 1989; Prothero and Lavin 1990; Lavin and Prothero 1992) provide an excellent basis for comparison of similar Manitoba lithics. The latter three accounts are notable for the many photomicrographs they contain, providing a ready means of visual comparison.

2.5 Archaeological Research Related to the Souris Gravel and Sand Deposit

The archaeological importance of siliceous rocks found in gravel exposures in and adjacent to the town of Souris, Manitoba, has been noted (Hlady 1965; Watrall 1976) but the deposit has not been studied in any detail. The scant available information on the deposit has been gathered in the context of studies of bedrock geology or ground water potential in the region (Halstead 1959; Elson 1962; Klassen 1965), and does not include petrographic analyses germane to any comparison of Souris material with similar lithic material found on surrounding archaeological sites.

Southwestern Manitoba is archaeologically well-known for the high density of mounds contained in a relatively small area, and much of the previous archaeological research conducted in the Souris area has focussed upon these features (Syms 1980:6). Throughout 1972 and 1973, R.J. Nash conducted an ambitious archaeological survey of southwestern Manitoba, including the Souris vicinity. Although primarily concerned with the question of how mound density would be reflected in changing settlement patterns, Nash and his field crew also conducted stratified and random surface sampling within a

research universe of nine townships. Artifacts were collected and shipped to the Manitoba Museum of Man and Nature for analysis. Although Nash was unable to complete his examination of the material collected, further analysis was conducted by Dr. E. Leigh Syms. Syms (1980) summarized the artifact assemblage from each site identified, and also discussed lithic material types and possible sources, classifying them as local, nearby or distant.

In 1978, Syms and Brandon University geologist Dr. Harvey Young returned to the Souris gravel pits for the purpose of obtaining a systematic sample of available lithic materials and determining their relative abundance. In order to collect as unbiased a sample as possible, Syms and Young collected all sand and gravel in three strips or "channel samples" down the exposed pit face. These samples, from channels 10 cm wide and 5 cm deep, were taken from the west, east and south walls in areas freshly exposed by gravel operations and undisturbed by rockhounds. Vertical length of the channel samples ranged from 6.3 to 7.0 m. Samples were subsequently separated into sand and gravel fractions, with the gravel component further sub-divided on the basis of lithology (H. Young, personal communication 1990). Percentages of sand and constituent rock types were calculated, providing a systematic quantification of the relative frequencies of material present (L. Syms, personal communication 1990).

Chapter 3: Tertiary Erosion and Deposition

3.1 Introduction

Any analysis of a lithic source would be incomplete without an examination of its origins. The Souris Gravel and Sand deposit consists of both lithics of uncertain age and provenance and Tertiary gravels eroded from older deposits in the Rocky Mountains. The period during which these re-deposited Tertiary gravels were being transported eastward was one of great continental aggradation and erosion. Few indications remain of the path these sediments followed, and our knowledge of the origins of the Souris Gravels is therefore based upon comparisons with similar gravels to the west, reconstruction of Tertiary drainage patterns, and the presence of nearly identical deposits buried beneath glacial till.

Uplift of the Canadian Rocky Mountains and the Interior Plains commenced in the early Tertiary and continued throughout the Miocene and Pliocene epochs. As uplift progressed, erosional forces moved vast quantities of debris eastward. By the Pliocene, erosion had progressed to such an extent that only small scattered patches of early Tertiary deposits were left on isolated uplands. In Alberta, the oldest known of these deposits is the Oligocene Cypress Hills conglomerate. In Saskatchewan, the oldest identifiable deposit derived from the Rockies is the Eocene Swift Current conglomerate. Both deposits consist of gravels mantling an unconformity which truncates Upper Cretaceous or older Tertiary strata. Tertiary gravels on the Northern Plains can be separated into three basic categories:

1. high level deposits found as remnants of formerly extensive plains, where they form protective caps which retard erosion of these uplands;

2. intermediate level deposits laid down after the high level material. These may consist either of gravels deposited directly by mountain streams or may be derived from the higher level remnants;
3. the last (and youngest) gravels and sands laid down by preglacial rivers prior to the onset of glaciation.

(Stalker 1968:156-157).

3.2 Cypress Hills Formation

3.21 Description of Deposit

The Cypress Hills stretch from southeastern Alberta into southwestern Saskatchewan (Fig.1). They cover an area 160 km in length from east to west and 24 to 32 km across (Furnival 1946:3). They presently stand some 610 m above the surrounding plains at an elevation of 1463 m above sea level on their western edge in southeastern Alberta and 1128 m at their eastern edge in Saskatchewan (Westgate 1968:16). The hills, as well as adjacent lower buttes and plateaux, are topped by a protective cap of conglomerate and sandstone. The Cypress Hills and other similar landforms are remnants of an extensive plain that formed in Oligocene times, from sediment that washed eastward as the Rocky Mountains rose. These remnants have been preserved largely because they occupied an interfluvial area between drainage to the ancestral Missouri River and to rivers to the north (Klassen 1989:138). The Cypress Hills were not covered by Laurentide ice during the Wisconsinan glaciation, during which Laurentide ice reached its limit at 1300 m elevation on the norther slope of the Cypress Hills upland (Klassen 1993:26). Formerly glaciated areas to the east, although some 200 m lower, were also spared.

Many of the cobbles in the Cypress Hills conglomerate exhibit numerous crescentic percussion marks, commonly caused as stones impact sharply upon each other during

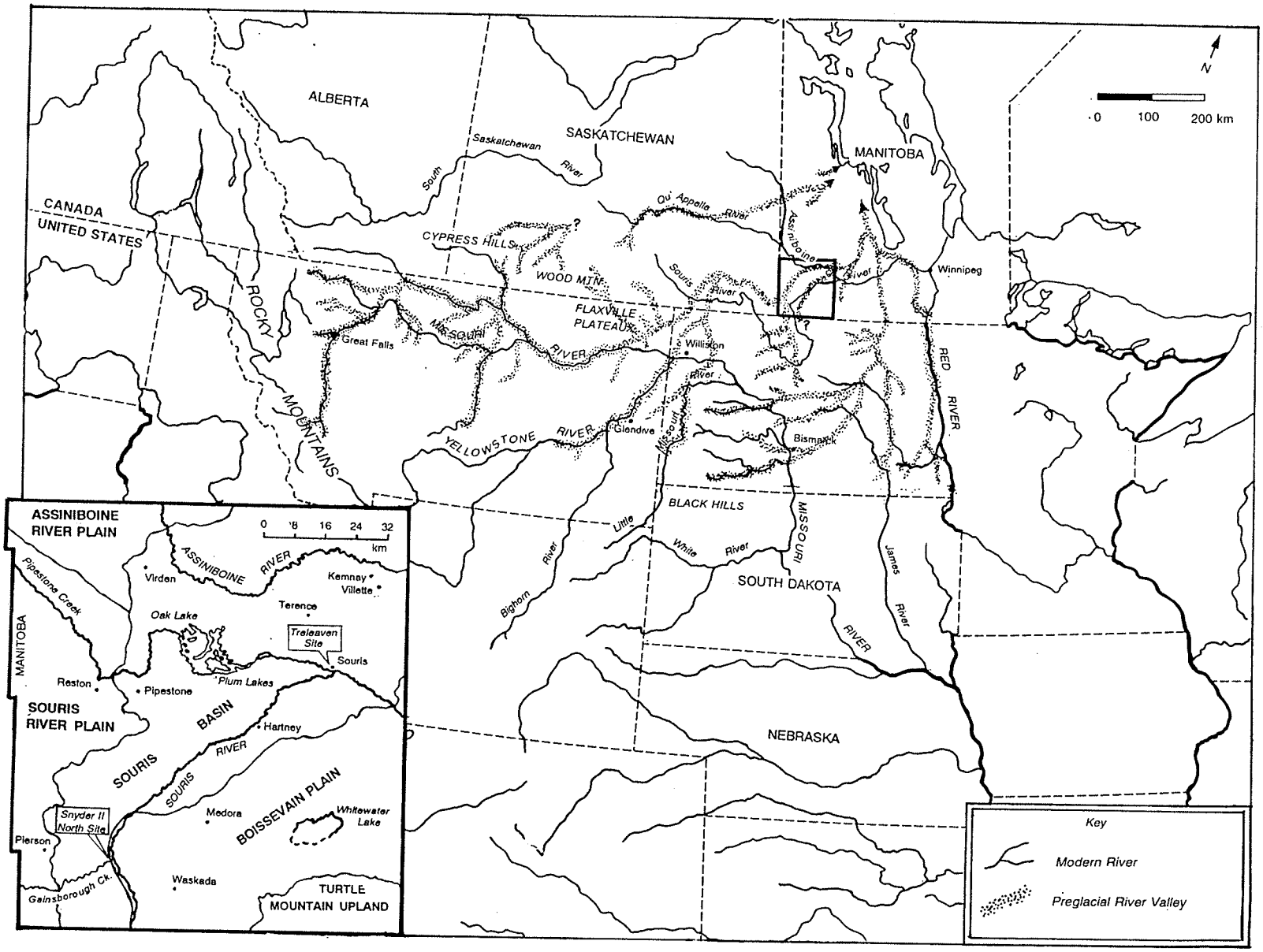


Fig. 1: Preglacial rivers in the study area (after Lemke *et al.* 1960, 1965; Klassen and Wyder 1970; Klassen, Wyder and Bannatyne 1970; Bluemle 1972; Bannatyne and Teller 1984; Prest, 1970).

fluvial transportation in a strong current (Alden 1932:6). Estimates of the deposit's average thickness have ranged from 7.5 to 15 m (Westgate 1968:12) to 168 m (Furnival 1946:118). Fraser *et al.* (1935:56) place the formation's average thickness at between 31 and 38 m on the Swift Current upland and "much less in other places." In actual fact, the thickness of the deposit varies greatly from area to area, even over short distances (Vonhof 1965b:143), but the present maximum thickness of the deposit, known as the Cypress Hills Formation, is probably about 76 m (Vonhof 1965b:143).

The conglomerate which caps the Cypress Hills is made up of hard, coarse sandstone and "fine-grained, soft, crossbedded sandstone ... in addition, there are a clay-pellet conglomerate, coarse, crossbedded, rusty, unconsolidated sands, fine buff-coloured silts, white silts, etc. Fragments of fossil wood and bones occur" (Fraser *et al.* 1935:56). According to Westgate (1968:12), minor lenses of bentonite are also present. The sands and gravels are deposited unevenly; there is more gravel in the deposit near the Alberta-Saskatchewan border than near the eastern edge of the deposit, where sand predominates (Vonhof 1965b:149). In addition, the size distribution of the coarse sand fraction ($>$ .32 mm grain size) shows a definite change from coarse to finer ($<$ .32 mm) material from west to east (Vonhof 1965b:149). This is an indication of stream movement in a north-easterly direction and is consistent with the behaviour of rivers flowing from mountainous regions onto flatter plains. Heavier particles are deposited closest to the source, and, as the river loses its energy, finely-grained sands and silts are deposited further away.

The gravels which make up the Cypress Hills conglomerate are mainly composed of quartzite and argillite, with lesser amounts of arkose, chert and volcanic rock. Vonhof

(1965b:150) has grouped the constituent rocks of the gravel into five types: extremely hard metaquartzites (metamorphosed sandstone), well-cemented orthoquartzites (unmetamorphosed sandstone), chert, quartz and miscellaneous rocks. The latter category consists of argillites, conglomerate pebbles, porphyries and other pebbles lithologically different from those of the other four classes. The metaquartzites and cherts together constitute at least 65% of the gravel deposit (Vonhof 1965:154). According to Westgate (1968:86) the frequency of all quartzites combined is greater than 95%.

3.22 Origins and Stratigraphic Relationships

Aggradation on the Cypress Hills Plain commenced in late Eocene times, as the Rocky Mountains rose and were, at the same time, eroded by streams with their headwaters in the newly-uplifted mountains. As uplift gradually came to a halt, northeastwardly flowing streams and rivers continued to carry a coarse traction load of primarily quartzite and argillite pebbles derived from Beltian and Paleozoic rocks in the mountains (Westgate 1968:77); these sediments were deposited over a vast area, including what is today the Cypress Hills region. It is believed that a second phase of uplift then occurred in the Interior Plains sometime in the Miocene or Pliocene, putting an end to deposition of the Cypress Hills conglomerate and again initiating erosion or dissection of the Cypress Hills Plain. In the process, Cypress Hills material was redeposited along valley bottoms, leaving only small areas of the original Cypress Hills Plain in southeastern Alberta and southwestern Saskatchewan.

Non-marine fossil vertebrates present in the gravels indicate the Cypress Hills Formation to be early Oligocene in age. Russell (1950:54) has indicated it may be equivalent to the Chadron Formation of South Dakota. Lithologically, the gravels appear identical to the Precambrian and Paleozoic rocks of the Rocky Mountains of northwestern Montana. Although Warren (1951:9) has postulated southwestern Alberta as the source of the Precambrian quartzites in the formation, this area of origin alone does not account for the presence of many of the rocks in the Cypress Hills Formation, particularly the porphyries (Vonhof 1965b:157). These rocks could, however, have been introduced into northeasterly-flowing rivers by tributary streams originating in the Highwood and Bearpaw Mountains of Western Montana. Outcrops of Precambrian quartzites belonging to the Belt Series are present in this area, and are cited as a likely source of the metaquartzites in the conglomerate. The cherts are likely derived from Paleozoic limestones in the area, as indicated by the presence of Paleozoic fossil fragments within the chert, rather than the Beltian rocks as suggested by Russell (1948).

The upper beds of the Cypress Hills Formation have been eroded, while the lower contact also rests on an erosional unconformity. Evidence suggests this erosional event was of considerable magnitude, as up to 214 m of sediment was apparently removed from the underlying sediments prior to the deposition of the Cypress Hill beds (Furnival 1946:116). Consequently, while large areas of the Cypress Hills in Saskatchewan rest on the Eocene age Swift Current beds, much of the Cypress Hills and Swift Current Plateaux in southern Alberta and southwestern Saskatchewan also rest on Cretaceous Eastend to Paleocene Ravenscrag Formations (Fraser *et al.* 1935:54).

3.3 Wood Mountain Gravels

3.31 Description of Deposit

The Wood Mountain Formation is a superficial deposit of irregularly bedded gravel and sands located southeast of the Cypress Hills and immediately north of the International border (Fig.1). It measures about 105 kilometres from its western to eastern edge, and about 42 km from north to south. The gravel component consists primarily of well-rounded quartzite and chert, while the sands are fine- to medium-grained and well-sorted. The gravels and sands are largely unconsolidated, although several outcrops contain well-indurated, coarse material held together by a calcareous cement (Vonhof 1965a:74). Vertebrate fossils indicate that the Wood Mountain Formation, which rests unconformably on the Paleocene Ravenscrag Formation, is Miocene in age and of non-marine origin. The deposit is overlain by a thin cover of soil and ranges from 3.6 m to as much as 27 m thick (Vonhof 1965a:50). Like the Cypress Hills, the Wood Mountain uplands were not covered by Laurentide ice during the Wisconsinan (Klassen 1993:26). Gravels assigned to the Wood Mountain deposit have been recognized in a number of Saskatchewan localities.

3.32 Origins and Stratigraphic Relationships

Wood Mountain gravels are thought to have been derived from the erosion, transportation and deposition along valley bottoms of material from older and more elevated deposits to the west. They are the only surviving topographic indication that deposition on the Canadian Plains prevailed over erosion during the Miocene (Vonhof

1969:158). The heavy mineral composition of the Wood Mountain gravels is very similar to that of the Cypress Hills, suggesting that either both Formations were derived from the same source or that the Wood Mountain deposits contain a significant proportion of reworked Cypress Hills material (Vonhof 1969:136). The gravel component of the Wood Mountain Formation contains a higher percentage of smaller pebbles than the Cypress Hills Formation; this is consistent with a scenario in which the Wood Mountain and Cypress Hills formations share a common source, with the smaller pebble size attributed to fluvial transportation of Wood Mountain sediments to a greater distance (Vonhof 1969:131).

Other notable differences in the lithology of the Wood Mountain and Cypress Hills formations suggest that the origins of the former are complex. The Wood Mountain gravels contain more chert and cherty sandstones than the Cypress Hills Formation, and there are significant differences in the kinds of porphyries that are found in each. This suggests that the Wood Mountain deposit was formed from a combination of Cypress Hills material and other fluvial sediments originating in northwestern Montana (Vonhof 1969:138).

Initially, the Wood Mountain Formation would have been deposited in a sedimentary basin. Regional uplift of the Northern Plains in the Miocene raised the region in which the Wood Mountain sediments had been deposited and initiated widespread erosion. Material from the Wood Mountain uplands was then redeposited to the north and south (Vonhof 1969:157). Although Vonhof (1965a, 1969) has identified this "Redeposited Wood Mountain Formation" as an informal, distinct stratigraphic unit, the Wood Mountain upland deposits and their redeposited sediments are still considered a

single unit, with an age spanning the middle to late Miocene to the latest Miocene, Pliocene or early Pleistocene (Vonhof 1969:123). Like other Tertiary uplands, the very fragmented character of the remnant uplands suggests that considerable erosion has taken place. The position of the Wood Mountain deposits to the south of the Cypress Hills suggests that the prevailing drainage of the region shifted southward throughout the period between the Oligocene and the Miocene (Vonhof 1969:161).

South of the main Wood Mountain area, redeposited Wood Mountain gravels grade into the lower-level Flaxville gravels of Montana, suggesting that the redeposited Wood Mountain material may be at least partly correlated with the Miocene to Pliocene age Flaxville gravels (Vonhof 1969:126). Again, the more southerly location of the Flaxville gravels suggests that Pliocene drainage had shifted southward since the Miocene (Vonhof 1969:161).

3.4 Flaxville Gravels

3.41 Description of Deposit

Originally named by Collier and Thom (1918), the Flaxville gravels cap a series of plateaux or benches in northeastern Montana (Fig.1). The term "bench", as used by Alden (1924:400) is restricted to "nearly flat (topographic) features which are clearly remnants of ancient river plains and which are not due to the stripping of softer shales from harder flat-lying sandstone". Smaller remnants of the same deposit are also found in southern Alberta and southern Saskatchewan. The Montana Flaxville plateaux stand approximately 976 m above sea level at the Western end of the Boundary plateau (the most

northerly of the Flaxville Plateaux), descending in elevation to about 793 m above sea level near the town of Flaxville, Montana. Mesas and buttes situated west of the Cypress Hills Plateau may also be Flaxville remnants. To the north of the Cypress Hills, any Flaxville remnants have been covered by glacial deposits (Westgate 1968:19).

The most northerly remnants of the Flaxville surface are located 3 to 6 km south of the highest portion of the Cypress Hills and slope to the south. The larger remnants are 4.8 to 6.4 km in length and 1.6 to 3.2 km wide.

3.42 Origins and Stratigraphic Relationships

Evidence suggests that the Flaxville Gravels once filled very broad valleys. These deposits, of Miocene to Lower Pliocene age (Westgate 1968:17), appear to have been derived from a combination of Cypress Hills conglomerate which was eroded and redeposited in broad valleys and new quartzitic gravels eroded from the Rocky Mountains during the interval of uplift that took place in the Miocene or Pliocene. Streams which would have been shifting back and forth across the fairly flat Cypress Plain would have begun vigorous vertical incision, eroding most of the upland areas. As equilibrium was reached, these streams would have once again begun cutting horizontally rather than vertically, enlarging valley bottoms. Material derived from both the Rocky Mountains and the Cypress Plain was then redeposited on these valley floors (Alden, 1932; Westgate, 1965b). Eventually, the Flaxville Plain formed below the level of the isolated remnants of the Cypress Plain. There is some evidence (Vonhof 1965a, b; 1969) that the Flaxville deposits are at least partly correlative with the Wood Mountain deposits to the north.

3.5 Preglacial Valleys

In order to understand the physical means by which the Souris gravel and sand was deposited in its present location, it is necessary to examine preglacial drainage on the Northern Plains. Vonhof (1969) has addressed many of the problems inherent in attempting to unravel the evolution of Tertiary drainage systems in western Canada: well-documented time-stratigraphic correlations are rare, existing Tertiary deposits represent only small fragments of the originals, widespread lithological similarities between deposits prevent all but the most broadly-based identification of source areas, and the dynamic fluvial environment in which deposits were laid down makes correlation between individual beds virtually impossible. Thus, although a number of incised preglacial valleys have been identified in bedrock, other river systems have left no direct evidence of their existence and must be reconstructed by indirect means such as surviving sediment deposits.

Prior to the last continental glaciation, patterns of drainage on the Plains were significantly different than contemporary patterns (Fig.1). The same rivers that carried sediments northeastward from the Rocky Mountains had been vigorously dissecting a slowly rising land surface. The onset of glaciation produced a marked change in continental drainage. Preglacial river valleys in the Rocky Mountains were least affected, as it was difficult for glaciers to greatly affect the deeply entrenched mountain rivers, but drainage patterns on the prairies were changed significantly as locally advancing ice lobes forced the diversion of drainage to the south (Stalker 1960:3). When the ice later retreated, the more southerly channels opened first, and the erosive effects of the large quantities of meltwater which spilled into them only served to more firmly entrench the

rivers in their new courses. Recent work by Kehew and Lord (1986, 1987) has indicated that catastropic flooding caused by failure of ice or debris dams and glacial lake outburst was a common occurrence as Laurentide ice retreated. Such outbursts were capable of eroding huge amounts of substrate, and quickly cut through deep till deposits and incised valleys into poorly-indurated bedrock, such as Cretaceous and Tertiary sediments on the Great Plains (Kehew and Lord 1987:98). These inter-glacial channels can be differentiated from preglacial channels on the basis of width, shape, trend and valley contents (Bluemle 1972; Stalker 1961; Kehew and Lord 1987). In contrast to glacial valleys, preglacial river valleys tend to be broad, ranging from 3.2 to 16 kilometres in width, and shallow, with gently sloping sides (Stalker 1961:4). This distinctive valley shape, in conjunction with the presence of preglacial gravel deposits and the clay till laid down in the initial advance of Laurentide or Cordilleran ice, have been identified as the primary criteria in the identification of preglacial valleys on the Plains (Stalker 1961:4).

The courses of the major preglacial rivers in Alberta have been examined by Stalker (1961), who has identified a number of major ancestral valleys in the central and southern portions of the province. Lemke *et al.* (1965, fig.2) have indicated two preglacial valleys crossing from southern Saskatchewan into Montana and thence to the preglacial Missouri River drainage. These preglacial rivers could have carried Cypress Hills and Flaxville material into the ancestral Missouri, to be transported northeastward.

The ancestral Missouri River has been the subject of considerable study, and, due to its northerly course through Manitoba, is of great relevance to the present study. As early as 1912, it was suggested that the preglacial Missouri followed a northerly course

into Canada (Beekly 1912:323). In discussing the former course of the Missouri and Yellowstone rivers, Alden (1932) identified a broad preglacial valley just south of the International border at Crosby, North Dakota, and stated that the point of junction of the Yellowstone with the upper Missouri River just prior to the last glaciation was somewhere "near or north of the Canadian boundary" (1932:58). He further hypothesized that the combined Missouri and Yellowstone drainage was not deflected to the south (to empty eventually into the Gulf of Mexico) until the more northerly route was blocked by continental glaciation.

Horberg and Anderson (1956:fig.2) suggested that the preglacial Missouri entered Canada in Manitoba to flow directly into the ancestral Red River. This hypothesis was essentially disproven by Meneley *et al.* (1956), who, through the use of well logs, traced the path of the preglacial Missouri through northwestern North Dakota into Canada, where it joined the ancestral Yellowstone River west of Estevan, Saskatchewan, before turning east to cross the Manitoba border (1956:fig.1). Wyder (1968) has studied the gravel deposits in the ancient Missouri River channel near Frobisher, Saskatchewan, where it is cut into the Ravenscrag Formation to a maximum depth of about 91 metres. The lower 61 to 46 m of this channel is filled with preglacial gravels which are overlain by glacial drift (Wyder 1968:126). Elson (1958:62) has suggested that the Missouri River joined the ancestral Assiniboine River west of Brandon, Manitoba, and subsurface mapping of bedrock topography (Klassen, Wyder and Bannatyne 1970) has identified evidence of preglacial valleys near the towns of Tilston and Pipestone.

Preglacial river courses in Montana and North Dakota have been examined extensively by Lemke *et al.* (1960; 1965) and Bluemle (1972). In southern Manitoba, ground resistivity, drilling and well logs have indicated a broad trough 48 km wide and 60 m deep passing directly through the Souris vicinity to drain into Hudson's Bay (Klassen and Wyder 1970; Klassen, Wyder and Bannatyne 1970). Other major preglacial valleys in Manitoba have been identified near Portage la Prairie, Dauphin and Winnipeg, all presumably draining northward (Klassen and Wyder 1970:map; Klassen, Wyder and Bannatyne 1970:map; Bannatyne and Teller 1984:fig.12).

3.6 Saskatchewan Gravels

3.61 Description of Deposit

The term "Saskatchewan gravels" is generally applied to numerous, scattered deposits of gravel and sand found on the Canadian Prairies which represent the last phase of deposition by preglacial rivers on the Northern Plains prior to disruption of drainage by Pleistocene ice sheets (Stalker 1968:155). Quartzitic Saskatchewan gravels have been identified throughout the western Canadian Plains and the northern Great Plains in the USA, including northern Montana. Although these gravels actually occur on multiple levels, they are extremely difficult to separate and are usually grouped together under one formational name. As well as mantling large areas of Alberta, they are found in the major preglacial valleys in Saskatchewan and have also been identified (Elson 1958:63) in southwestern Manitoba. They appear to lie everywhere unconformably upon bedrock and are often covered by glacial drift (Westgate, 1968:66). Although Horberg (1952) believed

the Saskatchewan gravels to be of non-glacial, late Tertiary origin, more recently, Stalker (1962, 1963a, 1963b; 1968) has stated that the Saskatchewan gravels are early Pleistocene in age.

In composition, the gravel component resembles Cypress Hills material, consisting of up to 98% quartzite, argillite and chert (Westgate 1968:90). Although some rocks of local origin are almost always incorporated, no material from the Canadian Shield is present. Most of the pebbles in the deposit are red or brown, and many take their reddish colour from ferric oxides. Cobbles may be consolidated by a calcareous or ferruginous cement, or lie loose in a sandy matrix (McConnell 1885:70).

Stalker (1968:158) has identified 11 criteria for the designation of a deposit as Saskatchewan gravel and sand. The major criteria deal with its composition and relation to bedrock: the deposit must not contain any stones of Precambrian Shield origin and must lie directly upon bedrock and at lower level than nearby (older) deposits laid down in the Oligocene to Pliocene. If the deposit is located within a valley, that valley must have the broad profile typical of preglacial valleys. The presence of one or more glacial till sheets over the deposit further increase the likelihood of its being Saskatchewan gravel and sand.

3.62 Origins and Stratigraphic Relationships

The Saskatchewan gravels "floor the major preglacial valleys and cover the several alluvial terraces below the erosional surface situated at about 4000 feet [1220 m] above sea level ... a surface probably correlative to the Flaxville level of Collier and Thom" (Westgate 1968:66). In other words, the Saskatchewan gravels correspond to Alden's no.

2 bench. According to Westgate (1965:90), the gravel is derived primarily from Beltian and Paleozoic rocks in the Rocky Mountains, but a significant proportion come from the Flaxville and Cypress Hills Plateaux.

The same preglacial rivers that were responsible for the formation of the Cypress Hills and Wood Mountain uplands carried large amounts of material eastward from the Rockies well into the Pliocene. Some of this load was deposited on the floodplains of these rivers; the remnants of these deposits constitute the earliest Saskatchewan gravel and sand. The Laurentide ice sheet ended this episode of deposition by blocking drainage and forcing streams to deposit their loads. Although the ice did not overrun all affected areas at once, its impact was felt progressively westward as base levels of rivers were raised. Currents slowed and forced the streams to deposit part of their loads (Stalker 1968:157). These deposits, laid down immediately prior to glaciation, are also considered Saskatchewan gravel and sand. Because proglacial lakes formed in many preglacial valleys, Saskatchewan Gravels are often overlain by clay and silt (Klassen 1989:139). Whitaker and Christiansen (1972) identify the Saskatchewan Gravels as the lowest deposits in a larger group of stratigraphic gravel, silt and clay designated the Empress Group. These deposits overlie Cretaceous and Tertiary bedrock but underlie glacial till in southern Saskatchewan and Alberta. Klassen (1989:138) notes that the Saskatchewan gravels unit is "largely equivalent" to the Souris Gravel and Sand. It must be assumed that the presence of shield rocks in the Souris deposits is the factor which precludes the two units from being considered entirely equivalent.

Although some dispute still exists over the age of the Saskatchewan gravels, the presence of the Pleistocene woolley mammoth, Mammuthus primigenius, and Pleistocene *Equus sp.* remains, in addition to C-14 dates of wood contained in the gravels near Edmonton and Lethbridge (which yielded a date of > 36,600 years and > 54,500 years respectively) indicate that the oldest (and topographically highest) Saskatchewan gravels are younger than Pliocene Flaxville deposits, and are likely early to late Pleistocene in age (Westgate 1965:91). A Pleistocene age is further supported by evidence uncovered near Edmonton, where frost wedges and involutions uncovered in Saskatchewan gravel and sand indicate that these deposits were undoubtedly laid down in a periglacial environment (Westgate and Bayrock 1964).

3.7 Souris Gravel and Sand

3.71 Description of Deposit

Deposits of gravel and sand which outcrop near Souris, Manitoba, are incompletely understood and have a complex depositional history. Current knowledge is based almost entirely upon research conducted by R.W. Klassen (1969, 1971), who was the first to designate these deposits the 'Souris gravel and sand' (1969:2). Siliceous rocks such as agate, fused shale or porcellanite, chert, silicified wood and silicified lignite are readily found where the deposit is exposed in a local gravel pit and along the banks of the Souris River (Fig.2).

The Souris gravel and sand deposit has been identified as a mixture of Tertiary gravels and sands with material introduced by glaciers and by glacial and interglacial

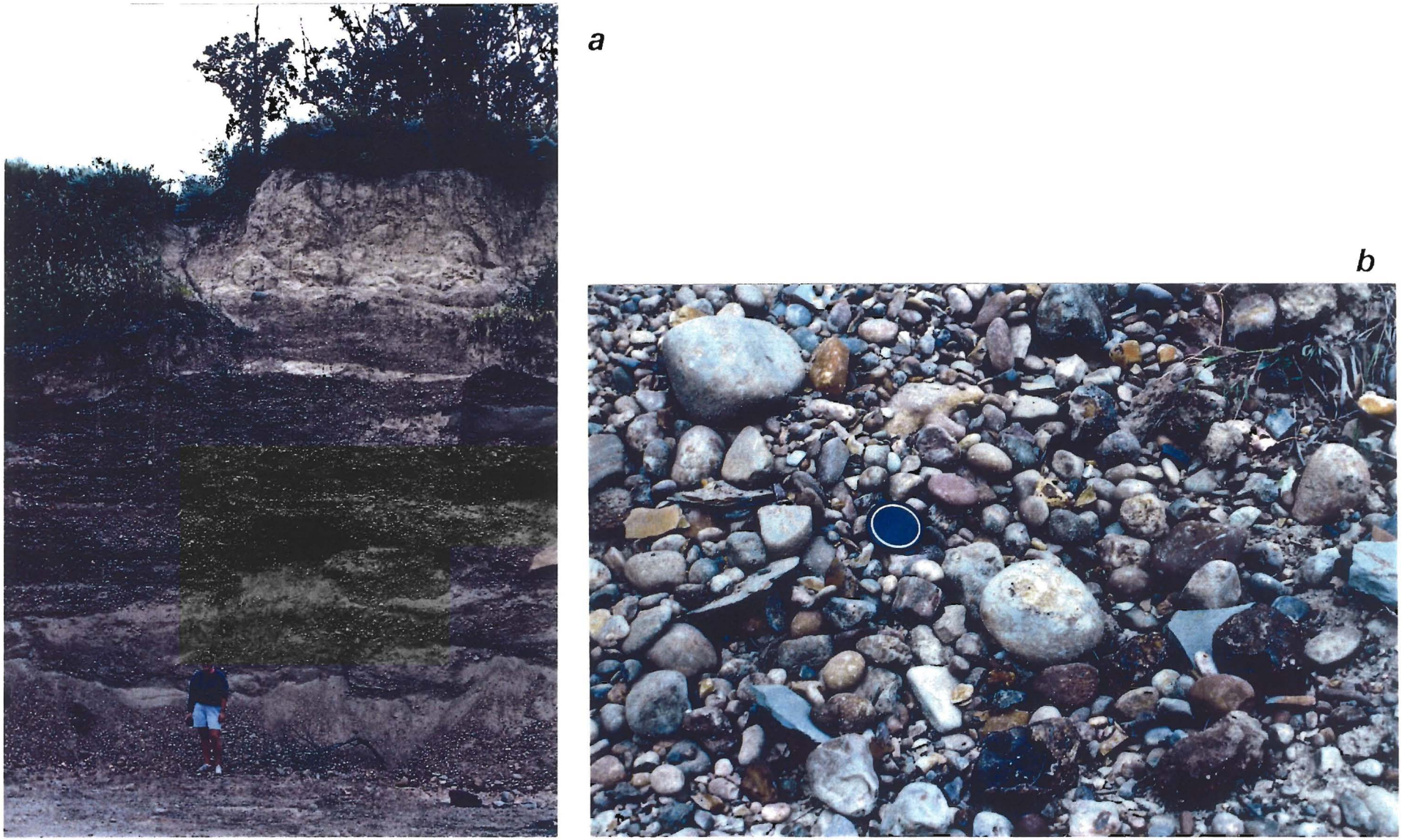


Fig. 2: (a) Souris gravel and sand exposed in the town of Souris; (b) siliceous cobbles in talus slope at bottom of exposure.

3.72 Origins and Stratigraphic Relationships

The Souris gravel and sand in the reference section at Souris, Manitoba, was deposited on the eastern side of the ancestral Missouri River valley (Klassen and Wyder 1970:6). The rocks of which the gravel is composed have a primarily eastern or Rocky Mountain source, but are mixed with glacial erratics. The uppermost portion of the deposit is truncated by an erosional unconformity and overlain by glacio-fluvial sediments. These sediments were deposited by proglacial Lake Hind, the last glacial lake to occupy the area. Testing across the preglacial Missouri valley near Frobisher, Saskatchewan, has indicated that gravel of a very similar lithology to the Souris exposure is also present there, and that these deposits are also in a position on the side wall of the valley (Klassen and Wyder 1970:6). Compositional analysis of the Frobisher deposit has indicated that it contains more than 70% gravels of a preglacial origin. These gravels are a distinctive light brown colour and are well-rounded, suggesting that, like the gravels at Souris, they were transported some distance in a fluvial environment. At no point were drift gravels identified below the preglacial material (Wyder 1968:117). Souris gravel and sand has also been identified in preglacial valleys in Manitoba near Shellmouth, Dropmore, Oak Lake, Villette and Pierson. Similar deposits could be expected to occur in a comparable position along other preglacial valleys, but, as indicated by the presence of glacial material in the Souris exposure, there is the possibility that much of these deposits have been greatly altered or even removed completely by glacial processes subsequent to their initial deposition. Wood taken from the Shellmouth and Dropmore deposits have yielded

radiocarbon dates of >41,000 and >42,000 years B.P. respectively (Klassen 1969:Table 1).

Despite the tremendous alterations wrought upon the surface of North America by glaciation, evidence of the four most recent glacial advances and retreats or interglacials has been found. During interglacials, formerly dammed river outlets would have been re-opened and rivers possibly re-routed along the edge of the ice sheet. It is possible that, during one such interglacial, renewed drainage to the north resulted in the transport and deposition of material derived from the Saskatchewan gravels in the Souris area. This is supported by Klassen's hypothesis that the Souris gravel and sand may have been deposited by streams within northeasterly-trending preglacial valleys in the Aftonian interglacial (1971:261).

Chapter 4: Methodology

4.1 The Study Area

The study area is in the extreme northern part of the Northeastern Plains (Wedel 1961) and could be considered a transitional zone between Prairie and Aspen Parkland ecozones (Syms 1980:2). The town of Souris is located 33 km southwest of Brandon, Manitoba, in SW 1/4 LSD 9, Sec. 34, Tp. 71, R. 21 WPM, at the confluence of the Souris River and Plum Creek and at an elevation of 420 m ASL. Physiographically, it falls within the Souris Basin (Fig.1), a glacial lake basin underlain by sand, silt and clay (Klassen and Wyder 1970:3). Areas of this largely flat basin are undulating, due to the fact that the lacustrine deposits are not sufficiently thick enough to completely cover irregularities in the basin floor (Johnston 1934:5). The Souris Basin is bounded by the Souris River, Assiniboine and Boissevain Plains, which are composed of ground moraine along with some areas of end moraine and outwash. The Souris River itself began as a spillway which connected proglacial lakes Regina and Hind (Klassen and Wyder 1970:3; Kehew and Clayton (1983:203). Much of the Souris Basin was forested prior to homesteading activity in the area (Syms 1980:2). Today, it has been largely cleared of forest for cultivation or pasture, but remains treed along existing waterways, with scrub in low-lying areas.

To the southwest of Souris, a number of smaller tributaries enter the Souris River. Originally formed as run-off was diverted around the receding edge of an ice lobe, these streams cut deeply through easily-eroded deltaic sand and gravel deposits as they near their confluence with the Souris (Syms 1980:2). The Snyder II Site (DgMg-15) is located in

this area, in Sec. 33, Tp. 2, R. 27 WPM, near the confluence of Gainsborough Creek and the Souris River (Fig.1). A large number of precontact and early historic artifacts have been collected from this site over the years by both researchers and local collectors alike. The Treleaven Site (DjMb-3) is located just 1.5 km from the town of Souris, in Sec. 35, Tp. 7, R. 21 WPM (Fig.1). It is likely a precontact 'workshop', and much of the artifact assemblage recovered consists of lithic debitage from tool manufacture.

4.2 Sampling Methods

Initially, it was expected that the systematic sample collected from the Souris gravel exposure in 1978 by Young and Syms could be utilized as a source of siliceous rocks for this study. The two criteria applied to selection of material from the sample were first, that the material had to be of a siliceous material suitable for knapping, and second, the cobble should be large enough to have been worked without great difficulty. However, it soon became apparent that only a small proportion of the cobbles obtained in Syms' and Young's sample met criterion two, that is, were large enough for knapping. In fact, the majority of the cobbles in the sample measured less than 5 cm in diameter. For this reason, material from the stratified sample was supplemented by material obtained through subsequent surface collection at the same source. As this study is concerned only with characterizing material present in the Souris sand and gravel deposit which may have been utilized in stone tool production rather than any typological or quantitative analyses, this sampling method is considered adequate. In fact, it is essentially the same method which

would have been employed by the tool manufacturer -- a visual inspection for cobbles of a siliceous nature of a size deemed large enough for knapping.

Forty-four samples of agate, fused shale or porcellanite, silicified wood, silicified lignite, quartzite and chert were collected from the Souris gravel pits for analyses. Two samples of material previously collected from Souris and identified as Knife River Flint were also obtained from the Manitoba Museum of Man and Nature. In order to compare Souris material with similar material from other sources, five samples of fused shale were obtained from a Montana outcrop of the Fort Union Formation as well as material from comparative collections at the Manitoba Museum of Man and Nature, consisting of two pieces of Knife River Flint from Dunn County, North Dakota, and seven samples of quartzite and eight pieces of chert from southwestern South Dakota and eastern Wyoming. Thirteen waste flakes of fused shale, agate, and material previously identified by excavators as "petrified wood" were obtained from the Treleaven Site (DjMb-3) collection housed at the Manitoba Museum of Man and Nature for comparison with the Souris material. Twelve waste flakes of fused shale, agate, and material previously identified as "petrified wood" were obtained for analysis from Snyder II North Site (DgMg-15) collections at the MMMN. In total, 103 samples were collected for analysis (Table 1).

Sample	Material	Thin section	INAA	$\delta^{18}O$	Sample	Material	Thin Section	INAA	$\delta^{18}O$	Sample	Material	Thin Section	INAA	$\delta^{18}O$
Souris					2121	chert	X			MS-13	Saul Quarry quartzite	X	X	X
P2	silicified wood	X	X	X	P1-4	chert	X	X		MS-15	Saul Quarry quartzite	X		
P1-9	silicified wood	X			P2-1	chert	X			MS-14	Sheep Mountain chert	X		
P1-21	silicified lignite	X			P1-3	chert	X			MS-18	Sheep Mountain chert	X		
P1-51	silicified lignite	X	X	X	1386	chert	X			MS-10	Platte County chert	X		
P2-5	silicified wood	X	X	X	P1-12	chert	X	X		***Treleaven Site***				
P1-52	silicified wood	X	X	X	1391	chert	X	X		T-1	fused shale		X	X
P1-10	silicified lignite	X	X	X	P1-14	chert	X			T-2	fused shale		X	X
P1-7	silicified lignite	X			2-1-8	chert	X			T-3	fused shale		X	X
7/M4	Knife River Flint	X	X		P1-1	chert	X	X		T-4	silicified lignite	X	X	
8/M1	Knife River Flint	X	X		P2-2	chert	X			T-5	silicified wood	X		X
YS-1	fused shale	X	X	X	P1-20	chert	X	X		T-6	silicified lignite	X	X	X
YS-2	fused shale	X	X	X	P2-30	chert	X	X		T-7	silicified lignite	X	X	X
P1-11	fused shale	X			***North Dakota***					T-8	silicified wood	X	X	
P2-3	fused shale	X	X	X	DC-14	Knife River Flint	X	X	X	T-13	agate	X	X	
P2-4	fused shale	X	X		MS-17	Knife River Flint	X	X	X	T-9**	sil. wood/sil. lignite		X	X
24822	fused shale		X		***South Dakota***					T-10	agate		X	X
P1-56	fused shale	X	X		MS-8	Flint Hills quartzite	X		X	T-11	agate	X	X	X
P1-8	fused shale	X			MS-20	Flint Hills quartzite		X		T-12	agate		X	
P1-53	agate	X	X		MS-7	Flint Hills quartzite	X			***Snyder II North Site***				
P2-16	agate	X	X	X	MS-6	Hell Canyon chert	X			S-16	silicified lignite	X	X	X
2392	agate	X			MS-9	Hell Canyon chert	X	X		S-17	Knife River Flint	X	X	X
P1-17	agate	X			88-3	Chadron chert	X	X		S-19	silicified lignite		X	X
P1-57	agate	X			MS-11	Chadron chert	X	X		S-20	Knife River Flint	X	X	
P1-55	agate		X	X	MS-19	Chadron chert	X	X		S-14	fused shale		X	X
P1-54	agate		X	X	***Montana***					S-15	fused shale		X	X
P1-60	quartzite	X		X	MS-1	fused shale	X	X		S-26	fused shale		X	X
1489	quartzite	X	X	X	MS-2	fused shale	X	X		S-21	agate	X	X	X
330	quartzite	X			MS-3	fused shale	X	X	X	S-24	agate	X		
92818	quartzite	X			MS-4	fused shale	X		X	S-25	agate	X	X	
21814	quartzite	X	X	X	MS-16	fused shale	X		X	S-22	agate		X	X
464	quartzite	X			***Wyoming***					S-23**	sil. wood/sil. lignite		X	X
1383	quartzite				MS-5	Saul Quarry quartzite	X	X	X					
P1-2	chert	X			MS-12	Saul Quarry quartzite	X							

** initially identified as agate.

Table 1: Lithic Samples and Analyses Conducted

4.3 Techniques Used

A combination of four physical and chemical analyses was used in this study. Following is a brief description of the methodology of each.

4.31 Thin sections

Of the total 103 samples obtained, thin-sections were made from 76 (Table 1). These are an excellent way to view a variety of lithic attributes, such as grain shape, size, mineral or fossil inclusions. When a slice of rock is ground to a thickness of 30 microns (μm), minerals within the rock matrix will exhibit characteristic colours when viewed under a polarizing microscope. These colours do not correspond in any way to the natural colour of the minerals, but are related to differences in their refractive indices.

Six steps are involved in the preparation of thin sections:

1. A slice or chip of rock is cut or broken from the specimen.
2. One surface is ground with a successively finer series of abrasives to produce a flat surface.
3. The chip is mounted, prepared side down, on a microscope slide.
4. The exposed unground surface is then ground in the same manner as in step two.
5. The section is ground down to a thickness of 30 microns and cleaned. A cover glass may or may not be cemented over it for protection.
6. Any surplus mounting medium is cleaned off and the section labelled (Allman and Lawrence 1972:40).

Rocks that are highly weathered, highly metamorphosed, water soluble or heat sensitive are notoriously difficult to prepare. In such cases, preparation is expedited by

impregnating the sample with a hardening medium such as resin. Surface impregnation is often sufficient if the material itself is able to withstand normal cutting and grinding at thicknesses greater than 30 μm but not of sufficient strength to withstand grinding as the section nears the 30 μm stage. If thorough impregnation is necessary, care must be taken to ensure the medium flows into the specimen uniformly without disruption of composition or particle orientation.

4.32 X-Ray Diffraction

X-rays do not obey the laws of reflection or magnetism, are diffracted by crystalline material, and fog photographic paper (Allman and Lawrence 1972:225). X-ray diffraction techniques can be used to identify the constituent minerals in a material by measuring its atomic structure (Allman and Lawrence 1972:230), and can also be used to give a quantitative estimation of the concentration of those minerals (Zussman 1977:416).

XRD patterns can be obtained using either a camera or a diffractometer. The camera used most commonly for petrographic analysis consists of a light-proof cylinder into which monochromatic (single wavelength) x-rays are directed via a tube or collimator (Allman and Lawrence 1972:231). The x-rays pass through the collimator and strike a glass slide coated with a powdered sample of the material being studied. The x-rays are diffracted by the atoms within the sample and pass through to strike photographic film, which, when exposed, will show a pattern of concentric circles characteristic of a mineral. A diffractometer works on the same principles, but uses an electronic counter to measure the diffracted beam, rather than recording it photographically. The pulses recorded by the

diffractometer are transmitted to a counter, which translates the pulses into peaks on a chart. These peaks will coincide with dark areas on a photograph of the same sample, and can be compared with diffraction patterns of known minerals to identify the composition of the material. The Geological Survey of Canada maintains a catalogue of XRD patterns from mineral specimens in the Systematic Reference Series of the National Mineral Collection of Canada to aid researchers in such comparisons (Bonardi and Traill 1975).

X-ray diffraction patterns were obtained by Dr. Fred Longstaffe at the University of Western Ontario. Microscopic inspection of thin sections and INAA indicated that the chert samples being studied were from a wide variety of unrelated sources; therefore, this material was omitted from XRD and oxygen isotopic analyses. Prior to oxygen isotopic analysis, the mineralogy and purity of 40 samples of agate, quartzite, fused shale, silicified wood and silicified lignite were checked by powder X-ray diffraction using a high brilliance Rigaku rotating anode X-ray diffractometer. Mineralogical impurities in excess of 2% can be detected using this procedure.

4.33 Instrumental Neutron Activation Analysis

Instrumental neutron activation analysis is based upon the principle that energy-carrying particles of several types -- such as protons, neutrons and electrons -- can be used to bombard atomic nuclei and in so doing convert stable atomic nuclei into radioactive nuclei having a greater atomic weight than the original stable isotope. This process can be induced in a nuclear reactor; the artificially-produced radioactive nuclei will decay and "emit radiation in unique ways" (Goffer 1980:74), usually by the emission of beta-particles

and gamma rays. The amount of gamma energy produced by an isotope is proportional to the amount of the isotope present and can be recorded by detectors.

INAA is an attractive method of studying archaeological materials for several reasons. The risk of contamination is minimal and artifacts need not be powdered for irradiation (Janusas 1984:45). Only a small sample is required, and great precision and accuracy is attained with low detection limits (Goles 1977:367). The specimen being studied is sealed inside a fused silica tube and suspended in the core of a nuclear reactor (Janusas 1984:45). It is then bombarded by neutrons. Because neutrons carry no electric charge, they are not repelled by atomic nuclei and are easily able to approach the atoms of the specimen and interact with them (Goffer 1980:74). A portion of the isotopes within the sample will be penetrated by the neutrons; at this point, they become radioactive and will decay at a rate characteristic of that isotope until it returns to a stable ground state. The intensity of the radiation given off as it decays is proportional to the amount of the isotope present (Janusas 1984:45). The emissions are measured, recorded, and expressed as a series of peaks on a graph. By comparing specimen peak heights with the peaks of these known standards, the concentration of various elements in the sample can be found and expressed quantitatively.

Dr. Ron Hancock at the University of Toronto SLOWPOKE Reactor Facility provided INAA data for 60 samples of agate, fused shale, quartzite, chert, silicified wood and silicified lignite. The sixteen elements examined were Si, Al, Cl, U, Dy, Ba, Ti, Sr, I, Br, Mg, Na, V, K, Mn and Ca. Sample masses ranging from 0.584 g to 1.47 g were placed into polyethylene containers and irradiated serially for 5 minutes at a neutron flux

of 2.5 x 10^{11} neutrons/cm^{-2}/s^{-1}. After a delay of between 11 and 21 minutes (to let ^{28}Al die to non-interference levels), the samples were counted for 5 minutes each using a germanium detector-based gamma ray spectrometer. Wood and lignite samples were recounted for 5 minutes after about 6 hours and fused shale samples were recounted the next day to get better values for Na and K.

4.34 Oxygen Isotopic Analysis

Analysis of stable isotopic composition has been used in the geological sciences for several decades, primarily in the determination of paleoclimates. Although its application to archaeology is fairly recent, it holds significant promise for the solution of archaeological problems (Janusas 1984:47).

In most elements, isotopic composition appears to be independent of geological source (Goffer 1980:57). In a very few cases, however, isotope concentrations do vary with source. Notable examples include lead, oxygen, strontium and sulphur. Oxygen in particular has been used to differentiate between visually inseparable materials (Janusas 1984; Herz 1987; Coleman and Walker 1979; Knauth and Lowe 1978; Shackleton and Renfrew 1973).

In conducting isotopic analysis, a mass spectrometer is used to determine the concentration of various isotopes in a sample. An ion source emits positively charged ions, which are separated into a mass spectrum by a series of magnetic fields. Atoms of greater mass and charge are deflected to a lesser degree than lighter atoms. These spectra are directed onto photographic film and a mass spectrograph is used to determine the

relative abundance of isotopes in a given element within the specimen (Goffer 1980:56). The difference between the concentration calculated is plotted and compared with a suitable standard.

Oxygen isotopic analyses of 40 samples (Table 1) were conducted at the University of Western Ontario by Dr. F.J. Longstaffe. Oxygen for isotopic analysis was liberated quantitatively from dried 15 mg samples by reaction with bromine pentafluoride at 600°C (Clayton and Mayeda 1963). Prior to reaction, samples were outgassed for two hours in vacuo at a temperature of 300°C. Oxygen was converted to carbon dioxide by reaction with an incandescent carbon rod, and the $\delta^{18}O$ value of the resulting gas measured using a Fisons OPTIMA dual inlet, gas-source mass spectrometer. Results are reported using the normal δ-notation in permil (‰) relative to Vienna Standard Mean Ocean Water (V-SMOW). Reproducibility of duplicate samples is normally better than $\pm$ 0.2 ‰. The University of Western Ontario laboratory routinely analyzes international standard NBS 28 at $+9.72 \pm 0.15$ ‰.

Chapter 5: Geological Origins and Distribution of Study Materials

5.1 Chert

Chert forms from the concentration of biogenic silica which is present in marine sediments. Many marine organisms, such as radiolarians and sponges, secrete silica to form the exoskeleton within which they live. When these organisms die, their siliceous skeletons are deposited in sediments, break down and become disseminated. As the organic material within decays, the pH of the sediments decreases, triggering the simultaneous dissolution of calcium carbonate and the precipitation of silica to form either chert nodules or beds, depending on the amount of silica present (Eley and von Bitter 1989). Chert most commonly occurs in limestone and dolomite, and contains mineral impurities in the form of iron and manganese oxides, carbonates, carbon and various clay minerals.

The cherts examined in this study came from a number of different sources. Two samples (MS-14, MS-18) of Sheep Mountain Dendritic Jasper and one of Platte County chert (MS-10) were obtained from *in situ* outcrops in Wyoming, while two samples of Hell Canyon chert (MS-6, MS-9) came from outcrops in Custer County, South Dakota. Erosion of chert-bearing deposits by glaciation and stream erosion have produced extensive gravel and till deposits containing well-rounded cobbles of chert throughout most of North America. The chert cobbles collected from the Souris gravel and sand deposit originated in Proterozoic and Phanerozoic rocks in the Rocky Mountains. As erosion of the uplifting mountains commenced in Tertiary times, these cherts were redistributed as cobbles in

gravel deposits over a wide area of the Northern Plains. Cobbles of Chadron chert (88-3, MS-11, MS-19) from an aboriginal quarry site (39FA67) near Oelrichs, South Dakota, were redeposited in a similar manner. These cherts occur in the conglomerate at the base of the Chadron Formation as secondary, well-rounded (waterworn) cobbles, and are thought to be derived from older Mississippian age geological formations in the Black Hills of South Dakota, such as the Pahasapa Limestone (Ahler 1977:134).

Chert is extremely variable in both colour and texture. Numerous analyses (for example, Sieveking *et al.* 1972; Luedtke 1978, 1979; Lazenby 1980) have shown that it exhibits a wide range of geochemical variation, not just between widespread geological localities, but within a single formation and even within a single cobble. This variation, in combination with chert's ubiquitous occurrence, makes individual chert types notoriously difficult to characterize. Despite these difficulties, a number of attempts at characterizing various chert types by chemical and physical means have met with a measure of success (Ingham and Dunikowska-Koniuszy 1965; Parkins 1977; Eley and von Bitter 1989; Prothero and Lavin 1990; Lavin and Prothero 1992).

5.2 Agate

Agate is found in a wide range of deposits. Most is formed as a secondary filling of chalcedonic silica in fissures, veins and gas-filled cavities in rock, usually lava flows. Larger cobbles often have a flattened appearance, resulting from the inability of the original cavity to maintain its round aspect under the pressure of the surrounding lava

(Dana 1962:215). More rarely, agate nodules may form as a cast in cavities previously occupied by trees; hence, the wood-like appearance of some of the Souris agates.

Chalcedonic silica exists in solution as an extremely finely-divided colloid, and is introduced to a cavity by percolation either through the surrounding rock or through fissures. Precipitation of the silica begins at widely-spaced centres of crystallization which usually form on some solid surface, such as the interior of a rock cavity. Silica is most commonly deposited as bands of radiating fibrous bundles, in which the fibres in each successive band grow from the free ends of preceding fibres (Ingham and Dunikowska-Koniuszy 1965). These discrete bands represent rhythmic deposition of the silica from solution (Dana 1962:216).

In North America, agates may be found *in situ* in the volcanic rocks of the Keewanaw Peninsula and Isle Royale, Michigan. Commonly called Lake Superior agate, it also occurs in beach deposits on the lake and in adjacent parts of Minnesota and Ontario (Dana 1962:215). Similar sources have been identified throughout the United States and Mexico and in eastern Canada, while gravel bar deposits along the Yellowstone River in Oregon, Wyoming and Montana are often cited as secondary sources. The assumption is that the original rock formation within which the agates formed has eroded away, leaving the resistant silica cobbles to be transported by ancestral and contemporary rivers (Dake, Fleener and Wilson 1938). Agates are found throughout the Northern Plains in Tertiary gravel deposits.

Bentonite is a decomposition product of water-lain volcanic ash (Murata 1940:586). The distribution of bentonite seams in North America suggest that a great deal of volcanic

activity occurred during the late Cretaceous in Western Montana (Caldwell 1983:303). It is believed that bentonite seams decrease with distance from the source; bentonite seams are thicker and more numerous in rocks of the Cypress Hills than in rocks of the same age in the South Saskatchewan River valley, which are in turn more abundant than in equivalent rocks of the Riding Mountain region in Manitoba (Caldwell 1983:303). The lava flows produced by this volcanism could have provided numerous cavities for agate formation and later erosion by preglacial rivers. Given the northeasterly flow of many preglacial rivers across the Northern Plains, it is possible that some or all of the agates which were deposited at Souris formed in the lava flows of western Montana.

5.3 Fused shale (porcellanite)

Fused shale is a vitreous or porcelain-like material found in varying amounts on sites throughout the northern Great Plains. It has been known by a variety of other names, including baked shale, fired brick, metamorphosed siltstone, grey chert, porcelanite, porcellanite, porzellanite and porcellanjaspis, although the latter two terms have been applied only to fused shale in European coalfield deposits (Fredlund 1976:208). Although the term "porcellanite" enjoys wide archaeological usage, it is also problematic, as the name has been applied by geologists to a number of vitreous or chert-like materials over the years. More recently, geological usage of the term has been confined to clay-rich siliceous sedimentary rocks, and Wilson (1990) cautions that archaeological usage of the term in reference to fused or baked shale may soon be seriously outdated as well as

confusing to the reader. For this reason, the term "fused shale", which also gives some description of the material's origins, will be used herein.

The sediments in which fused shale is formed originated in the wetland marsh deposits of the Paleocene Fort Union Formation of the United States and its Canadian correlate, the Ravenscrag Formation. The Manitoba equivalent of the Ravenscrag, the Turtle Mountain Formation, outcrops in several areas in the Turtle Mountain region of southwestern Manitoba (Fig.3). The Ravenscrag and Fort Union Formations underlie glacial till over an extremely large area of the northern Great Plains, including most of Montana and somewhat smaller areas of North Dakota, Wyoming, Saskatchewan and Alberta (Fig.3).

Alden (1932:4) has described the Paleocene physiography of the northern Plains as "great freshwater lakes and marshes in which extensive deposits of sand, clay, and lignite had been accumulating." This period of prolonged deposition appears to have come to an end with the early Tertiary uplift of the Rocky Mountains; as the western margin of the continent rose and folded, inland lakes drained and continental deposits were incised by northeasterly-flowing streams. An erosional unconformity exists over the entire extent of the Ravenscrag/Ft. Union Formation, apparently the result of widespread erosion by these northeasterly-flowing tributaries. Deposits of different ages rest on this unconformity in different regions; in eastern Montana, the fluvial and lacustrine deposits of the Oligocene White River Formation; in western North Dakota, the Eocene Golden Valley Formation; and in Saskatchewan and Alberta, the coarse conglomerates of the Oligocene Cypress Hills Formation. Furnival (1946:107) describes the Ravenscrag as

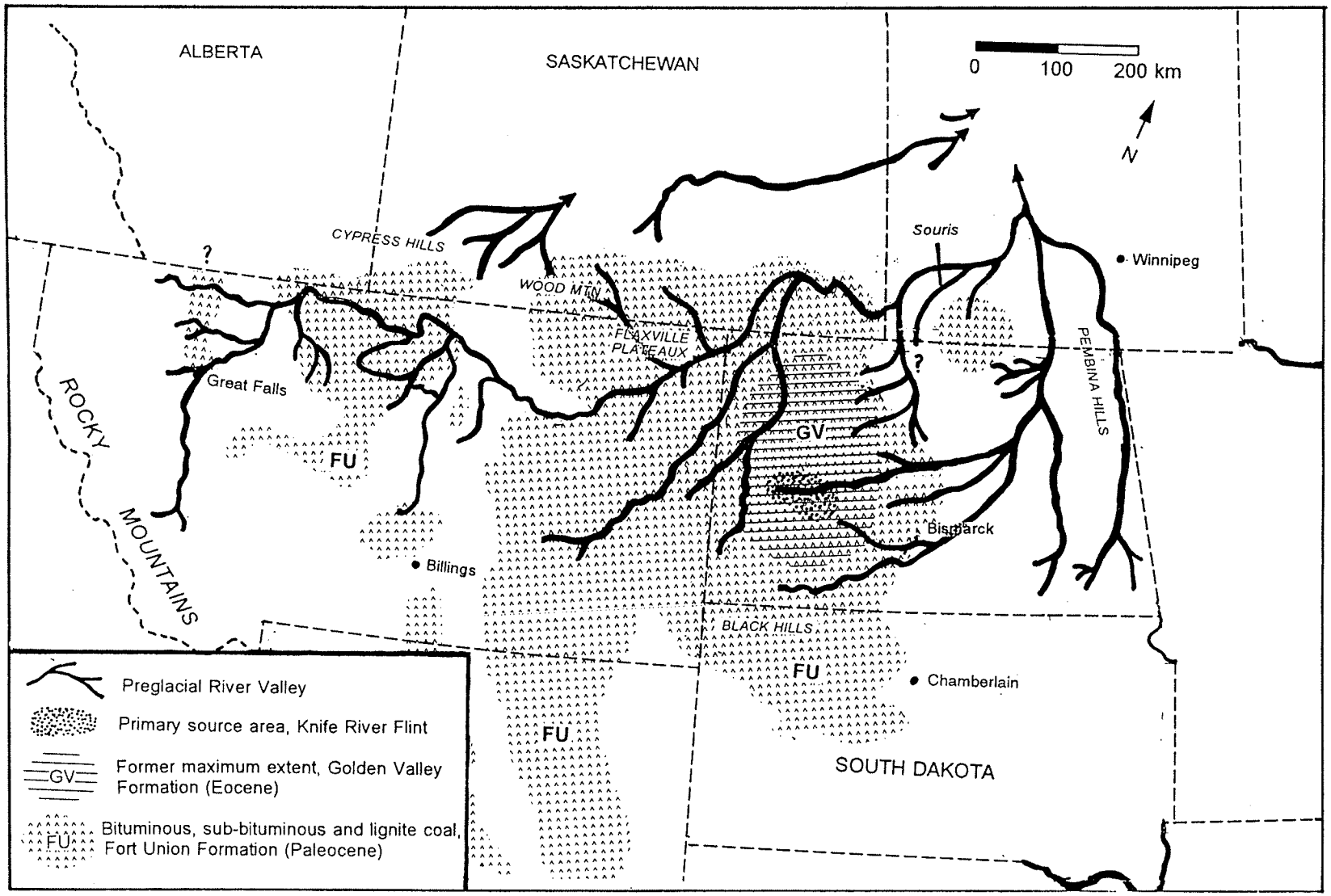


Fig. 3: Outcropping of sub-bituminous and lignitic coal, Paleocene Fort Union Formation and former maximum extent of the Eocene Golden Valley Formation. Information taken from Fredlund (1976) and Gregg (1987).

> a monotonous series of grey to buff weathering, uniformly finely bedded and interbedded, soft, grey to brownish grey clays and shales and grey and buff to light brown, fine sands, silts, argillaceous sands, and sandy shales. Lignite seams are plentiful ... thin laminae of lignitic and organic plant material are abundant ... bentonite beds and brown weathering clay ironstone concretionary layers, as well as hard sandstone and siltstone concretionary layers are present.

According to Williams and Dyer (1930:68), the Ravenscrag Formation is to be correlated most closely with the Tongue River Member of the Fort Union Formation. Consisting of light grey, calcareous sand, silt, clay and lignite beds, the Tongue River Member is up to 700 feet thick in Montana and narrows to a thickness of approximately 300 feet in North Dakota (Howard 1960:16).

Rogers (1917) has estimated that extensive deposits of lignite and sub-bituminous coal in North Dakota, South Dakota, Montana and Wyoming cover approximately 517,960 km^2. Most of this coal occurs in Fort Union sediments. In the Estevan area of southern Saskatchewan, lignite seams are thick enough to have made strip mining an economically viable endeavour.

The shales of the Fort Union Formation are transformed into fused shale when coal seams burn (Fredlund 1976). Although active coal burns can still be observed today, the phenomenon has apparently been occurring since Miocene or Pliocene times, likely since soon after the deposits formed (Bryson 1952:71). The burning process begins at the exposed surface of the seam and progresses downward; when the seams are of sufficient thickness, the great heat produced metamorphoses adjacent clay sediments. Overlying strata collapse as support is lost, and fissures open to the surface, introducing the oxygen needed to feed the combustion process. Combustion usually begins either spontaneously

or as the result of natural causes such as lightning strikes; however, there have also been documented cases of coal seams being ignited through human action. Where the burned seams cover large areas, they may have a great effect on the local topography. The metamorphosed sediments that surround burned lignite seams are very resistant to weathering and often form a protective caprock which stands out prominently in regional relief. Such relief is evident in the Culbertson Lignite Field of northeastern Montana, where extensive areas of burned coal seams along the Missouri River have created a series of "irregular-shaped mesa-like spurs separated by sharp valleys" (Beekly 1912:321).

The degree to which the sediments surrounding a burning coal seam are affected appears to be determined by a combination of heat intensity and retention, proximity or distance of the adjacent sediments from the burning seam, degree of oxidation, and the mineral composition of the surrounding sediments. Fredlund (1976:208) has recognized four different types of material produced: baked shale, porcellanite, fused glass, and fused shale and clinker. It should be noted that Fredlund's "porcellanite" is the fused shale referred to in this study.

In Montana, fused shale is abundant archaeologically, with its frequency of occurrence on sites averaging up to 95% of the total artifact assemblage (Fredlund 1976:210). It has been documented in lesser amounts on sites throughout western North Dakota, southern Saskatchewan and southwestern Manitoba. Westgate (1969) states that the coal-bearing Ravenscrag Formation is exposed regularly along the Cypress Hills escarpment in southern Saskatchewan and Alberta. Several other southern Saskatchewan outcrops of the Ravenscrag have been reported (Wettlaufer 1960; Denner and Reeves

1979), and at one of these, a pre-contact quarry site has been identified at which abundant archaeological evidence can be found in the form of fused shale cores, flaking debitage and quartzite hammerstones (Thomas 1983:76). Another such source locality in the Cypress Hills has apparently been mined for years by people who have "removed truckloads of the distinctive material as curiosities" (Thomas 1983:77). Archaeologically, fused shale debitage has been documented on many sites in southern Saskatchewan, including several in the Wood Mountain Uplands (Walker 1974).

In Manitoba, the lignite seams of the Turtle Mountain deposit are thin and there have been no reported instances of combustion and subsequent formation of fused shale, although debitage and artifacts have been recorded *in situ* in the southwestern part of the province (Syms 1979, 1980).

5.4 Silicified Wood, Silicified Lignite and Knife River Flint

Silicified wood, silicified lignite, and the homogeneous silicified lignite known as Knife River Flint are all formed by the siliceous replacement of plant material, differing only marginally in the type of plant material present. All are closely-related in both geological origins and geochemistry and will therefore be discussed together.

5.41 Distinguishing Knife River Flint from other silicified organic materials

Silicified wood, as the name suggests, consists primarily of wood replaced by silica. Degree of preservation of the original cell structure varies and may be complete enough to allow for the identification of species, or so poorly preserved that only a few

cells are visible. Silicified lignite, however, forms from layers of compressed plant material made up of woody stems, leaves, moss and other plant remains. As with silicified wood, preservation of original structure varies. Knife River Flint is a high quality (i.e., homogeneous, finely-grained) silicified lignite (see discussion below). Where original cell structure is well-preserved, it is possible to differentiate silicified wood from silicified lignite by the predominance of non-woody plant remains; where preservation is poor, it is not possible to distinguish between the two.

5.42 Questions of Provenance and the Formation of Knife River Flint

There remains some ambiguity as to the original provenance of much of the silicified wood and silicified lignite studied and the conditions under which these materials form. In the first published microscopic examination of Knife River Flint, Clayton *et al.* (1970) suggested it formed from the silicification of lignite in the HS (Hard Siliceous) bed of the upper or Camels Butte Member of the Eocene Golden Valley Formation (Table 2). A decade before Clayton's analysis, Porter suggested that "the material referred to in the archaeological literature as 'Knife River flint' is either closely related to petrified wood or else actually is part of the petrified logs" (1960:43). Porter described large cobbles of KRF which apparently exhibited a woody surface appearance. He hypothesized that KRF may have formed in the Paleocene Tongue River Member of the Fort Union Formation when cavities left by partially-decayed trees filled with silica. In this way, he suggested, the original outline of the trunk is preserved, and the interior filled by microcrystalline quartz in which short, rotted fragments of wood are suspended (Porter 1960). Although

				Eastern Montana	*Western North Dakota*
Cenozoic	Quaternary	Recent		Alluvium, eolian sands and silts, slope wash, and products of mass movement.	
		Pleistocene		Till, stratified drift, eolian sands and silts, slope wash, and products of mass movements.	
	Tertiary	Pliocene or Miocene		Flaxville gravel: Thickness, 30 ft. average. Fluvial sands and gravels. Pebbles waterworn and stained with iron oxide. Almost exclusively quartzite and chert north of Missouri River, but includes silicified igneous rocks in Yellowstone drainage basin. One probable occurrence reported in North Dakota.	
		Miocene or Oligocene		Rimroad gravel: Thickness, 30 ft. average. Fluvial sands and gravels capping high divide between Yellowstone River and Redwater Creek. Similar to Flaxville gravel.	Not reported in North Dakota.
		Oligocene		White River formation: Thickness, 250 ft. Clays, shales, sands, limestone; fluvial and lacustrine.	
		Eocene		Not reported in easternmost Montana.	Golden Valley formation: Thickness, 100 ft. Micaceous sands and silts and clay lenses, underlain by gray carbonaceous shales and white and yellow-orange clays.
		Paleocene	Fort Union formation	Sentinel Butte member: Thickness ranges from 210 ft. in Montana to 550 ft. in North Dakota. Somber sandstones, shales, clays and lignite coal; some bentonite. Lower part interfingers with upper part of Tongue River member.	
				Tongue River member: Thickness ranges from 700 ft. in Montana to 300 ft. in North Dakota. Light-gray, calcareous sand, silt, clay, and numerous lignite beds; weathers yellow to buff; loglike concretions as much as 30 ft. thick.	
				Lebo shale member: Thickness, 400 ft. Dark shale and thin beds of white sandstone and sandy clay.	Ludlow (250 ft.) and Cannonball (300 ft.) members: The continental shales, sandstones and lignite of the Ludlow grade eastward into the marine sands and clays of the Cannonball.
				Tullock member: Thickness 165 ft. Light and dark shales and sands, locally yellowish; coal seams in dark shales.	
Mesozoic	Cretaceous	Upper Cretaceous		Hell Creek formation: Thickness ranges from 575 ft. to 100 ft., west to east. Largely shale in Montana but some sandstone in lower part and a persistent coal seam at top. Gray to brown bentonitic sandstone and shale in North Dakota.	
			Montana group	Fox Hills sandstone: Colgate sandstone -- thickness, 80 ft. Brown sandstone with concretions. Basal member -- thickness 80-200 ft. Yellow clay, silt, sand.	Fox Hills sandstone: Thickness, 180-320 ft. Brown to gray sandstone.
				Bearpaw shale: Thickness, 1,200 ft. Dark-gray shale; layers of bentonite.	Pierre shale: Thickness, 2,390 to 930 ft., west to east. Dark-gray bentonitic shale with ironstone concretions and selenite. Present also in the Cedar Creek anticline in eastern Montana.

Table 2: Stratigraphy of exposed formations of eastern Montana and western North Dakota (Howard 1960).

somewhat contrary to Clayton's analysis, Porter's theory found support as recently as 1983, when thin sections of KRF from both the primary source in North Dakota and the secondary gravel deposit at Souris were identified as silicified wood, with no mention of other plant remains being present (Thomas 1983). However, this theory does not explain why KRF is not widely found in deposits across the Northern Plains in which silicified wood is found in abundance. It is also unclear whether other plant material was present in the samples described by Porter; if so, his description is not inconsistent with the definition of silicified lignite given above. Therefore, Clayton's definition of Knife River Flint as silicified lignite will be adopted herein.

Further clarification should be given to the use of the term "flint" rather than "chalcedony". Many references to Knife River Flint in the past literature refer to it as "Knife River chalcedony" or "dark brown translucent chalcedony" (Clark 1984:175). This name is, however, inconsistent with the geological definition of chalcedony. According to current definition, *chalcedony* is defined as a microcrystalline variety of quartz, having a fibrous structure. It is brown to grey in colour, waxy, and is deposited in cavity fillings from aqueous solutions (Klein and Hurlbut 1985:442). In contrast, *flint* and *chert* are granular microcrystalline varieties of quartz. The distinction between the two is somewhat arbitrary; commonly, the term "flint" is used to describe dark, siliceous nodules found in chalk or limestone deposits, while "chert" is used for lighter coloured, bedded deposits (Klein and Hurlbut 1985:442). Microscopic examination of the silicified lignite from the Knife River quarries reveals a granular structure; thus, use of "Knife River chalcedony" is deemed incorrect, and the term "Knife River Flint" is preferred.

5.43 Geological Origins

Siliceous replacement of wood can be by either fibrous chalcedony or micro-crystalline quartz grains. Cell walls are often replaced by finely fibrous chalcedony when wood is silicified (Scurfield and Segnit 1984:157), while cell luminae are commonly infilled by microcrystalline quartz. Chalcedony tends to preserve the original cell structure better than microcrystalline quartz. When quartz grains are the replacement medium, a single grain often encompasses a number of wood cells, either obliterating them or preserving them as faint ghost-like outlines visible under plane polarized light (Scurfield and Segnit 1984:158).

Replacement of organic material by silica begins at closely-spaced centres of crystallization. Under conditions of replacement, many places exist for crystals to nucleate. When filling a cavity, nucleation can only occur on the cavity surface or on other grains. Individual crystals grow outward until they encounter the advancing edges of surrounding crystals. The proximity of the nucleation, and therefore the grain size of the quartz, may be determined by the rate of replacement (Folk and Weaver 1952). Replacement tends to favour close spacing and therefore the formation of microcrystalline quartz rather than fibrous chalcedonic silica (Folk and Weaver 1952).

Volcanic ash is a naturally-occurring silicate which is atomized by volcanic explosions. Ejected into the upper atmosphere, it may settle thousands of miles from its source in beds of varying thickness (Crawford 1955:7). Pumicite may be a significant contributor of silica for the silicification of wood and other detrital plant remains. Large amounts of silica are liberated when the volcanic ash is weathered, and the silicification

of plant remains is greatly enhanced when they are buried in sediments rich in volcanic ash (Murata 1940). The presence of pumicite is well-documented throughout Alberta and Saskatchewan in close association with Cypress Hills and Wood Mountain deposits (Crawford 1955).

Lignite is also composed of plant material, being a brownish black coal intermediate between peat and bituminous coal. It forms by the compaction under pressure of peat -- partially-carbonized vegetable tissue formed by the decomposition of plants and wood in water or bogs. In the presence of silica-rich groundwater, this material, like wood, may become silicified. Again, replacement is by microcrystalline quartz, and plant cell walls are often infilled with fibrous chalcedony.

The silicified lignite known as "Knife River Flint" has long been an important material to Native groups throughout the Northern Plains, and has been widely used from Clovis to late pre-contact cultures (Clark 1984:175). Given its importance, distribution, and the amount of study it has received, it is somewhat surprising to realize that it has only relatively recently become known to archaeologists. The first published account by Crawford appeared in 1936, but it was only in the 1940s that archaeologists began to connect the brown chalcedony found on midwestern sites with the North Dakota flint (Clark 1984:173).

As noted, Knife River Flint (KRF) may have formed from the silicification of lignite in the HS bed of the Eocene age Golden Valley Formation (Clayton *et al.* 1970). Although the Golden Valley Formation is thought to have covered much of North Dakota (Fig.3), it is possible that silicification took place over a relatively localized area where

the combination of plant debris, soil and groundwater chemistry and topography were favourable, rather than throughout the entire extent of the bed (Clayton *et al.* 1970; Ahler 1986). Other researchers have hypothesized that lignite beds over a fairly large geographic area in North Dakota and possibly eastern Montana may have been transformed into KRF by similar processes working at different geological times (Gregg 1987:369). Alternatively, KRF may also have been formed by the silicification of lignite beds within the extensive Fort Union/Ravenscrag group. Notably, a layer of bentonite and volcanic ash up to 5.8 m thick has been identified in the upper or Sentinel Butte Member of the Ft. Union Formation in western North Dakota (Forsman 1983). If these deposits are a source of Knife River Flint, it could be expected to occur throughout eastern Montana, eastern Wyoming, southern Saskatchewan and northwestern South Dakota (Clayton *et al.* 1970:287).

5.44 Distribution

According to Frison and Stanford (1982), silicified wood is widespread in occurrence on the Northern Plains. Murata (1940) identifies silicified wood in a number of sedimentary and volcanic geological formations in the United States, covering an extensive geographical area which includes Nebraska, Wyoming, Montana and North and South Dakota. Lemke (1960) has identified silicified wood in the Fort Union Formation in the Souris River region; others have described silicified tree stumps in the Tongue River Member of the Fort Union Formation in Powder River County, Montana (Bryson 1952) and underlying the Golden Valley Formation in North Dakota (Hickey 1977). Large

pieces of silicified wood have been observed in the Paleocene Ravenscrag Formation, the Oligocene Cypress Hills deposits and also, apparently *in situ*, in Saskatchewan's Upper Ravenscrag beds (Fraser *et al.* 1935), which contain volcanic ash up to several feet thick. The presence of silicified wood in Cypress Hills, Wood Mountain and Flaxville deposits indicates that it could be expected to occur in other Tertiary gravels throughout the Northern Plains. Ravenscrag exposures have been identified in the southern Frenchman River Upland, the Wood Mountain Upland, and in the Twelve Mile Lake, Lake of the Rivers and Big Muddy Valleys (Fraser *et al.* 1935). Silicified wood has also been observed along the South Saskatchewan River to the east of Swift Current Creek. Interestingly, a silicified wood quarry, EdNw-28, has been identified near the confluence of Swift Current Creek and the South Saskatchewan River (Thomas, 1983:62). Large segments of silicified logs and stumps have been found at the site; similar very large tree segments with roots intact have, in the past, been recovered from the Souris gravel and sand (L. Syms, 1991, personal communication). If the Saskatchewan deposits are considered a source of these large tree segments, the manner by which they survived transport relatively intact remains uncertain.

Silicified wood with internal swirls of red, grey, white and brown, often with fairly well-preserved cell structure, has also been identified in the Wood Mountain gravels of south-central Saskatchewan, where it has been termed "agatized" wood (Broughton 1975). Clayton *et al.* (1970) note that silicified wood from Paleocene age deposits is almost identical in colour and lustre to Knife River Flint and that an examination of internal structure is often necessary in order to differentiate between the two. Artifacts made from

silicified wood have been reported on archaeological sites in Yellowstone Park, Wyoming (Dorf 1964; Syms 1980) and throughout southern Manitoba (Syms, 1980; Young and Syms 1980). In Saskatchewan, "petrified" wood artifacts have been identified at the Long Creek Site near Estevan (Wettlaufer 1960) and on several sites in the Wood Mountain Upland (Walker 1974).

Broughton (1976) reports the occurrence of silicified lignite in Miocene sand and gravel deposits in the Wood Mountain area of south-central Saskatchewan, and suggests that the Golden Valley Formation presents a likely source for the erratics (1976). Johnson (1986) notes the occurrence of silicified lignite on many archaeological sites throughout southern Saskatchewan. However, silicified lignite also occurs throughout the Paleocene Fort Union Formation, which outcrops extensively throughout Montana and North Dakota. In Saskatchewan, silicified lignite is also known as "silicified peat" (Johnson 1976).

Much of the Golden Valley Formation was presumably eroded some time late in the Cenozoic (Clayton *et al.* 1970:285), so that only scattered remnants of the original deposit remain. Although no KRF has ever been found *in situ* in extant remnants of the Golden Valley Formation, of interest is the recent discovery of KRF-like material within Golden Valley beds in the "Little Badlands" region of North Dakota (Ahler 1986:11). This mottled dark grey to dark brown opaque material forms a lens within the formation that measures from 2 to 10 cm thick and covers an area several hundred metres^2 in extent.

Knife River Flint typically occurs as cobbles and boulders in secondary alluvial, lag and slope-wash deposits. The primary source area for KRF lies in a fairly restricted part of North Dakota in Dunn and Mercer Counties, estimated to cover an area of

approximately 2000 km^2 (see shaded area, Fig.3). Notably, it is absent in glacial drift throughout this area (Clayton *et al.* 1970). It has been hypothesized that lignite beds over a fairly large geographic area in North Dakota and possibly eastern Montana may have been transformed into KRF by similar processes working at different times (Gregg 1987). This is an important point to consider when questions of local availability and trade are addressed.

Clayton *et al.* (1970) have identified 29 major concentrations or groups of quarries from which KRF cobbles were mined prehistorically. Each concentration contained from 15 to 2400 individual excavations, ranging in size from 3 m to 20 m in diameter. The average density of the pits has been estimated at 75 per hectare within the main quarry area. Lesser amounts of KRF have been observed in other locations throughout western North Dakota. It is worth noting that, although KRF is relatively rare in glacial till in the main source area, it is more common in alluvial, lag and slopewash deposits (Clayton *et al.* 1970:285). Ahler (1986:12) suggests this may be due to the way in which limestones and other softer rocks would have been broken down by transport, resulting in higher concentrations of KRF than would be found in secondary context outside the limits of glacial activity. Cobbles of KRF are commonly found in Pleistocene and Holocene age stream gravels along the present-day Missouri River well into South Dakota.

As previously stated, Hlady's (1965) assertion that Souris is a source of Knife River Flint has been vigorously disputed. Syms (1977) states that, although the occasional cobble of KRF is indeed found at Souris, it does not appear in sufficient quantities to be considered a "source", a claim with which Clayton agrees:

> I spent about 30 minutes in a Souris gravel pit near Brandon last summer and couldn't find a single pebble of Knife River Flint. I don't doubt that some Souris gravel does contain a few pebbles of Knife River Flint derived from the Knife River valley. However, I don't think it is possible that it could be abundant enough to be quarried ... (L. Clayton, personal communication 1971, cited in Syms 1977:28).

The question of whether Knife River Flint was locally available in the Souris gravels has been debated for almost three decades. The first person to address the subject was Walter Hlady, who, in 1965, reported finding significant quantities of Knife River Flint (KRF) in the Souris deposit. In later years, Leonoff (1970) and Clayton *et al.* (1970) reiterated Hlady's claim. However, subsequent research has cast doubt upon the existence of significant quantities of KRF in the Souris gravels, and it has been argued (Syms 1980) that Hlady may have misidentified KRF in his original claim. Knife River Flint can be easily mistaken for other materials, particularly silicified wood and dark chalcedony.

Artifacts made from Knife River Flint are widely distributed on sites throughout much of the Northern Plains and adjacent regions; this raw material was, prehistorically, one of the most widely-used and most sought-after in North America. This was probably due primarily to its excellent conchoidal fracture and corresponding ease of workability. Its value would have been increased by the fact that there are no more locally-occurring raw materials of comparable quality in southern Manitoba, with the possible exception of Selkirk Chert, which occurs along the Red River to the north of present-day Winnipeg, and porphyritic rhyolite, found in large quantities along the Winnipeg River. However, good exposures of Selkirk chert are rare, and where it does occur is often inaccessible due

to high water levels (Syms 1980). Porphyritic rhyolite, while possessing fairly good flaking qualities, is still not as high quality a material as KRF.

5.5 Quartzite

When water containing dissolved silica or calcium carbonate percolates through interstitial pore spaces in sand deposits, SiO_2 or $CaCO_3$ precipitates around and between the quartz grains, cementing them into a sandstone. Archaeologists have traditionally applied the term "quartzite" to any quartzitic sandstone, regardless of the degree and type of cementation. This is not problematic if an approximate identification of material type is all that is required. However, if an attempt is being made to identify possible sources for the material, it should be recognized that not all "quartzites" are created equal, and that the different types often look macroscopically identical.

True quartzites are formed from sandstones which are so well-indurated that they fracture through the constituent quartz grains rather than around them. These are most often sandstones which have undergone metamorphism subsequent to their formation. Because unmetamorphosed sandstone often appears very similar both macroscopically and microscopically to metamorphic quartzite, the need for a term to describe this similar yet different material led to the popularization of the term "orthoquartzite" in the 1940s (Pettijohn *et al.* 1987). Its use engendered more confusion, however, due to the longstanding perception that any quartzite was an extremely durable, non-friable rock. Many alternatives have been suggested, including the terms "quartz arenite" and "quartz sandstone". For simplicity, the term "quartz sandstone" will be adopted herein.

The quartz sandstones and metamorphic quartzites recognized by archaeologists as quartzite can be divided roughly into two groups. Quartz sandstone is consolidated when interstitial silica is precipitated around and between sand grains (Skolnick 1963). Microscopically, this rock contains well-rounded quartz grains, usually cemented with diagenetic silica. This interstitial silica may appear in many forms, including microcrystalline subhedral crystals (chert), coarsely crystalline subequant crystals, fibrous chalcedonic silica and euhedral syntaxial overgrowths on quartz grains (Blatt, Middleton and Murray 1980).

Quartzites form when sandstones are subjected to pressure and an increase in temperature. This causes alteration in the shape and crystallographic structure of the constituent quartz grains to adjust to the imposed stresses (Skolnick 1963). Grains typically become elongated, and small, polyhedral quartz crystals develop at stress points within the detrital quartz grains (Blatt, Middleton and Murray 1980). Individual quartz grains will also develop undulose extinction during metamorphism.

Some quartz sandstones are so well-cemented that they are true quartzites, fracturing through constituent quartz grains rather than around them (Pettijohn *et al.* 1987). Skolnick (1963) has described the formation of these quartzites by compaction and pressure solution in some detail. Pressure solution occurs under low temperature and pressure, and results in the solution and removal of quartz at points of pressure (usually grain junctures). This produces elongation and straightening of shared grain borders; if pressure continues, grain boundaries become increasingly complex and sutured. Although Skolnick suggested the term "pressolved quartzite" for these "intermediate" quartzites in

order to differentiate them from quartz sandstone and quartzite, the term does not appear to have gained acceptance in geological literature.

Ahler (1977) applies the term "solid quartzite" to a dense, finely-grained, homogeneous quartzite extracted from major aboriginal quarries in the Black Hills of southwestern South Dakota and from the Spanish Diggings quarries of southeastern Wyoming. These quartzites have been assigned to the Cretaceous Dakota sandstone (Ahler 1977). Of the seven samples obtained from comparative collections at the Manitoba Museum of Man and Nature, two were from the Flint Hills area of the Black Hills (South Dakota), and five were collected from the extensive aboriginal quarries in the Spanish Diggings area of southeastern Wyoming (Saul 1969). All comparative samples were obtained from primary source outcrops (Ahler 1977). Secondary accumulations of Cretaceous quartzite cobbles occur in the basal conglomerate of the Oligocene Chadron Formation which outcrops extensively in the White River drainage in South Dakota.

Like the quartzites in other secondary gravel deposits to the west, Souris quartzites appear to have originated in the Rocky Mountains. Erosion of the newly-uplifted Rockies in the early Tertiary by northeasterly-flowing rivers deposited large amounts of quartzitic gravel over wide areas of Alberta, Saskatchewan and Montana. In subsequent erosional events, this gravel was redeposited on a series of benches and along river valley bottoms. Similar gravels are found today as remnant plateaux and valley deposits in Montana and Saskatchewan.

Chapter 6: Analytical Results and Discussion

6.1 Physical Properties

6.11 Chert

6.111 Macroscopic appearance

All the chert samples from Souris (Table 1) are very hard, well-rounded cobbles exhibiting a wide range of colours, including an almost translucent tan, mottled opaque red and tan, purple and tan, and speckled varieties (Fig.4). No patination (weathering) of the cortex is evident, although all are heavily scarred by collision during fluvial transport. Lustre ranges from earthy to waxy. Most samples have good conchoidal fracture, and many are visually similar to the chert samples from South Dakota and Wyoming.

The Chadron chert cobbles are also well-rounded, covered by impact scars, are a mottled tan, red and grey colour, and exhibit good conchoidal fracture. Freshly fractured surfaces have a waxy lustre, although in coarser-grained examples, individual quartz grains can be seen, resulting in a "sugary" or glassy texture. The cortex of these cobbles is moderately vuggy or covered by large pits.

The two samples of Sheep Mountain dendritic jasper examined differ somewhat in macroscopic appearance. Sample MS-18 is a yellowish-brown colour with black speckles throughout, while MS-14 is a light greyish brown with red speckles throughout. Both are very finely-grained and homogeneous in texture. Lustre is waxy, and conchoidal fracture is excellent.

Although from the same geological formation, the two samples of Hell Canyon chert are very different in appearance. Sample MS-9 is finely-grained, with good

Fig. 4: (a) Souris chert; (b) Platte County chert (Wyoming); (c) Sheep Mountain Dendritic Jasper (Wyoming); (d) Hell Canyon chert (South Dakota); (e) Chadron chert (South Dakota).

conchoidal fracture and an earthy lustre. It is a tan colour, with internal bands of darker brown and grey. The cortex is rough and weathered. The second sample (MS-6) is a banded purple and grey colour, is very coarsely-grained and exhibits poor conchoidal fracture. Numerous vugs within the rock are infilled by coarsely-grained quartz, and many fractures are evident. The cortex exhibits a small degree of weathering.

The sample of Platte County chert (MS-10) is a mottled light and reddish purple with a vuggy, weathered cortex. Fracture is blocky, and numerous vugs within the rock have been infilled by coarse quartz grains. Fractures running through the rock have not been infilled by coarser quartz, but are a slightly discoloured darker purple. Freshly broken surfaces have an earthy texture.

6.112 Microscopic features

Microscopically, the cherts examined occupied a wide range of grain sizes and textures. Grain size in the Souris cherts ranged from cryptocrystalline (< 3 μm in diameter) to coarse (> 65 μm in size), although the majority were between 3 μm to about 30 μm, with coarser quartz and chalcedonic silica inclusions. Chalcedonic silica was most often observed as infilling in fractures. Several samples contained coarser quartz in which grain boundaries were fuzzy and indistinct. Dark red and brown mineral inclusions give the cobbles their mottled red and tan appearance (Fig.5a,b).

The two samples of Hell Canyon chert differ significantly microscopically as well as macroscopically. The finer-grained sample (MS-9) is a homogeneous crypto-crystalline to microcrystalline material containing quartz grains up to 26 μm in diameter. Opaque

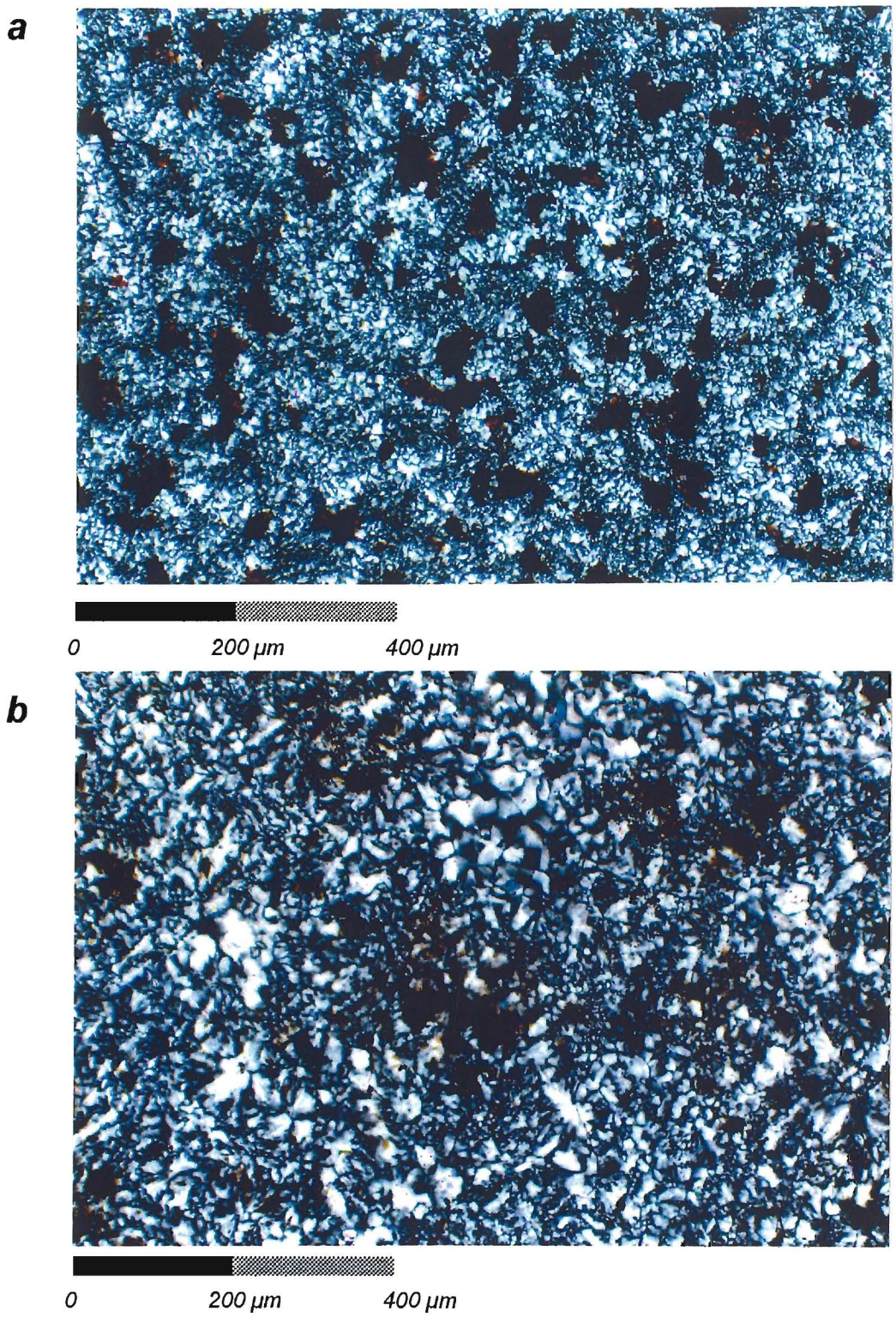


Fig. 5: Souris cherts P2-1 (a) and P1-3 (b) under crossed polars. This chert is commonly called "jasper". The red coloration is produced by hematite.

minerals, visible under both crossed polars and plane polarized light as dark spots, are more concentrated where banding occurs. Sample MS-6 has numerous vugs infilled by a combination of chalcedonic silica and drusy quartz grains of up to 85 μm in diameter in a matrix of microcrystalline quartz grains averaging 15 μm in diameter.

Although visually distinctive, Platte County chert sample MS-10 was microscopically similar to the Hell Canyon chert. It too consisted of primarily cryptocrystalline quartz with numerous vugs infilled by larger quartz crystals.

Grain size in the Chadron cherts ranges widely from < 3 μm to > 160 μm. Vugs in the rock are often infilled by a combination of chalcedonic silica and drusy quartz. Circular mineral deposits visible in sample MS-11 in plane polarized light (Fig.6a) are optically continuous across quartz grains between crossed polars (Fig.6b, arrow). This feature was not visible in hand specimens and does not occur in the mottled Souris cherts which the Chadron cobbles so closely resemble. Successive growth stages in the quartz grains (Fig.6b, lower left) are often visible. Opaque mineral inclusions appear as dark spots, and replacement of fossils also occurs. In some cases, fossils have not been replaced and are present as calcite.

Sheep Mountain dendritic jasper is a homogeneously cryptocrystalline material. The macroscopic dark "speckles" in the rock are resolved microscopically as opaque concentrations of mineral inclusions. Occasional vugs are infilled by quartz grains averaging 80 μm in diameter. As with Chadron chert, drusy quartz replacement of fossils (Fig.7) is also visible.

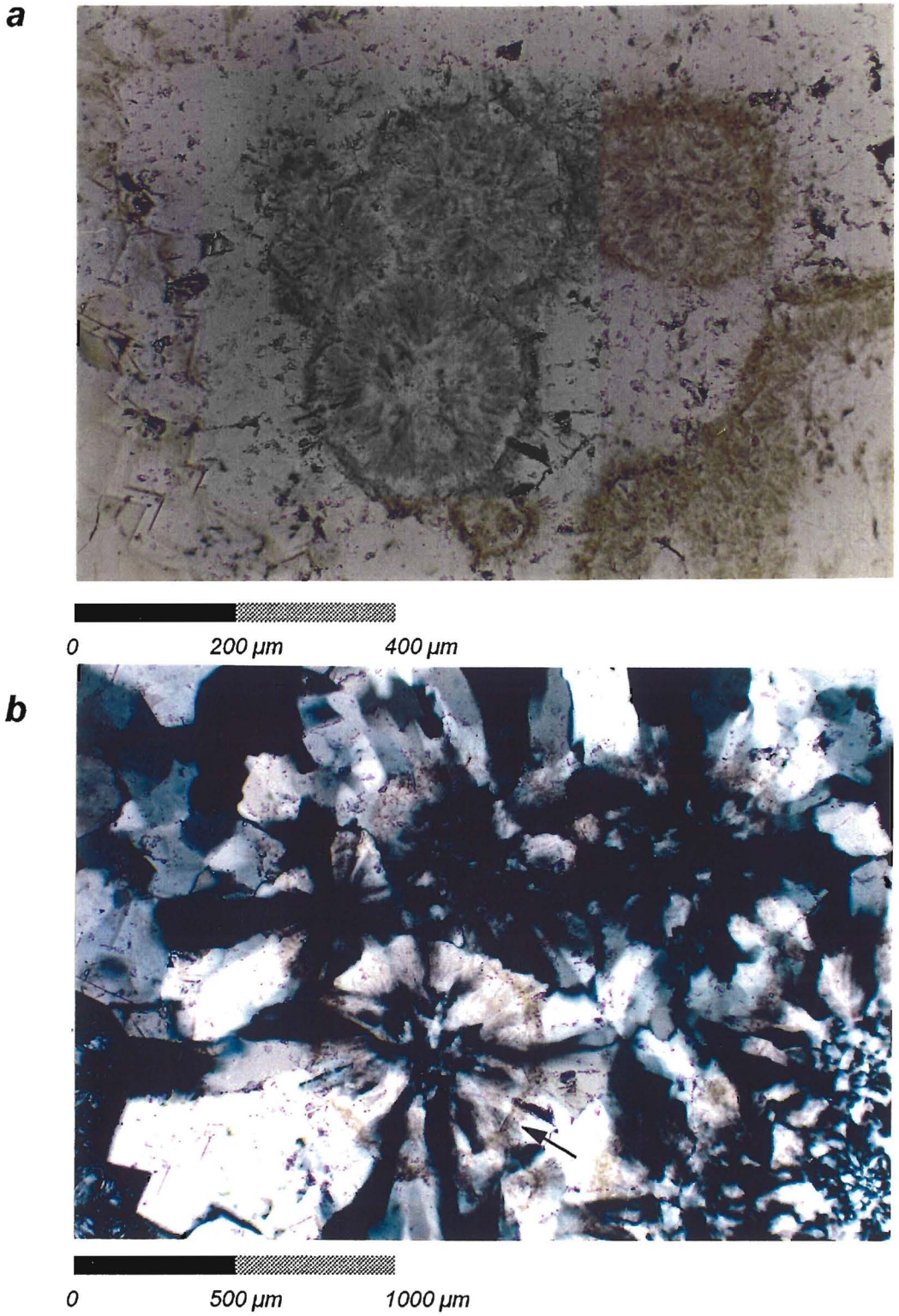


Fig. 6: Circular staining in Chadron chert MS-11 under (a) plane polarized light and (b) under crossed polars (arrow).

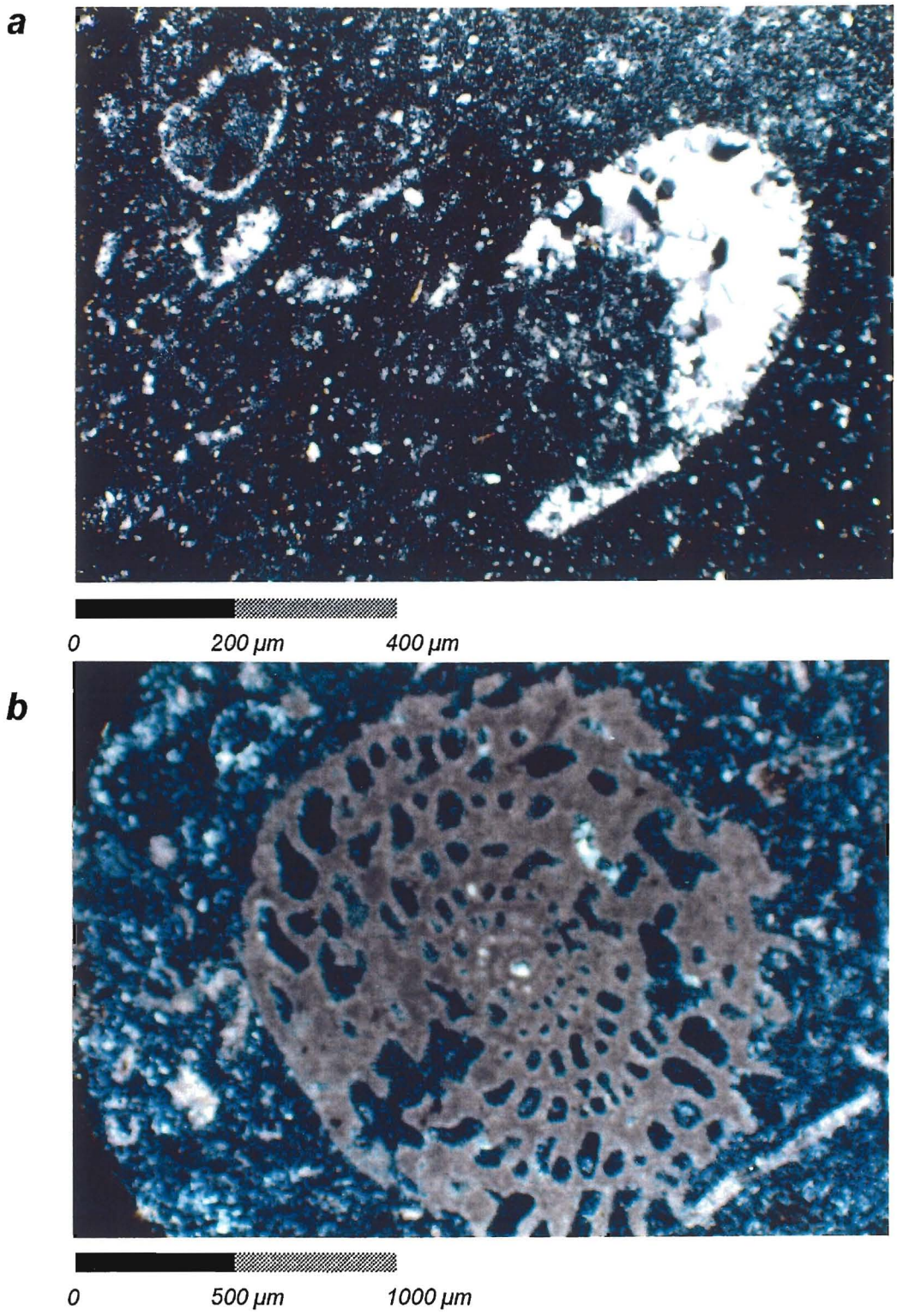


Fig. 7: Replacement of fossils by quartz in (a) MS-18, Sheep Mountain Dendritic Jasper, and (b) MS-11, Chadron chert.

Fossils in thin sections have been used with success to differentiate between cherts from different geological formations or localities (Parkins 1977; Eley and Von itter 1989; Prothero and Lavin 1990; Lavin and Prothero 1992). Fossil remains present within cherts from South Dakota and Wyoming serve to distinguish these cobbles from Souris cherts, in which fossils were largely absent.

6.12 Agate

6.121 Macroscopic appearance

Agates may range in size from small cobbles about 2 cm in diameter to larger examples up to 30 cm in diameter. Larger examples weighing hundreds of kilograms are not unknown (Dana 1962:211). The surface of the agate may be completely smooth, covered by botryoidal projections or have a rough "orange peel" texture. Distinct bands within the agate are concentric to the outer surface of the nodule and differ in thickness, colour and translucency (Dana 1962:210). Mineral inclusions produce a number of patterns, including dendritic ('moss' agates), fortification (internal bands in a polygonal pattern, reminiscent of the outline of a fortress), 'polka dot' and banded varieties. Most nodules are flattened on at least one side, owing, as stated, to the deformation of the gas-filled cavities in which many form. Agates are found in a wide variety of colours, from milky white or grey through many shades of brown and, more rarely, green, blue, lavender and black (Dana 1962:213).

Agates from the Souris gravels average 3.5 to 4.5 cm in diameter (Fig.8). All are well-rounded and are covered with the crescentic impact scars typical of cobbles which

Fig. 8: Cobbles of Souris agate.

have been transported by water. Some portions of the cortex also have a rough "orange peel" appearance. Although rounded, surfaces are knobby and irregular, sometimes with the outer appearance of wood. Most are translucent, ranging from nearly colourless to a pale brown, although smoky grey and white varieties are also found. Lustre is typically waxy. Dendritic and fortification patterns are commonly observed.

Archaeological waste flakes are translucent and pale yellowish brown to almost colourless, and most contain mineral inclusions which form small black spots. Macroscopically, small flakes of agate are similar in appearance to both Knife River Flint and silicified wood, and the very small size of the waste flakes studied makes identification difficult. In particular, banding in small fragments of agate can be easily mistaken for the growth rings in wood.

6.122 Microscopic features

Agates are distinctive in thin section, consisting primarily of fibrous bundles of chalcedonic silica. Minimal interference with crystal growth produces a radiating or sheaf-like appearance, in contrast with the random, interlocking equant grains of microcrystalline quartz found in cherts. Minerals such as iron and manganese oxides and salts, when precipitated from the solution, contribute to the variety of patterns observed. Where radiating bundles meet, a 45° angle is formed between silica bundles. Between crossed polars, several sections display alternating bands of fine and coarse chalcedonic silica that are not visible under plane polarized light. Bands are optically continuous across silica bundles (Fig.9a,b). Fractures filled with coarser silica cut across both coarsely- and

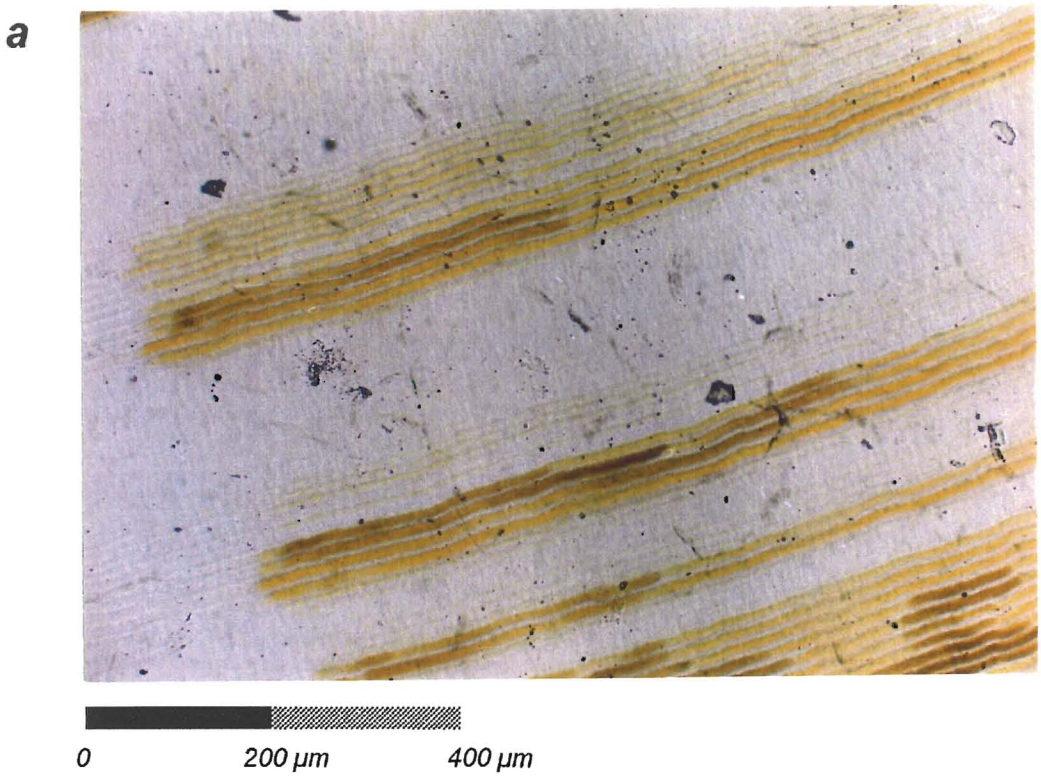


Fig. 9: Banded agate P1-17 under (a) plane polarized light and (b) under crossed polars, showing optically continuous banding across fibres.

finely-grained bands of chalcedonic silica. Most of the agates examined show a combination of fibrous silica with microcrystalline quartz and larger equant quartz grains (Fig.10). In sample 2392, microcrystalline quartz has formed as an infilling between adjacent fibrous bundles. The centre of this agate is filled with very large equant quartz grains.

6.123 X-ray Diffraction Patterns

The X-ray diffraction patterns obtained for all agates are typical of quartz; only trace quantities of other phases can be detected (Fig.11).

6.13 Fused Shale

6.131 Macroscopic appearance

Fused shale or porcellanite appears in a wide range of colours, with various shades of grey being most common and red and purple coloration less usual. Banded grey and yellow and black and yellow varieties are also found in parts of Montana. At Souris, grey, red and purple fused shale are found, but the banded grey and yellow variety appears to be absent (Fig.12).

Fragments of grey fused shale obtained from Montana have a very thin, hard brown surface rind. A similar hard rind on a sample of red Montana fused shale (MS-2) is whitish-yellow. These samples, found at the base of an outcrop of the Fort Union Formation, are jagged and irregular in shape because they have not been transported by water.

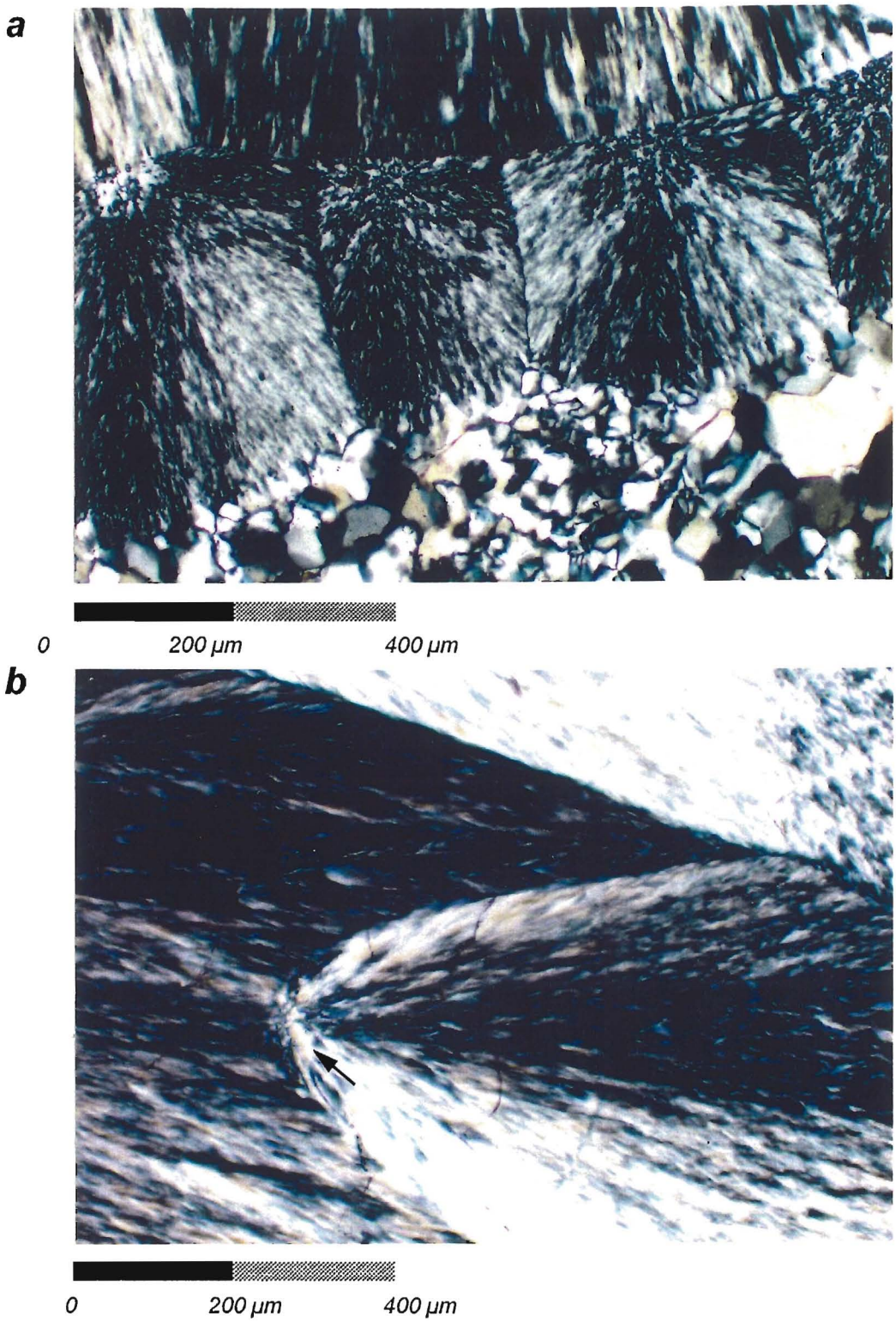


Fig. 10: (a) Treleaven agate T-13, showing combination of fibrous chalcedonic silica and microcrystalline quartz, and (b) Snyder agate S-24, showing point where crystallization of silica bundle began.

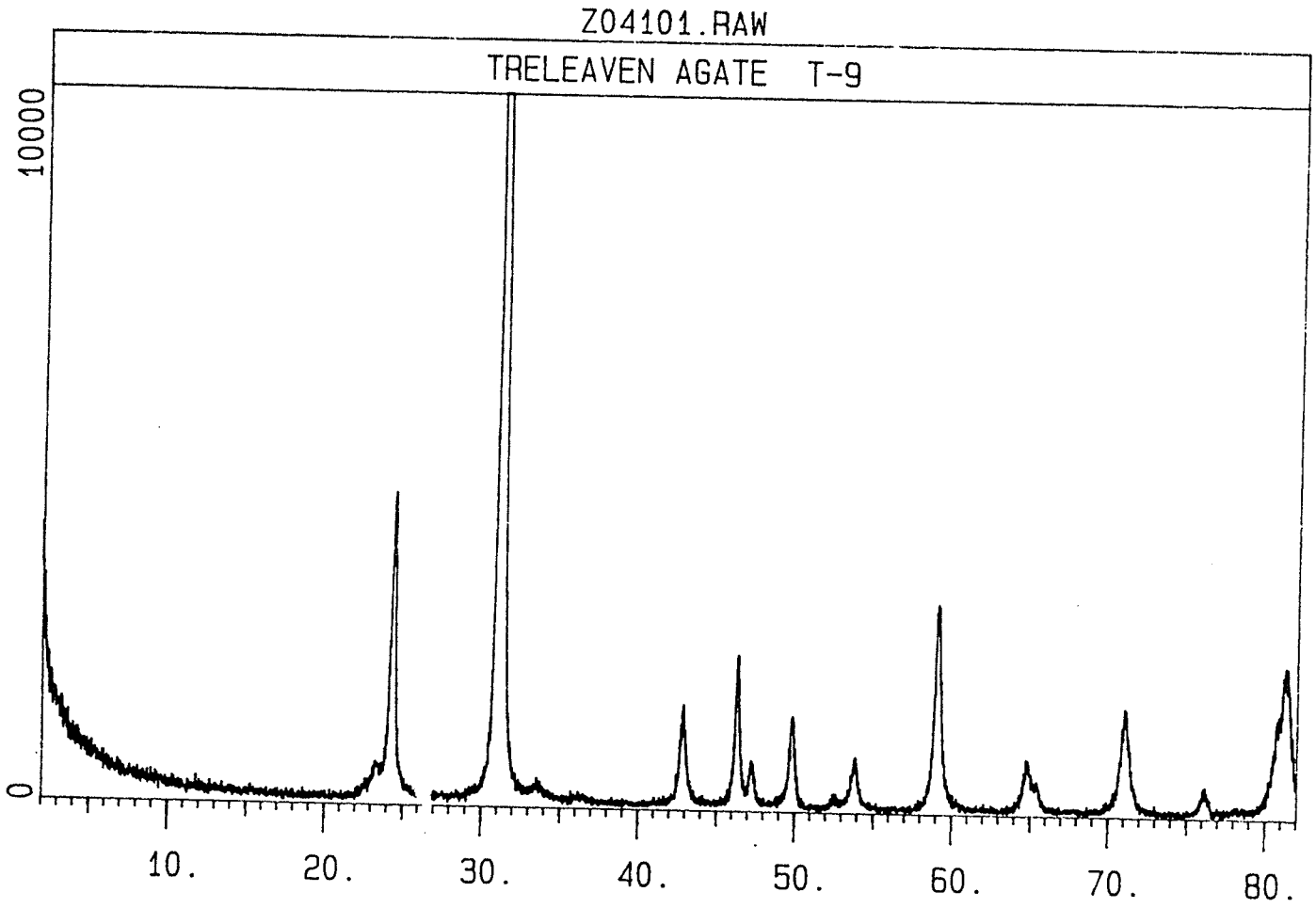


Fig. 11: X-ray diffraction pattern for Treleaven agate sample T-9. The x-axis is given in degrees two-theta for Co Kα radiation. The y-axis is given in counts/second. The pattern is characteristic of quartz, with only trace contribution from other phases. The most intense diffraction of quartz (at ≈31° two-theta) is off-scale, and reaches 29,500 counts/second.

Fig. 12: Fused shale cobbles from Souris (left) and outcropping of the Fort Union Formation, Montana (right). Note rounding and chalky weathering rind in Souris samples.

In sharp contrast, fused shale collected at Souris occurs as well-rounded cobbles up to 8 cm in diameter. They are covered by a soft, thick, chalky weathering rind and bear numerous crescentic impact scars, probably as a result of erosion during fluvial transportation. Several of the Souris samples have internal layering which appears as bands of lighter and darker material.

Fused shale typically exhibits a dull, earthy lustre, although it may occasionally appear waxy. This waxy lustre occurs when the shale has been exposed to very high levels of heat and the original texture of the sediment has been destroyed, producing a more vitreous form of fused shale (Rogers and Lee 1923). Red varieties of vitreous fused shale are similar in appearance to jasper.

Fracture ranges from poor and blocky to very good and conchoidal. In some of the more vitreous archaeological material, numerous percussion ripples are clearly visible on flake surfaces. Despite its generally good flaking qualities, however, fused shale is softer and has poorer flaking characteristics than good quality chalcedony or chert. When lacking the residual cortex, fused shale artifacts are easily confused with jasper or other finely-grained varieties of chert.

6.132 Microscopic features

On a microscopic level, fused shale is distinctive (Fig.13). Thin sections of porcellanite are often nearly opaque, and show only homogeneous and very finely-grained clay sediments lacking the clearly-defined quartz grains present in the cherts which they

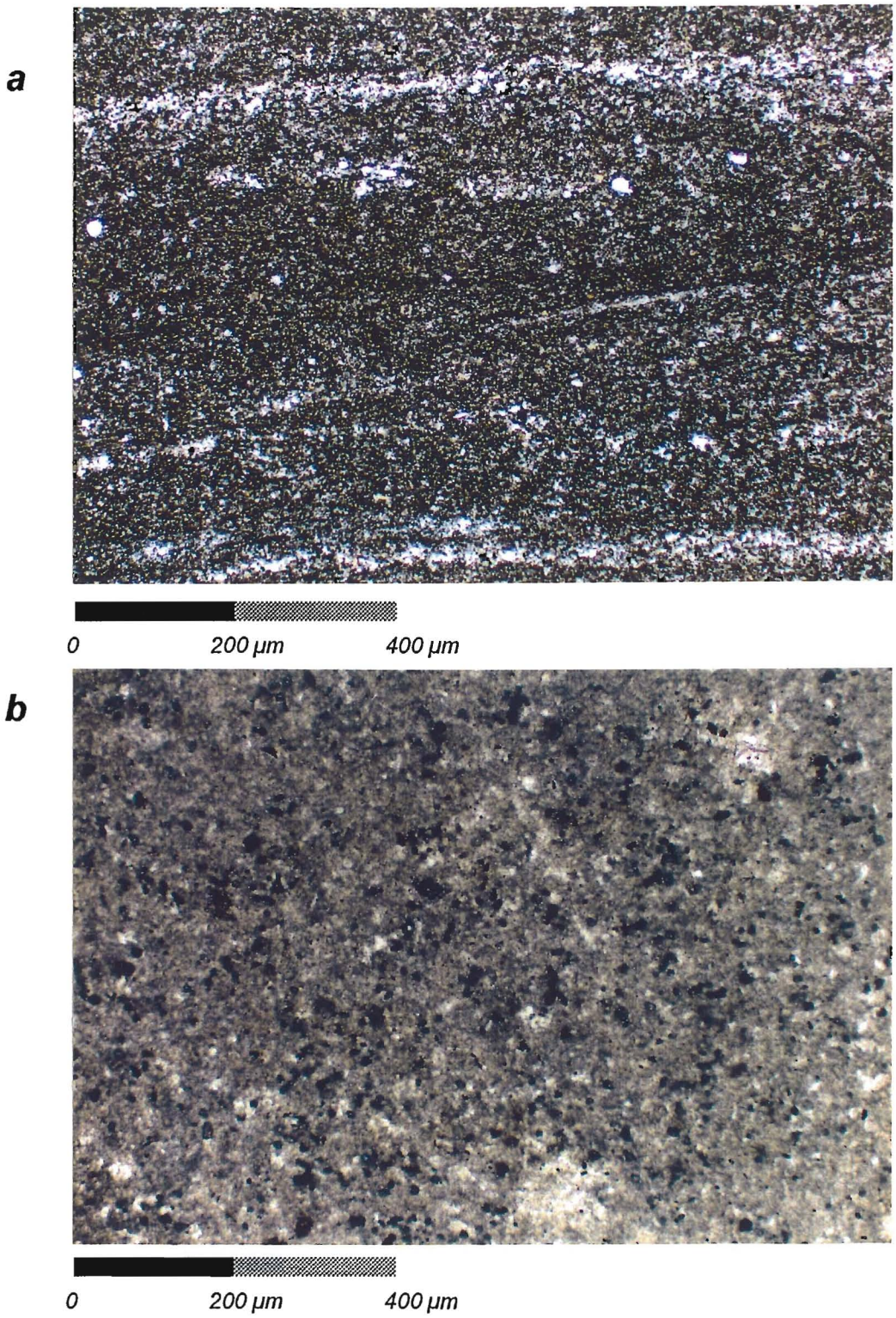


Fig. 13: Photomicrographs of Souris fused shale (a) P1-11, a red variety, and (b) P-3, a grey variety. Note banding in (a), which is also visible macroscopically as bands of lighter and darker colour.

may superficially resemble. Some banding may be seen (Fig.13a), but individual grains are difficult to see even at high magnification, due chiefly to the opacity of the material.

6.133 X-ray Diffraction Patterns

The X-ray diffraction patterns for fused shale exhibit several interesting features (Fig. 14). First, the intensities of X-ray diffractions obtained for the fused shale are much lower than for all other sample types encountered in this study. Second, unlike the other samples, a broad hump appears in the XRD pattern between ≈ 20 and 40° two-theta. This hump may be interpreted to indicate an abundance of very poorly crystallized material in the fused shale samples, probably material produced by dehydroxylation of clay minerals during the natural burning of the samples (Longstaffe, personal communication 1993). Third, the crystalline material that has remained in the fused shale samples is dominated by plagioclase, and has an XRD pattern closest to that of high albite. High albite is uncommon in geologic environments, and probably originated here by transformation of low albite (deposited as part of the original sediment) during very high temperature processes associated with burning (Longstaffe, personal communication 1993). Fourth, in two samples, both from the Treleaven site, a significant diffraction at ≈ 12.2° two-theta (Fig.14b) suggests the presence of amphibole, probably hornblende, as a minor phase. The amphibole is unlikely to be of detrital origin in such rock types. This amphibole is likely of pyrometamorphic origin -- that is, produced during the natural burning (Longstaffe, personal communication 1993). Finally, trace amounts of quartz (of probable detrital origin) were also detected in fused shale samples.

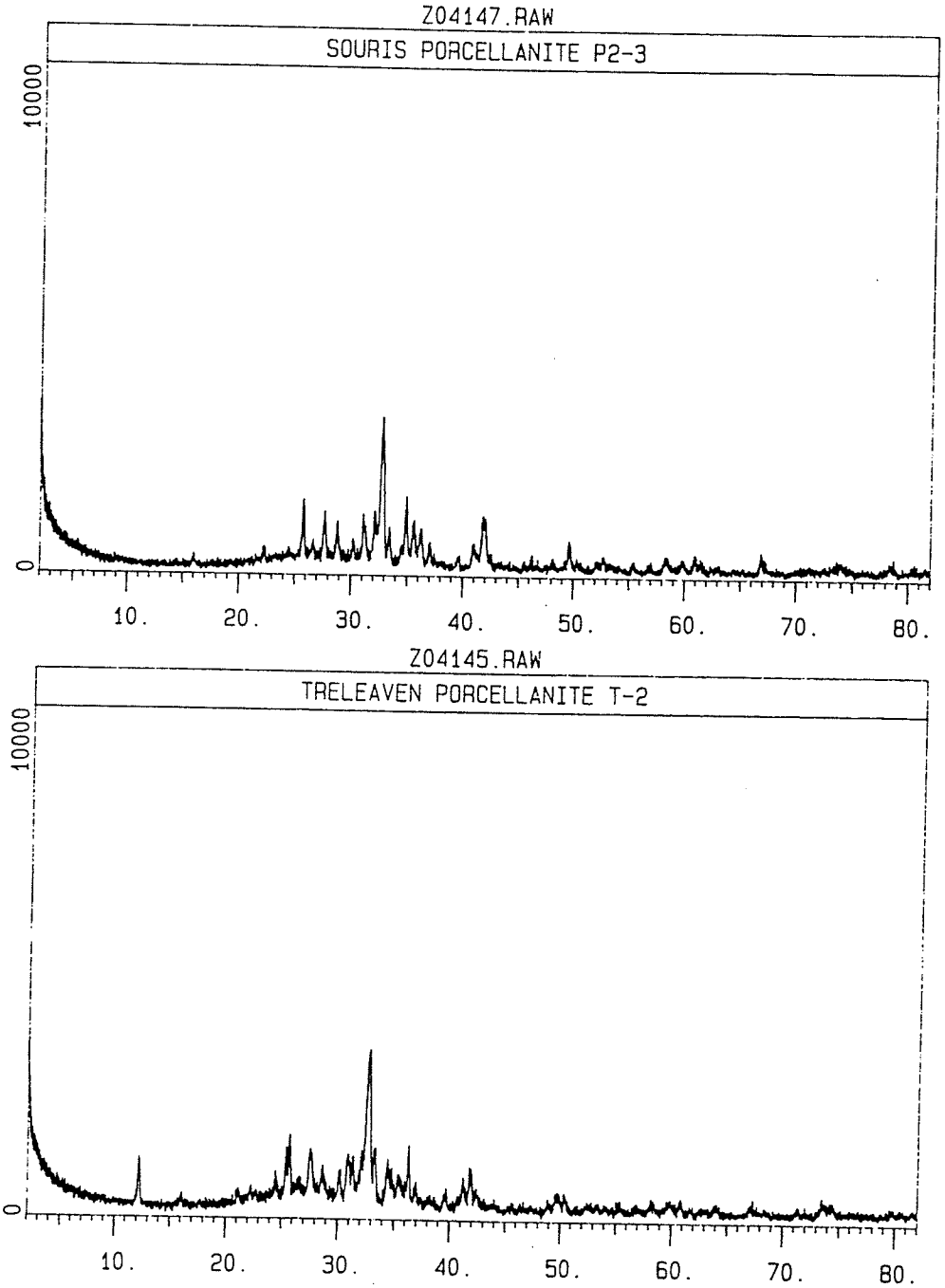


Fig. 14: X-ray diffraction patterns for: (a) Souris fused shale sample P2-3. The x-axis is given in degrees two-theta for Co Kα radiation. The y-axis is given in counts/second. The broad hump between 20 and 40° two-theta indicates an abundance of glassy material. The remainder of the sharp diffractions indicate the presence of plagioclase (similar to high-albite) and trace amounts of quartz. Note the much lower maximum intensity of the strongest diffraction compared to the highly crystalline quartz illustrated in Fig. 11. (b) Treleaven fused shale sample T-2. Axes as in (a). Note the additional sharp diffraction at ≈12.2° two-theta (probably horneblende) that is absent from all other porcellanite samples except T-3.

6.14 Silicified Wood, Silicified Lignite and "Knife River Flint"

6.141 Macroscopic appearance

Silicified wood appears in a wide range of forms in the Souris gravel and sand deposit. Cobbles are generally irregular in shape but rounded, probably by fluvial transport (Fig.15). Most samples measure less than 20 cm in diameter (Syms 1980). Colour varies with the degree of preservation of the original cell structure. In specimen P2, where wood structure is very well-preserved both macro- and microscopically, the material is a translucent medium brown colour closely resembling Knife River Flint. Such material displays very good conchoidal fracture. Material that has less wood structure visible is often much darker in colour, although a single small cobble will often exhibit a range of colours from dark brown through light brown to yellow, and some fragments are a mottled grey, red, white and brown.

Cobbles from Souris range from those in which external wood structure is obvious to those in which structure is externally almost non-existent. Many samples show greyish white to light brown patination which has formed along cracks or layers in the wood where the outer bark was formerly eroded. Such specimens fracture along blocky, irregular planes which probably correspond to growth rings.

In contrast to Wood Mountain silicified lignite, cobbles of Souris silicified lignite (Fig.16), although tabular, are well-rounded. They range in colour from dark to light brown, and light grey examples have also been noted (Broughton 1976). Although it is typically opaque with an earthy lustre, some samples more closely approach the translucency and waxy lustre of Knife River Flint. Such specimens also have a fairly

Fig. 15: Souris silicified wood.

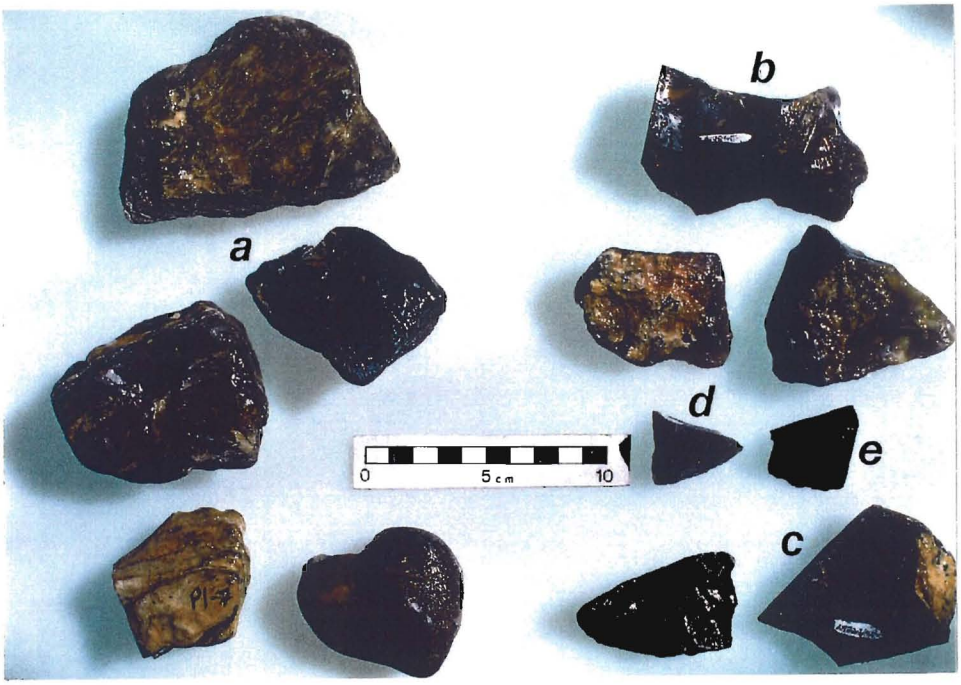


Fig. 16: (a) silicified lignite from Souris. (b) and (c) are "Knife River Flint" from Souris; (d) and (e) are Knife River Flint from Dunn County, North Dakota.

good conchoidal fracture as opposed to the irregular, blocky fracture of the majority. White and grey lenses of detrital plant remains are abundant throughout. The surfaces of the cobbles are covered with the impressions and raised remnants of compressed twigs and leaves. Often, cobbles are covered by a whitish-grey to yellowish-orange weathering rind.

Many cobbles of silicified lignite have layered plant remains visible on their surfaces. Other samples, containing more dispersed plant matter and having fairly good conchoidal fracture, more closely approach the quality of Knife River Flint. In general, the silicified lignite samples examined, including those previously identified by archaeologists as Knife River Flint, occupy a continuum from those which are opaque, earthy in lustre, have a high concentration of poorly-dispersed detrital plant lenses and exhibit poor conchoidal fracture to those samples which are translucent, have a waxy lustre, contain well-dispersed plant remains and exhibit excellent conchoidal fracture.

The colour of Knife River Flint has variously been described as "root beer brown", "beer bottle brown" and "coffee-coloured" (Clark 1984; Gregg 1987). Each of these terms is an accurate, if somewhat subjective, description of the colour of an unpatinated piece of KRF. Clayton *et al.* (1970) give a range of Munsell colours for KRF, describing "typical" examples as being a very dark brown 10YR 2/2 or 3/2. The brown colour of the flint results from the dispersal of the organic matter throughout (Clayton *et al.* 1970). It can be mistaken for other materials, particularly dark chalcedony and, in small translucent flakes, agate.

Knife River Flint usually occurs as flattened or blocky cobbles averaging 10 to 20 cm in diameter. These cobbles often have a cortex or rind of either weathered KRF or

remnants of the less siliceous bedrock in which it originally formed. Good quality KRF which exhibits good conchoidal fracture may contain "occasional, diffusely bounded but lenticular splotches of pale yellow, cream, or white opaque material" up to 1 mm in thickness and ranging from 3 to 10 mm in maximum dimension (Ahler 1986). Knife River Flint has a waxy lustre, with freshly-fractured surfaces being somewhat more glassy.

6.142 Microscopic features

The amount of relict cell structure present in the silicified wood varies greatly. Sample P2 (Fig.17) has extremely well-preserved internal structure in which cell walls are clearly visible in plane polarized light and appear to have been replaced by fibrous silica, while luminae have been filled by microcrystalline quartz. Cell walls may also be darkened by the presence of fine carbon or iron, as in sample P1-7 (Fig.18). Most other specimens display little relict cellular structure, although isolated areas of preserved structure are visible within the finely-grained matrix. Although all of the silicified wood samples were composed of microcrystalline quartz, occasional patches of fibrous chalcedonic silica were common.

Of the three archaeological samples identified by excavators as "petrified" wood from the Treleaven site, only two (T-5 and T-8) showed regular wood structure under magnification. The remaining sample (T-4) was classified as silicified lignite on the basis of thin section analysis.

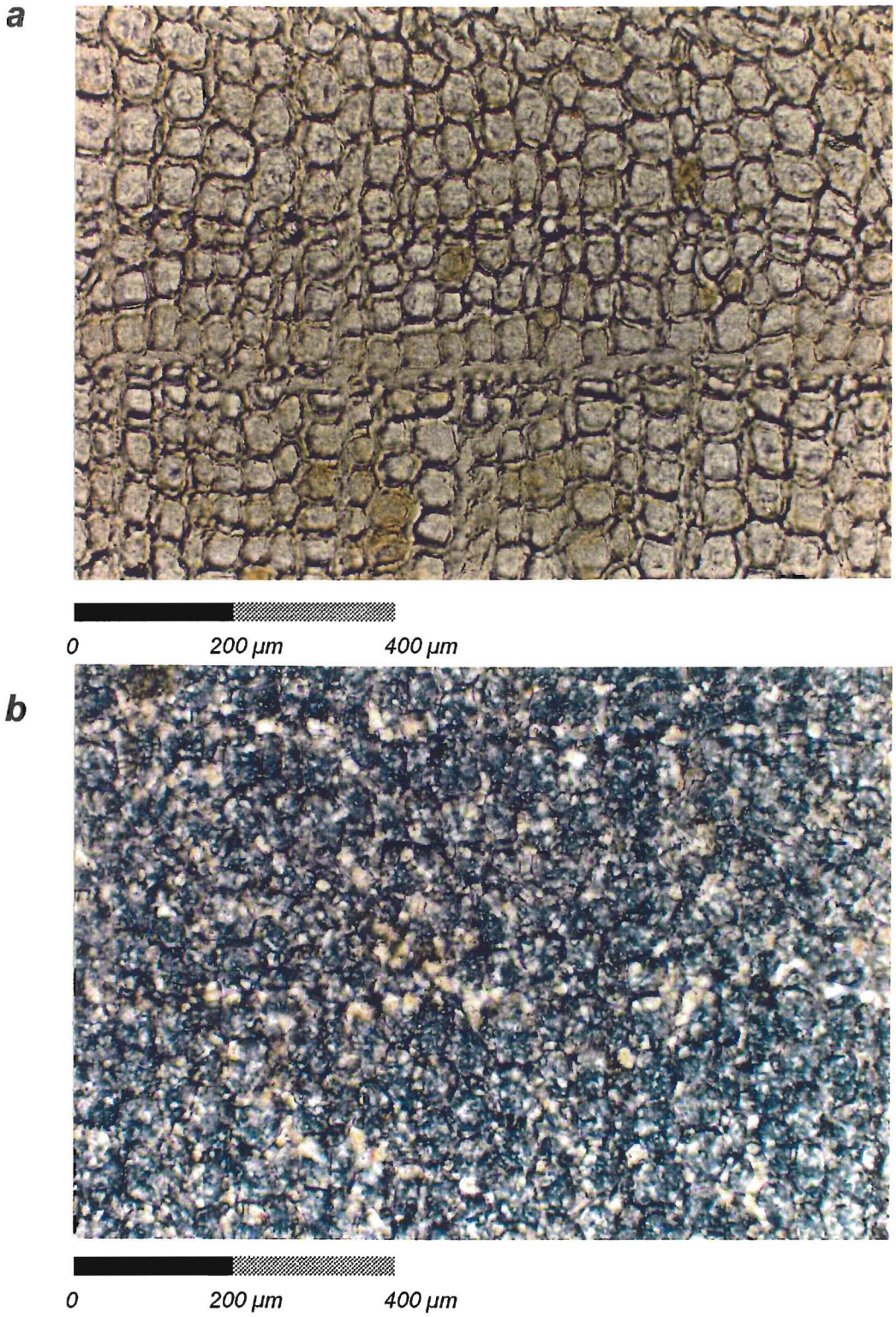


Fig. 17: Souris silicified wood sample P-2 under (a) plane polarized light and (b) crossed polars. Note replacement of wood with microcrystalline quartz in (b).

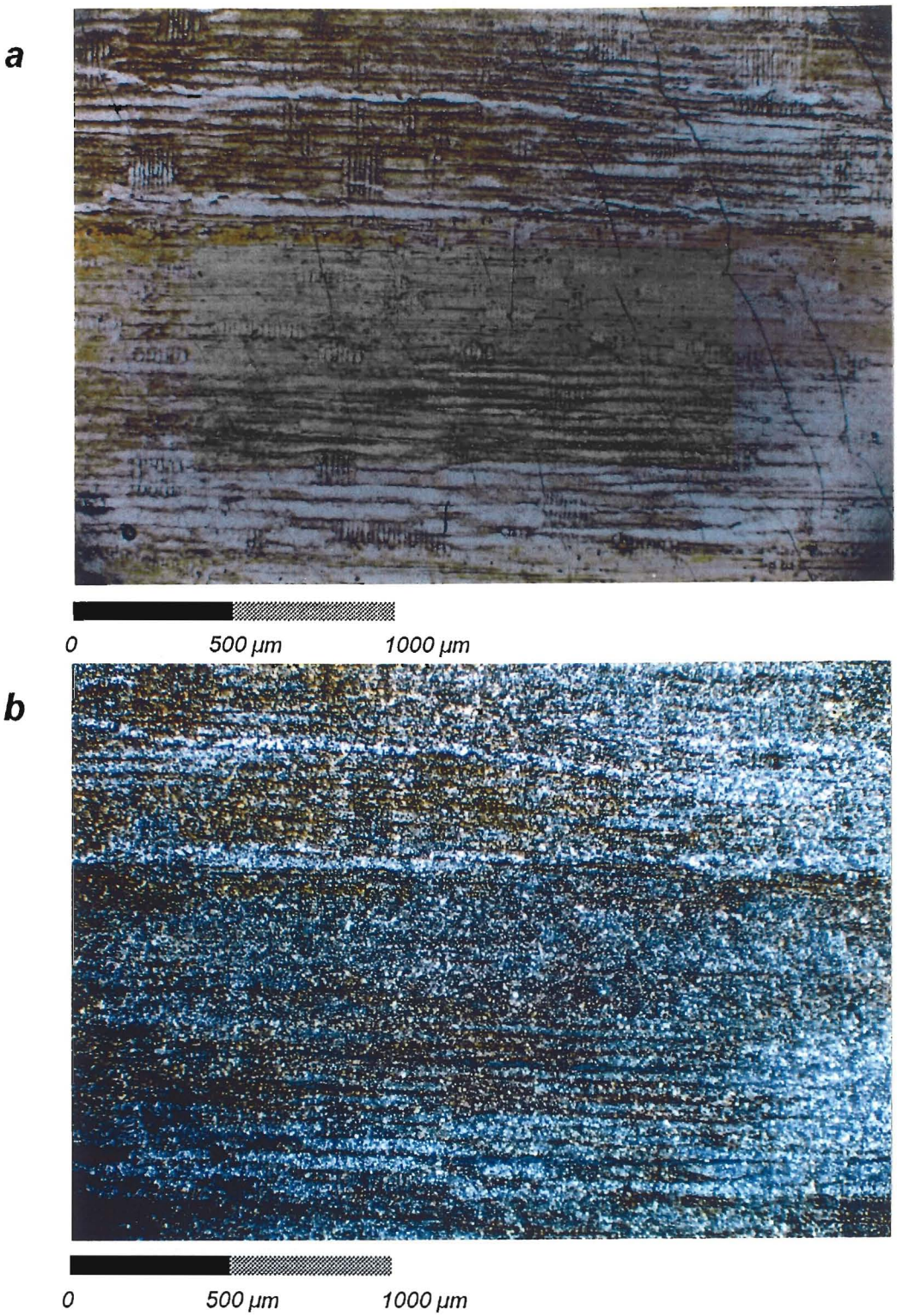


Fig. 18: Souris silicified wood sample P1-7 under (a) plane polarized light and (b) crossed polars, showing details of cell wall staining.

Silicified lignite, like silicified wood, is composed of microcrystalline quartz, throughout which larger quartz crystals occur. Numerous layers of compressed plant material are visible as darker lenses within the siliceous groundmass, and occasionally the outline of preserved plant cells is visible (Fig. 19a). Small cavities and lenses may be filled with quartz, and appear to be molds left by decayed stems and bark (Broughton 1976). No fibrous silica was present in the samples examined, although occasional lighter bands, apparently in-fillings of former cavities by microcrystalline quartz, are present. Comparative samples of "Knife River Flint", although essentially indistinguishable from the other silicified lignites examined, contain small areas of larger quartz crystals and fibrous silica scattered throughout a microcrystalline groundmass (Fig.20a).

In most cases, quartz grain size in the Knife River Flint was slightly smaller than in the other silicified lignites. This supports observations made by Thomas (1983), who compared Knife River Flint from the primary source area in North Dakota with macroscopically similar material from both Souris and Pilot Butte, Saskatchewan. He describes all samples examined as consisting of extremely fine crystalline quartz with spherulitic chalcedony and slightly coarser quartz dispersed throughout. He reports that the Souris and Pilot Butte samples were not dissimilar from the main source KRF, differing only in the greater dominance of extremely fine crystalline quartz in the North Dakota material (Thomas 1983:51).

In addition to the overall smaller grain size in the Knife River Flint studied, dark lenses of plant remains tend to be more diffuse and lighter lenses of quartz in-filling occur

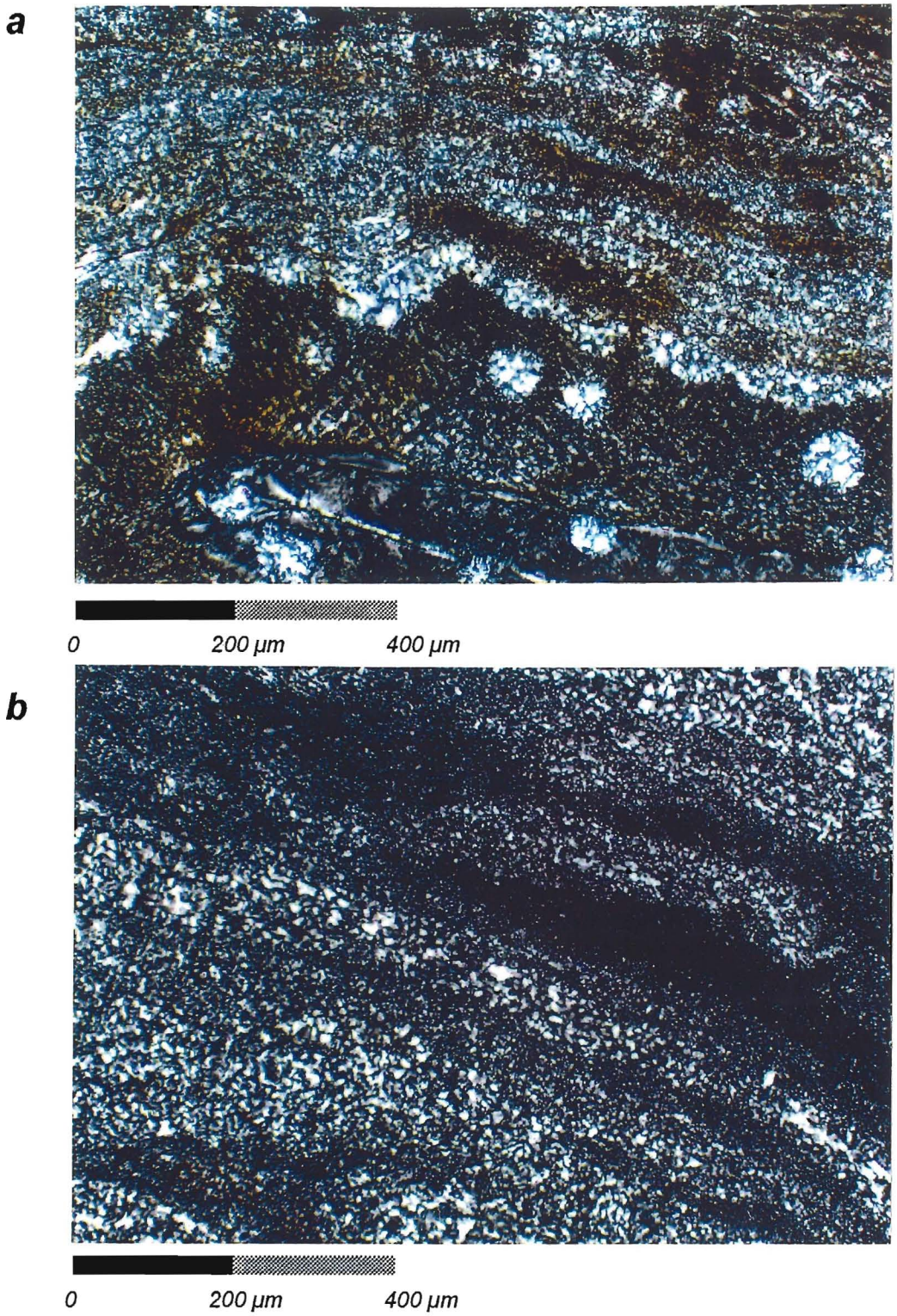


Fig. 19: (a) silicified lignite P1-10 under plane polarized light, showing layers of compressed plant material. Note parenchyma-like mass of plant tissue, replaced by silica, at bottom of photomicrograph. (b) Souris "Knife River Flint" 8/M1 under crossed polars.

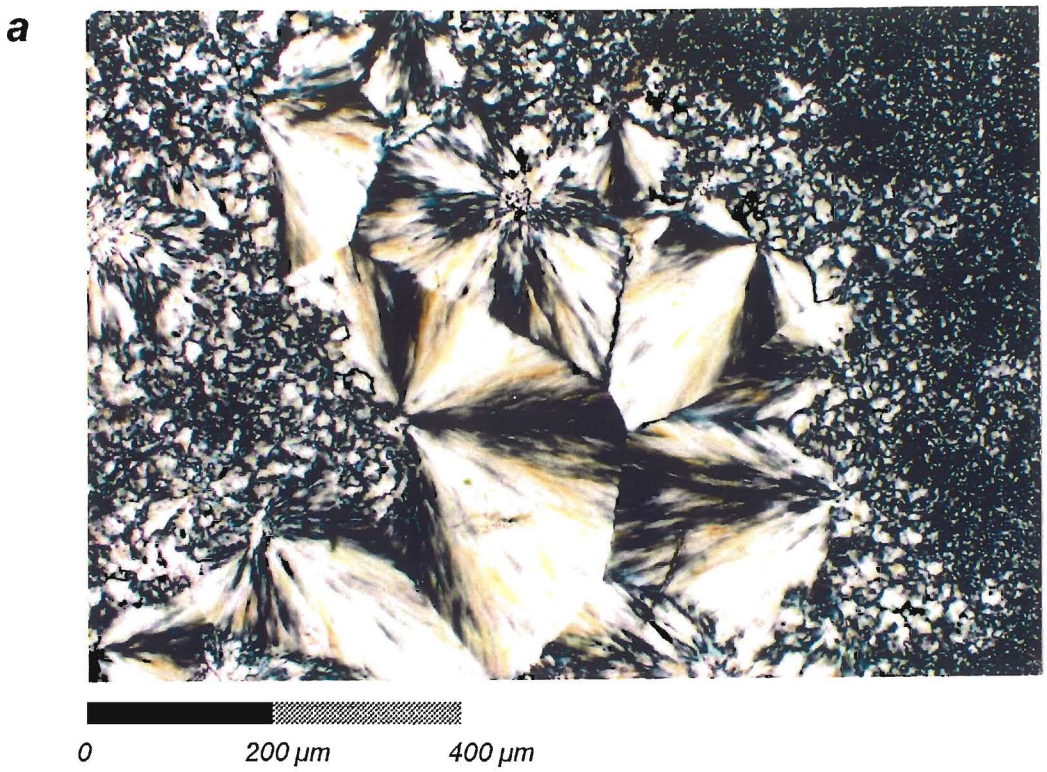


Fig. 20: Knife River Flint from the primary source area in North Dakota: (a) DC-14, illustrating the formation of fibrous chalcedonic silica within the surrounding microcrystalline quartz matrix; (b) MS-17. Note similarities between this sample and the Souris sample shown in Fig.19b.

with greater frequency than in the poorer quality silicified lignites. Layers of flattened detrital plant remains are visible, and often cellular structure is apparent. Between crossed polars, these plant remains appear as diffusely-bordered dark bands within the lighter matrix. The distorted character of the organic layers aids in differentiating Knife River Flint microscopically from silicified wood, in which the wood rings are more regular and, unless the wood has been subject to secondary deformation, much more parallel to each other.

6.143 X-ray Diffraction Patterns

The XRD patterns obtained for all samples of silicified wood and silicified lignite (including KRF) confirmed that these materials are composed almost entirely of quartz. Quartz crystallinity (that is, sharpness and resolution of individual diffractions) is slightly higher than, but similar to, the agate samples (Fig.11), but lower than quartzite samples (Fig.21).

6.15 Quartzite

6.151 Macroscopic appearance

Quartzite cobbles from the Souris gravel and sand exposure are extremely well-rounded. The cobbles, which rarely exceed 7 cm in diameter, vary in colour from tan or greyish-tan to brown and purple (Fig.22). No patination or other surface weathering ofany kind is apparent, although some cobbles retain patches of a calcite cement. Numerous faint impact scars are the result of long-distance fluvial transport. These cobbles are hard

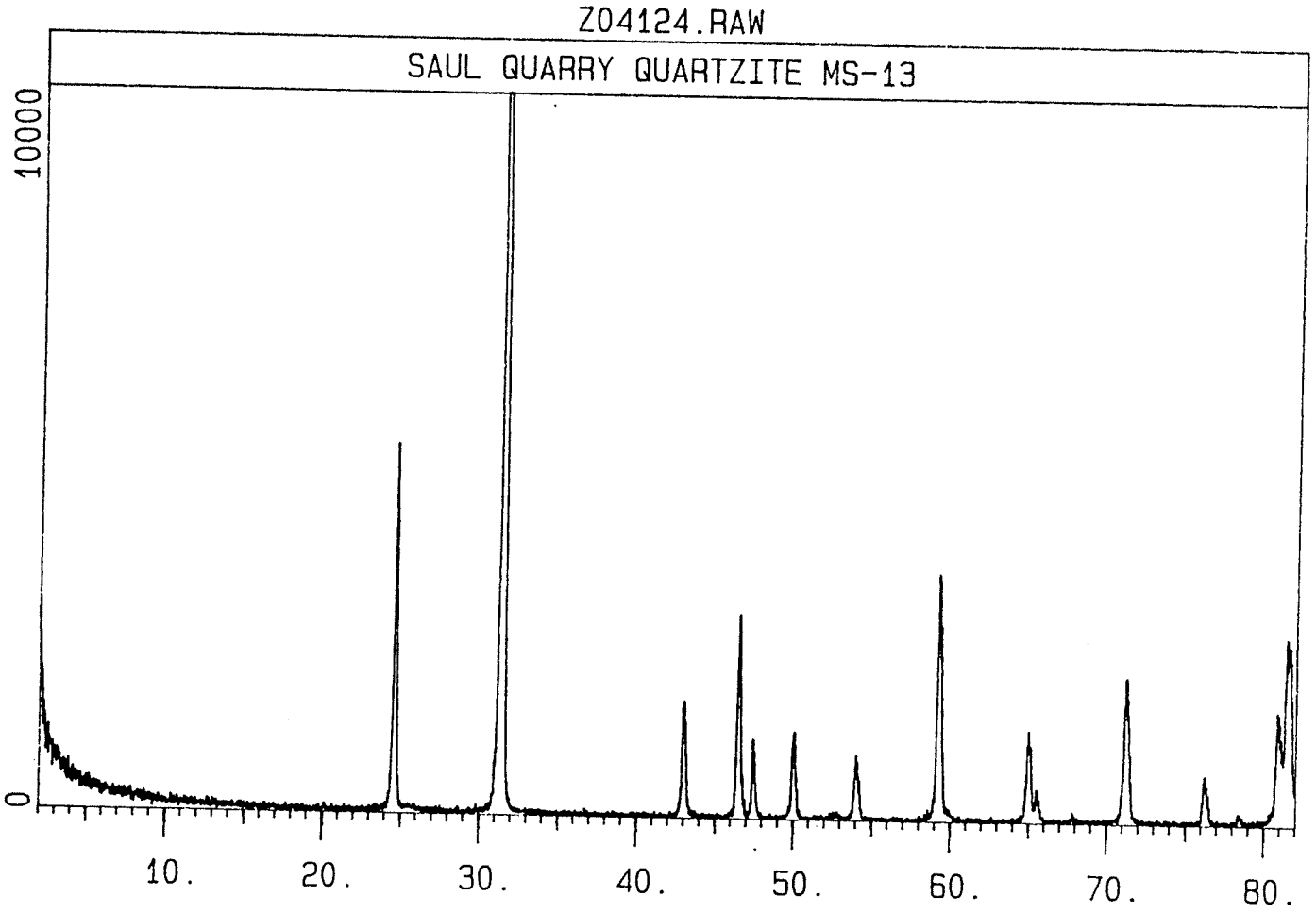


Fig. 21: X-ray diffraction pattern for Saul Quarry quartzite sample MS-13. The x-axis is given in degrees two-theta for Co Kα radiation. The y-axis is given in counts/second. The pattern is characteristic of very well-crystallized quartz. The most intense diffraction of quartz (at $\approx 31°$ two-theta) is off-scale, and reaches 21,608 counts/second.

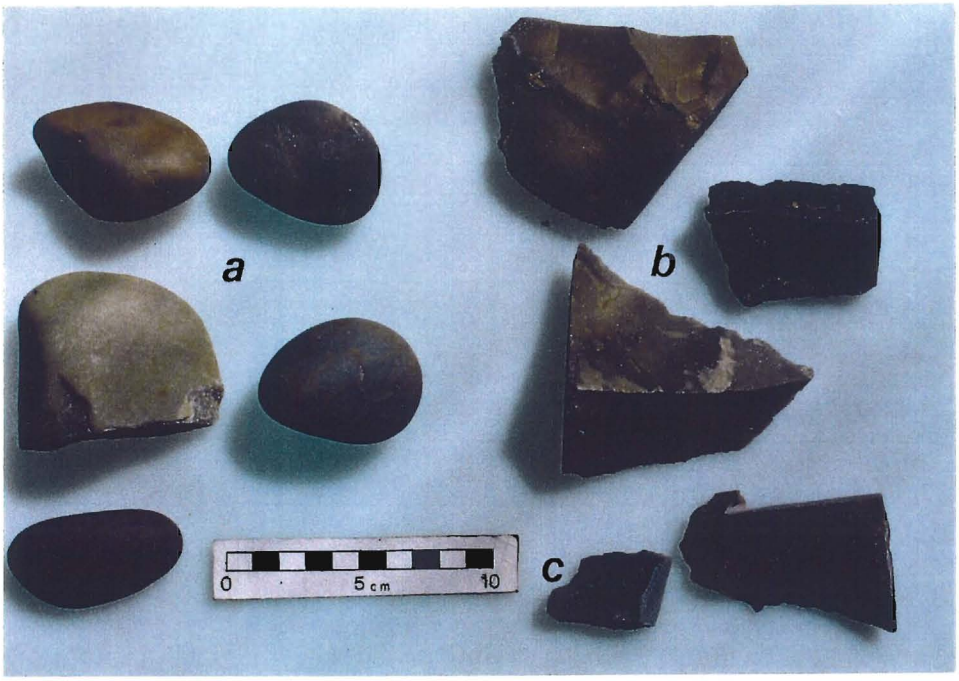


Fig. 22: Quartzite cobbles from (a) Souris, Manitoba; (b) Saul Quarry, Wyoming; (c) Flint Hills, South Dakota.

and dense, and difficult to fracture. Vugs and fissures are almost non-existent. Grain size ranges from fine to coarse. The coarsely-grained samples have a distinctly sugary appearance on freshly-broken surfaces.

Saul Quarry and Flint Hills quartzite, like the Souris cobbles, are finely-grained and very hard. They are also tan to greyish-tan and purple (Fig.22). Unlike the Souris samples, however, some discoloration and weathering occurs on cobble surfaces. The cortex of the Saul Quarry samples also tends to be vuggy and pitted, although few vugs are present on the interior.

6.152 Microscopic features

The Saul Quarry (MS-5, MS-12, MS-13 and MS-15) and Flint Hills (MS-8, MS-20 and MS-7) samples are composed of well-rounded grains of quartz cemented by interstitial silica, i.e., are quartz sandstones. In some, this cementing silica appears as overgrowths on quartz grains and in others as microcrystalline interstitial quartz. Quartz sandstones MS-5, MS-8, MS-13 and MS-15 have apparently been subjected to some degree of pressure solution by compaction, as illustrated by the incipient interlocking boundaries of quartz grains (Fig.23a,b).

The Souris quartzites consist of both quartz sandstones and quartzites. Sample 1383 is very similar microscopically to the Saul Quarry quartz sandstones, with rounded quartz grains cemented by microcrystalline quartz. Souris quartzites commonly contain elongate quartz grains exhibiting undulose extinction, highly-sutured, interlocking grain bound-

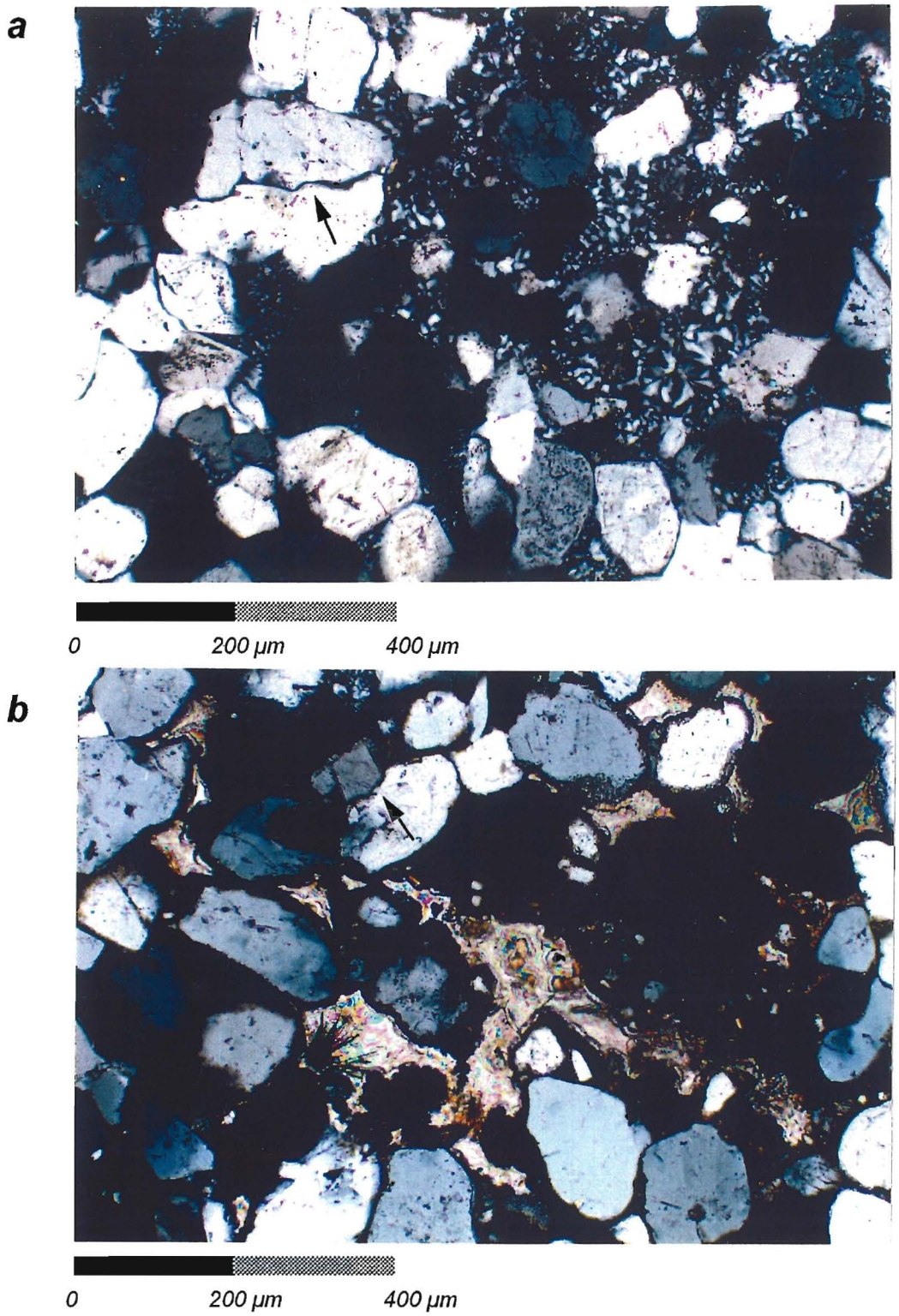


Fig. 23: Saul Quarry quartz sandstones (a) MS-15 and (b) MS-5 under crossed polars, showing incipient intergrowth of quartz grains (arrows).

aries and the development of polyhedral quartz crystals at stress points (Fig.24a,b). Muscovite is often present as thin plate-like lamellae between grain boundaries.

Samples which were very similar macroscopically were often very different microscopically. For example, Saul Quarry MS-5 (Fig.23b) and Souris 21814 (Fig.24b) were both a light tan colour, finely-grained and homogeneous with few vugs. Both were extremely hard and dense and exhibited very good conchoidal fracture. However, microscopic examination showed that MS-5 was a quartz sandstone, while 21814 was a quartzite with extremely elongated grains having complex, sutured borders.

6.153 X-ray Diffraction Patterns

The XRD patterns confirm that the quartzite samples consist entirely of well-crystallized quartz (Fig.21). No diffractions typifying more poorly-crystallized silica, or other phases, have been detected.

6.2 Chemical Composition

6.21 Instrumental Neutron Activation Analysis

Of all the materials studied, fused shale proved to be as easily distinguishable from other rock types geochemically as it was microscopically (see summary of INAA results, Table 3). All the fused shale samples had higher levels of Al, K, Na, Ca, V and Ba, and lower levels of Si than the other samples. This results from its origins in the heating and dehydroxylation of clay minerals, which are high in Al, K and trace elements (F. Long-

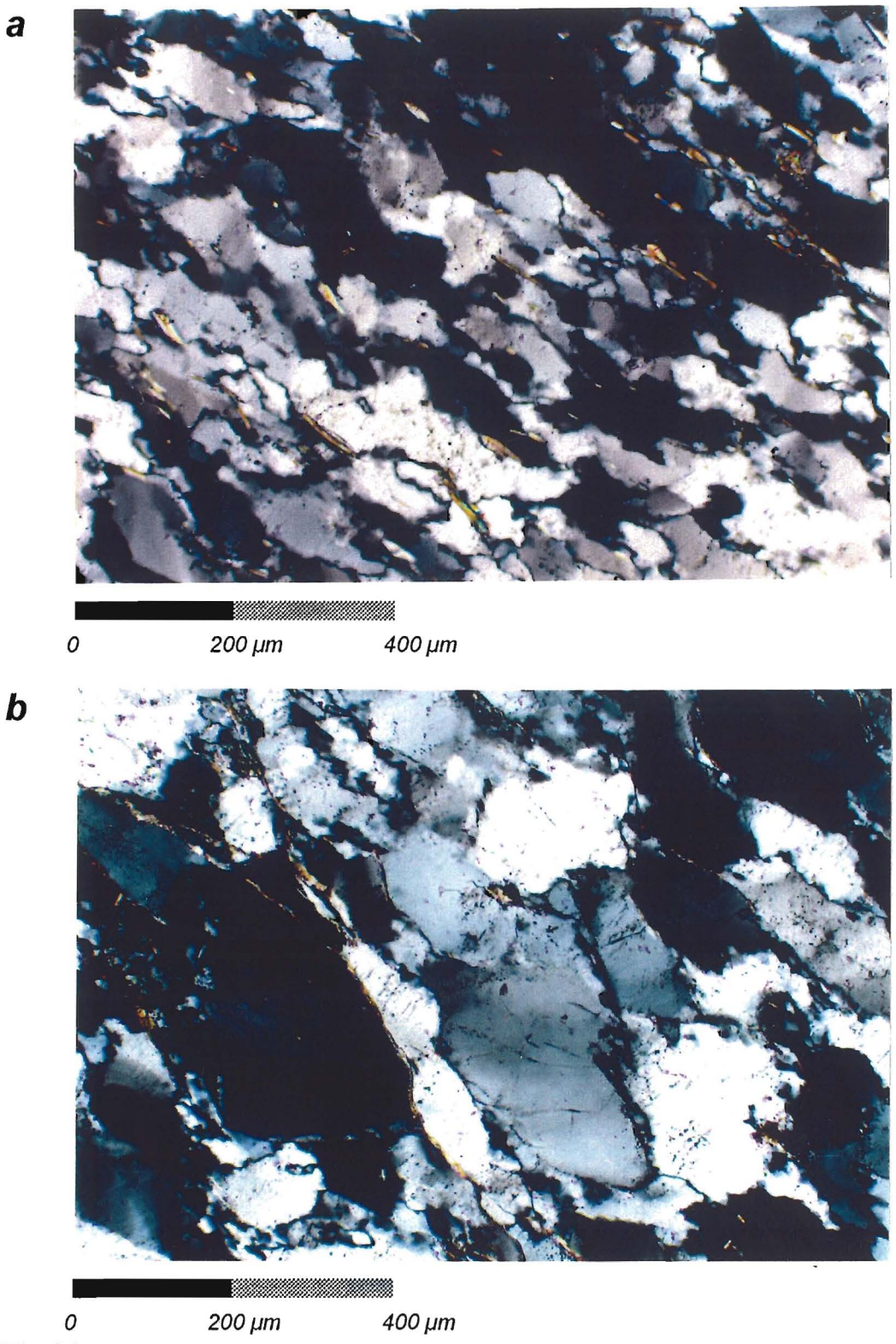


Fig.24: Elongation of quartz grains in quartzite and formation of smaller grains of quartz at points of stress: (a) Souris sample 92818, and (b) Souris sample 21814.

Table 3: Elemental Composition by Material (ppm)

Sample	*U*	*Dy*	*Ba*	*Ti*	*Sr*	*I*	*Br*	*Mg*	*Si*	*Na*	*V*	*K*	*Al*	*Mn*	*Cl*	*Ca*
Fused shale																
P1-56	2.1	1.2	820	4,050	≤130	≤3	≤11	7,000	≤180,000	4,700	153	30,000	108,000	120	≤73	4,400
P1-56	3.1	1.8	880	4,390	≤120	≤2	≤7	≤3,000	≤110,000	4,910	208	22,000	123,000	140	≤43	4,100
P2-3	2.8	3.3	880	3,030	≤260	≤6	≤21	21,000	≤270,000	3,100	103	35,000	80,000	560	≤92	6,200
YS-1	≤2.9	3.4	≤430	≤2,510	≤740	≤17	≤62	14,000	≤710,000	7,850	160	27,000	72,000	2,060	≤230	44,000
P2-4	5.6	3.1	790	3,100	≤550	≤11	≤26	21,000	≤790,000	5,400	89	35,000	84,000	1,000	≤160	43,000 ±2,000
24822	4.8	3.1	1,100 ±100	4,200 ±300	≤190	≤10	≤24	17,000	≤350,000	12,600	151	26,000	88,000	1,200	≤190	45,000 ±2,000
MS-1	5.3	3.6	730	3,300	≤530	≤11	≤26	27,000	≤350,000	6,200	91	36,000	78,000	1,300	≤170	60,000
MS-2	2.4	2.8	660	2,500	≤420	≤9	≤20	26,000	≤310,000	8,100	62	30,000	70,000	620	≤180	86,000
MS-3	5.7	3.7	880	2,600	≤480	≤10	≤22	32,000	≤350,000	7,600	71	36,000	58,000	950	≤170	60,000 ±2,000
YS-2	3.4	4.0	570	3,330	≤330	≤7	≤19	31,000	250,000	2,210	101	29,000	71,000	990	≤66	49,000
YS-2	≤1.9	3.6	≤270	3,240	≤440	≤10	≤37	31,000	≤440,000	2,540	89	30,000	70,000	910	≤120	50,000
T-1	4.2	3.5	820	6,940	≤360	≤7	≤20	22,000	≤250,000	7,180	96	41,000	84,000	980	≤87	35,000
T-2	≤1.5	2.7	650	2,920	≤370	≤8	≤30	16,000	≤380,000	5,510	71	36,000	78,000	810	≤130	38,000
T-3	≤1.8	4.5	710	3,500	≤440	≤9	≤25	24,000	≤330,000	2,230	127	39,000	93,000	1,030	≤81	41,000
S-14	4.5	3.3	500	2,900	≤220	≤4	≤12	30,000	≤160,000	2,960	92	36,000	78,000	570	≤54	42,000
S-14	≤1.5	2.7	490	3,130	≤320	≤7	≤27	28,000	≤340,000	2,960	93	27,000	79,000	540	≤110	45,000
S-15	≤1.9	≤1.2	670	3,990	≤480	≤9	≤26	27,000	≤340,000	5,650	119	33,000	92,000	1,070	≤120	75,000
S-26	≤1.6	3.1	670	3,240	≤360	≤8	≤29	22,000	≤390,000	7,180	77	31,000	75,000	640	≤150	67,000
Agate																
P1-53	≤0.07	≤0.04	93	≤19	≤12	≤0.2	≤0.8	≤100	450,000	195	≤.27	≤60	200	11	≤3	120
P1-53	≤0.09	≤0.05	56	≤21	≤14	≤0.2	≤0.2	≤170	460,000	166	≤0.35	≤90	100	7	≤5	100
P1-54	≤0.09	≤0.05	≤11	≤22	≤13	≤0.2	≤0.4	≤120	470,000	47	≤0.30	≤70	200	0.95	12	≤50
P1-54	≤0.14	≤0.07	≤18	≤44	≤32	≤0.6	≤2.1	≤230	430,000	44	≤0.57	≤80	≤40	70	≤7	≤98
P1-55	≤0.08	0.05	23	≤23	≤14	≤0.2	≤0.5	≤120	450,000	189	≤0.30	≤90	200	9.7	16	140
P1-55	≤0.14	≤0.07	59	≤41	≤29	≤0.5	≤1.9	≤250	420,000	196	≤0.54	≤90	≤40	48	≤8	1,400
P2-16	0.20	≤0.03	47	≤17	≤10	≤0.1	≤0.3	≤300	460,000	122	≤0.24	≤80	200	3.5	≤7	87
P2-16	0.20	≤0.04	33	≤22	≤15	≤0.3	≤0.9	≤160	460,000	124	≤0.34	≤90	100	17	≤5	≤62
T-9*	17	≤0.11	78	≤55	≤50	≤0.9	≤3.0	≤350	450,000	23	36	≤100	100	61	≤14	≤160
T-11	≤0.08	≤0.03	≤9	≤12	≤10	≤0.1	≤0.4	≤110	460,000	60	≤0.22	210	300	0.98	≤3	97
T-11	≤0.11	≤0.05	28	≤26	≤24	≤0.05	≤1.5	≤160	450,000	53	≤0.47	≤60	300	39	≤6	110
T-12	0.28	≤0.02	≤7	≤10	≤8	≤0.02	≤0.3	≤80	460,000	41	≤0.19	≤50	100	2.6	≤5	≤45
T-13	≤0.08	≤0.04	38	≤20	≤18	≤0.04	≤1.1	≤130	450,000	101	≤0.38	≤80	100	26	≤5	130
S-21	≤0.04	≤0.03	12	≤12	≤7	≤0.1	≤0.2	≤70	460,000	40	≤.18	180	100	1.8	≤4	≤20
S-21	≤0.10	≤0.05	39	≤21	≤15	≤0.2	≤0.7	≤190	450,000	56	≤0.41	190	200	4.7	≤5	≤40
S-22	≤0.12	≤0.07	52	≤31	≤18	≤0.3	≤0.7	≤170	460,000	157	≤0.37	≤270	≤40	7.9	16	≤79
S-22	≤0.07	≤0.03	270	≤16	≤15	≤0.2	≤0.7	≤130	450,000	149	≤0.27	≤80	≤40	8.6	15	110
S-22	≤0.06	≤0.04	180	≤15	≤13	≤0.2	≤0.5	≤120	460,000	154	≤0.21	≤90	200	9.8	17	81
S-23**	21	≤0.09	150	≤54	≤33	≤0.5	≤1.5	≤220	450,000	112	17	≤90	100	49	≤7	350
S-23**	25	≤0.10	120	≤38	≤32	≤0.6	≤1.3	≤280	450,000	132	17	≤420	100	23	26	220
S-25	≤0.07	≤0.03	≤7	≤12	≤11	≤0.03	≤0.4	≤100	460,000	103	≤0.20	230	100	5.4	≤7	130
S-25	≤0.08	≤0.03	25	≤18	≤16	≤0.03	≤0.9	≤130	440,000	115	≤0.37	240	100	17	≤5	210

* ultimately classified as silicified wood/silicified lignite (see text)

** ultimately classified as silicified wood/silicified lignite (see text)

(Table 3 continued next page)

Table 3, continued

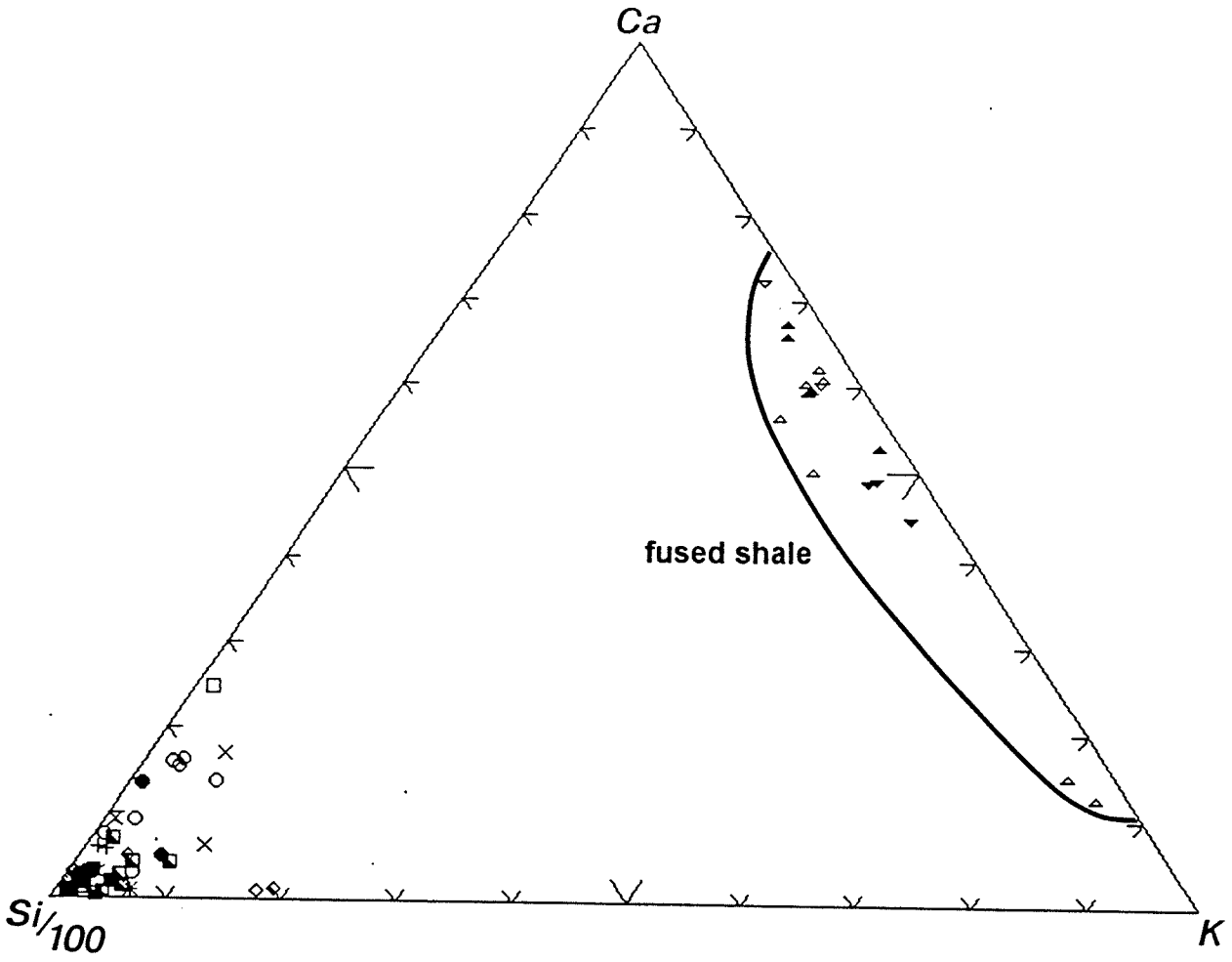
Sample	U	Dy	Ba	Ti	Sr	I	Br	Mg	Si	Na	V	K	Al	Mn	Cl	Ca
Silicified wood/silicified lignite																
P1-10	4.4	0.08	310	≤17	≤14	0.08	≤0.8	≤120	450,000	68	5.8	140	100	10	≤5	470
P1-10	5.4	0.20	780	≤39	≤33	0.20	≤1.5	≤270	460,000	94	11	140	1,000	43	27	900
P1-51	0.77	0.09	150	≤15	≤11	0.09	≤0.5	≤110	450,000	39	5.2	190	100	7.2	≤3	860
P2-5	1.3	0.07	86	≤10	≤8	0.07	≤0.3	80	450,000	43	1.6	≤50	200	5.0	9	370
DC-14	2.1	0.91	32	≤24	≤15	≤0.2	≤0.5	≤190	460,000	95	≤0.38	≤70	400	1.3	10	95
MS-17	2.1	≤0.04	50	≤18	≤12	≤0.21	≤0.48	≤150	450,000	154	0.8	310	350	0.68	19	≤54
7/M4	2.6	0.37	86	≤28	≤17	≤0.35	≤1.1	≤150	440,000	65	2.4	≤85	≤40	37	≤6.7	150±30
8/M1	1.3	≤0.03	150	≤17	≤10	≤0.19	≤0.48	≤130	440,000	110	≤0.35	270±30	470	1.8	16	140
P2	1.3	0.07	40	≤14	≤8	≤0.15	≤0.38	≤110	450,000	39	≤0.28	≤47	≤30	0.52	18	85
P1-52	0.27	≤0.05	150	89	≤27	≤0.05	4.6	≤220	450,000	563	13	420	1,200	420	≤10	780
T-4	0.9	≤0.12	270	≤64	≤49	≤0.12	≤2.6	≤310	470,000	215	6.1	380	2,000	130	≤10	260
T-6	1.1	0.09	150	≤15	≤12	0.09	≤0.6	≤120	450,000	32	2.9	≤50	100	5.4	≤4	130
T-7	0.27	≤0.05	80	≤25	≤20	≤0.05	≤1.4	≤140	450,000	47	1.9	≤60	≤40	38	≤5	710
T-8	2.5	≤0.09	160	≤50	≤39	≤0.09	≤2.0	≤250	450,000	37	23	≤80	≤40	105	19	≤84
S-16	17	0.52	260	62	≤21	0.52	≤1.2	≤170	460,000	105	1.4	190	200	18	≤7	920
S-17	0.49	≤0.04	55	≤18	≤14	≤0.04	≤0.6	≤120	450,000	68	5.5	≤70	300	17	≤3	≤71
S-19	0.85	≤0.04	48	≤15	≤11	≤0.04	≤0.5	≤120	450,000	17	≤0.34	≤30	200	1.1	≤7	140
S-20	≤0.07	0.14	148	≤14	≤11	0.14	≤0.6	310	470,000	215	6.1	380	2,000	130	≤10	260
Quartzite																
21814	0.55	0.80	260	170	14±2	≤0.29	≤1.3	180	470,000 ±1,000	47±1	2.6	1,100 ±70	2,100	10	63±3	≤73
1489	0.53	0.83	170	130±10	19±2	≤0.29	≤1.2	≤170	450,000 ±1,000	55±1	3.4 ±0.2	960 ±50	1,700	17	95±3	≤61
MS-5	35±1	0.48	87±3	460±15	≤6.3	≤0.20	≤0.64	≤210	440,000 ±1,000	56±2	4.3 ±0.2	≤93	640	5.3	25±2	≤89
MS-13	37	0.12	110	190±10	≤5.6	≤0.21	≤0.71	≤190	460,000 ±1,000	39±1	3.6	≤83	420	3.6	13±1	≤88
MS-20	4.6	0.29	46±2	190	≤29	≤0.33	≤1.6	≤170	460,000	75	14.6	220±40	480	19	21±2	250±30
Chert																
P1-12	6.7	≤0.06	270	≤29	≤20	≤0.38	≤1.1	≤180	440,000	49	4.2	120	≤40	23	27±3	1,100 ±100
1391	6.7	≤0.04	140	≤21	≤12	≤0.24	≤0.52	≤100	480,000	37	2.4	≤51	200	11	37	500
P1-4	0.83	≤0.05	105	≤28	≤19	≤0.35	≤0.96	≤180	430,000	109	5.8	≤72	≤40	14	39	≤55
P1-20	23.6	≤0.07	730	≤35	≤20	≤0.42	≤0.82	≤190	470,000	240	57	≤92	≤50	10	25	24,000
P2-30	1.0	0.14	120	≤16	≤9	≤0.18	≤0.37	≤100	470,000	250	0.9	580	810	4.2	15	350
P1-1	2.4	≤0.06	330	≤28	49±7	≤0.40	≤1.0	≤200	450,000	180	3.0	380	420	14	20	1,000
MS-19	7.8	≤0.05	410	≤33	≤19	≤0.39	≤1.3	≤150	460,000	130	4.7	≤100	330	34	32	290
88-3	2.6	≤0.05	460	≤27	≤18	≤0.35	≤0.94	≤170	450,000	190	0.56	≤76	300	20	77	≤53
MS-11	9.5	≤0.05	105	≤28	≤19	≤0.35	≤0.96	≤180	430,000	109	5.8	≤72	≤40	14	39	≤55
MS-9	0.48	≤0.03	22	≤16	≤9	≤0.18	≤0.38	≤90	490,000	42	2.7	≤59	510	5.0	25	310

staffe, personal communication 1993). A ternary plot of Ca, Si and either K or Al separates the fused shales from the cherts, agates and silicified woods and lignites very effectively (Fig.25), in which the fused shale clusters along the right-hand side of the plot.

The five Souris and five American cherts selected for INAA have very disparate trace element levels, and do not group appreciably by source (Figs.26 & 27). They are also similar in trace element composition to the silicified woods and lignites, and no combination of trace elements could be found to separate the two material types (Fig.26).

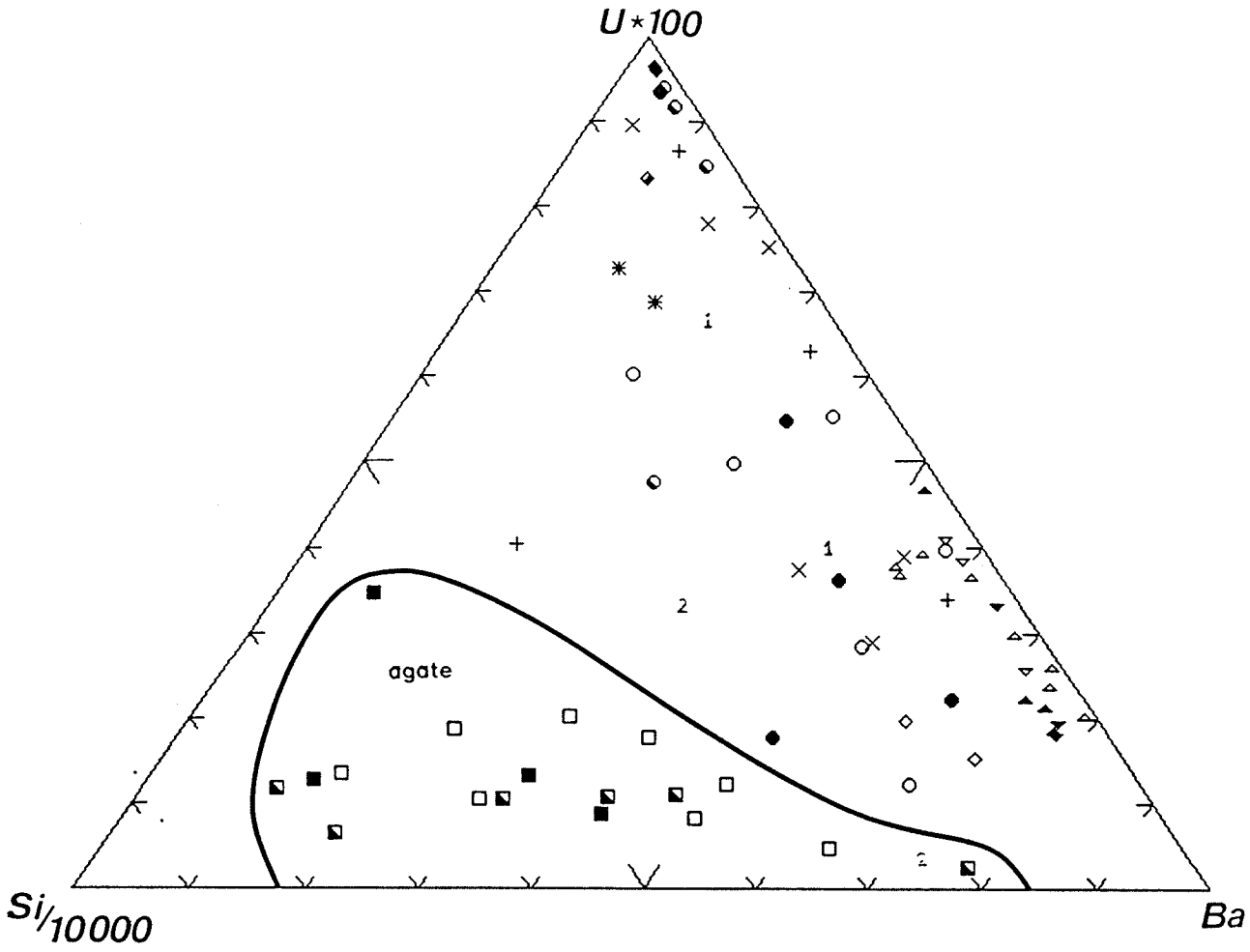
Unlike the chert, INAA of both the Souris agate cobbles and archaeological waste flakes indicate that they are chemically distinctive from other visually similar materials, including Knife River Flint and silicified wood. The agates examined are consistently lower in Ba and U than the silicified woods and lignites (Fig.26).

Two very small waste flakes, one from the Treleaven Site (T-9) and one from the Snyder II Site (S-23), are the apparent exceptions to this rule. Although both had the translucent light brown appearance of agate, they were enriched in Ba and U relative to other agate samples and plotted consistently within the range of compositions of the silicified lignites and woods. Both also had $\delta^{18}O$ values which were high (Table 4) when compared to values for the other agates, but similar to the silicified woods and silicified lignites. Unfortunately, their small size precluded the making of thin sections, so that microscopic structure could not be examined. Given the geochemistry of these samples, it appears likely that these two samples were in fact silicified wood or silicified lignite, and that it was their small size that led to their misidentification.



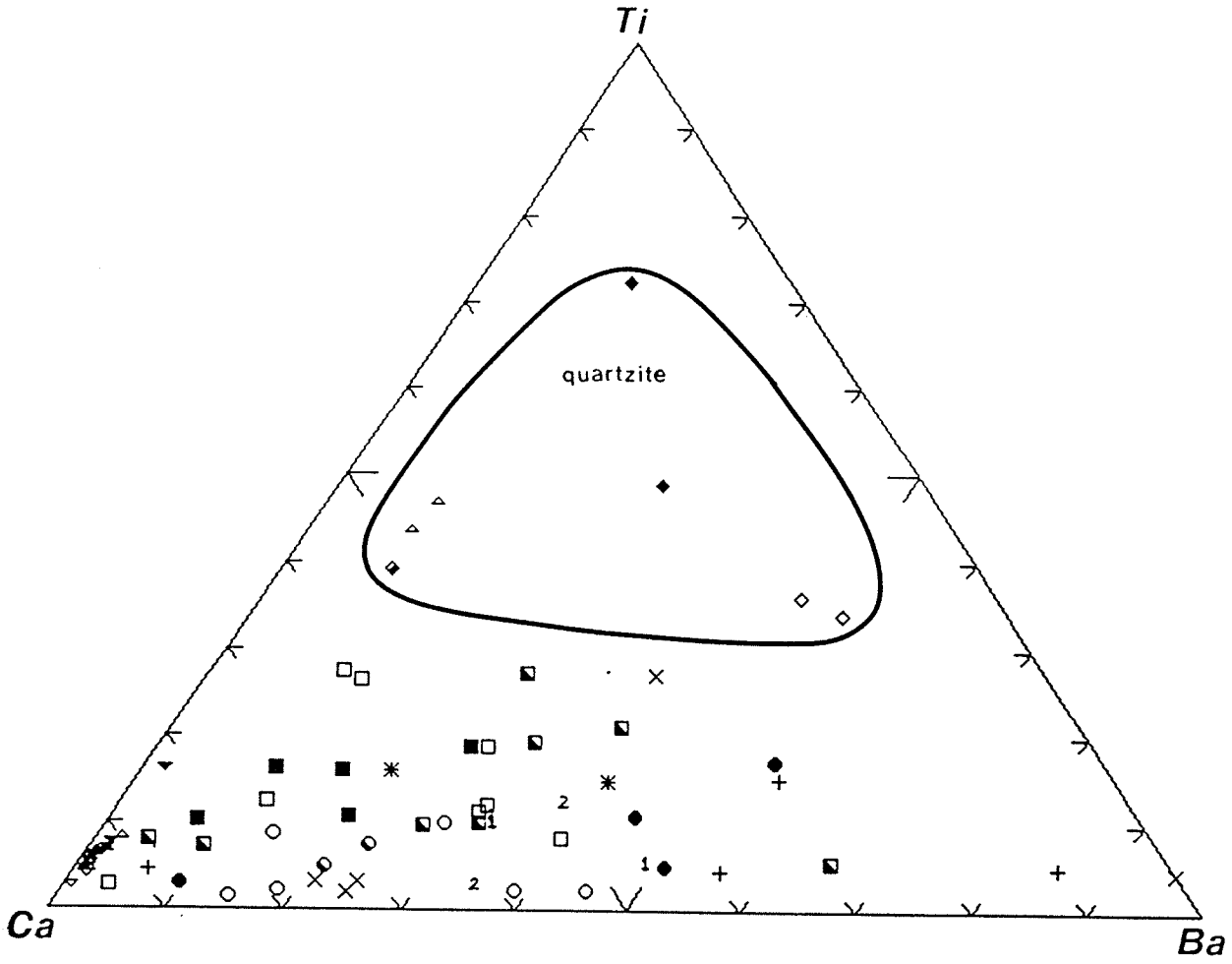
- Souris chert
- Hell Canyon chert
- Chadron chert
- Souris quartzite
- Saul Quarry quartzite
- Flint Hills quartzite
- Souris agate
- Treleaven agate
- Snyder II North agate
- Souris fused shale
- Fort Union fused shale
- Treleaven fused shale
- Snyder II North fused shale
- Souris sil. wood/sil. lignite
- Treleaven sil. wood/sil. lignite
- Snyder II North sil. wood/sil. lignite
- Knife River Flint, N.D.
- 1 Souris "Knife River Flint"
- 2 Snyder II North "Knife River Flint"

Fig.25: Ternary plot of Si, Ca and K. Note complete separation of fused shale from all other samples.



- Souris chert
- Hell Canyon chert
- Chadron chert
- Souris quartzite
- Saul Quarry quartzite
- Flint Hills quartzite
- Souris agate
- Treleaven agate
- Snyder II North agate
- Souris fused shale
- Fort Union fused shale
- Treleaven fused shale
- Snyder II North fused shale
- Souris sil. wood/sil. lignite
- Treleaven sil. wood/sil. lignite
- Snyder II North sil. wood/sil. lignite
- Knife River Flint, N.D.
- 1 Souris "Knife River Flint"
- 2 Snyder II North "Knife River Flint"

Fig. 26: Ternary plot of Si, U and Ba, showing separation of agates from other lithic types.



- Souris chert
- Hell Canyon chert
- Chadron chert
- Souris quartzite
- Saul Quarry quartzite
- Flint Hills quartzite
- Souris agate
- Treleaven agate
- Snyder II North agate
- Souris fused shale
- Fort Union fused shale
- Treleaven fused shale
- Snyder II North fused shale
- Souris sil. wood/sil. lignite
- Treleaven sil. wood/sil. lignite
- Snyder II North sil. wood/sil. lignite
- Knife River Flint, N.D.
- 1 Souris "Knife River Flint"
- 2 Snyder II North "Knife River Flint"

Fig. 27: Ternary plot of Ca, Ti and Ba, showing separation of quartzites from other lithic types.

Table 4: Oxygen Isotopic and Mineralogical Results

Sample	*Description*	*Mineralogy**	*$\delta^{18}O$ SMOW*
P2-3	Souris fused shale	amorph > > plag > qtz	7.00
YS-1	Souris fused shale	amorph > > plag > qtz	3.42
YS-2	Souris fused shale	amorph > > plag > qtz	12.29
MS-3	Fort Union fused shale (Montana)	amorph > > plag > qtz	6.43
MS-4	Fort Union fused shale (Montana)	amorph > > plag > qtz	12.41
MS-16	Fort Union fused shale (Montana)	amorph > > plag > qtz	8.78
T-1	Treleaven fused shale	amorph > > plag > qtz	14.00
T-2	Treleaven fused shale	amorph > > plag~hbl > qtz	6.12
T-3	Treleaven fused shale	amorph > > plag~hbl > qtz	2.91
S-14	Snyder II North fused shale	amorph > > plag > qtz	10.50
S-15	Snyder II North fused shale	amorph > > plag > qtz	4.84
S-26	Snyder II North fused shale	amorph > > plag > qtz	11.29
P1-54	Souris agate	qtz	14.85
P1-55	Souris agate	qtz	17.79
P2-16	Souris agate	qtz	16.89
T-9	Treleaven silicified wood/lignite	qtz	29.79
T-10	Treleaven agate	qtz	22.08
T-11	Treleaven agate	qtz	11.78
S-21	Snyder II North agate	qtz	14.18
S-22	Snyder II North agate	qtz	20.41
S-23	Snyder II North silicified wood/lignite	qtz	26.00
DC-14	Knife River Flint (North Dakota)	qtz	26.26
MS-17	Knife River Flint (North Dakota)	qtz	27.08
P1-10	Souris silicified lignite	qtz	23.04
P1-51	Souris silicified lignite	qtz	22.72
P2-5	Souris silicified lignite	qtz	22.41
T-5	Treleaven wood	qtz	18.90
T-6	Treleaven silicified lignite	qtz	19.23
T-7	Treleaven silicified lignite	qtz	26.45
S-16	Snyder II North silicified lignite	qtz	27.28
S-17	Snyder II North silicified lignite	qtz	26.57
S-17	Snyder II North silicified lignite	qtz	26.83
S-19	Snyder II North silicified lignite	qtz	26.95
P2	Souris silicified wood	qtz	25.71
P1-52	Souris silicified wood	qtz	17.47
1489	Souris quartzite	qtz	14.04
21814	Souris quartzite	qtz	14.02
P1-60	Souris quartzite	qtz	13.39
MS-5	Saul Quarry (Wyo.) quartzite	qtz	14.89
MS-13	Saul Quarry (Wyo.) quartzite	qtz	14.86
MS-8	Flint Hills (S.D.) quartzite	qtz	17.16

* qtz = quartz, amorph = x-ray amorphous material, hbl = amphibole, plag = plagioclase

It was not possible to separate the silicified lignites from the silicified woods by geochemical analysis (for the purposes of this discussion, the term "silicified lignite" will include Knife River Flint). Regardless of which elements were plotted, these materials consistently grouped together. Similarly, no separation of Knife River Flint from other silicified lignite, silicified wood or chert could be obtained. The silicified lignite and wood were consistently richer in uranium and poorer in vanadium than either fused shale or agate.

Plants, particularly mosses, lichens and aquatic bryophytes, are significant accumulators of uranium. Very high uranium levels have been recorded in fossil woods, while dry peat has been found with a uranium content of as much as 3.1% (Dunn *et al.* 1985). The organic acid components in peat bogs readily absorb and adsorb uranium, concentrating it by as much as 26,000 times (Dunn *et al.* 1985). Thus, the source of the uniformly high uranium levels in the silicified lignite and silicified wood in the study sample could be attributed to the origin of these materials in plant remains. This characteristic could prove useful in the identification of very small flakes or samples of silicified wood and lignite in which organic cell structure is poorly preserved.

Souris quartzite samples 1489 and 21814, Saul Quarry quartzite samples MS-5 and MS-13 and Flint Hills quartzite sample MS-20 were submitted for INAA. Results indicated that it was possible to differentiate between Souris and American samples on the basis of trace element composition. The Souris quartzites were lower in U and Ba and higher in Mn, Cl and Ba than those from Saul Quarry. K and Al levels were much higher

in Souris samples. The single Flint Hills sample was lower than all others in Mn, Cl and Ba but intermediate between Souris and Saul Quarry samples in Ti, K and Al. A plot of Ti, Ca and Ba separates the quartzites from most other samples, with the exception of fused shale sample P1-56 which is lower in Ca and higher in Ti than the other fused shales (Fig.27).

6.22 Oxygen Isotopic Analysis

The oxygen isotope compositions of the source and archaeological materials (Table 4) fall into three broad categories when plotted (Fig.28):

i. the highest values (+17.47 to +29.79 ‰) were obtained for silicified wood and silicified lignite;

ii. the lowest values (+2.91 to +14.00 ‰) were obtained for fused shale, and

iii. intermediate values were obtained both for agate samples (+11.78 to +22.08 ‰) and quartzite (+13.39 to +17.16 ‰).

Based upon the results obtained, Dr. F. Longstaffe reports the following observations: The distinct grouping of $\delta^{18}O$ values by rock type reflects differences in the processes by which these materials formed. The generally high $\delta^{18}O$ values of the silicified wood and silicified lignite reflect their crystallization at low temperatures in the presence of meteoric to brackish water (F. Longstaffe, personal communication 1993). Silicified lignites from both the Souris and Knife River localities exhibit only a narrow range in $\delta^{18}O$ values (<1 ‰) at each locality. The $\delta^{18}O$ values for material from the two sources do not overlap, the difference in mean values between the two groups being 4.20 ‰. Similar behaviour

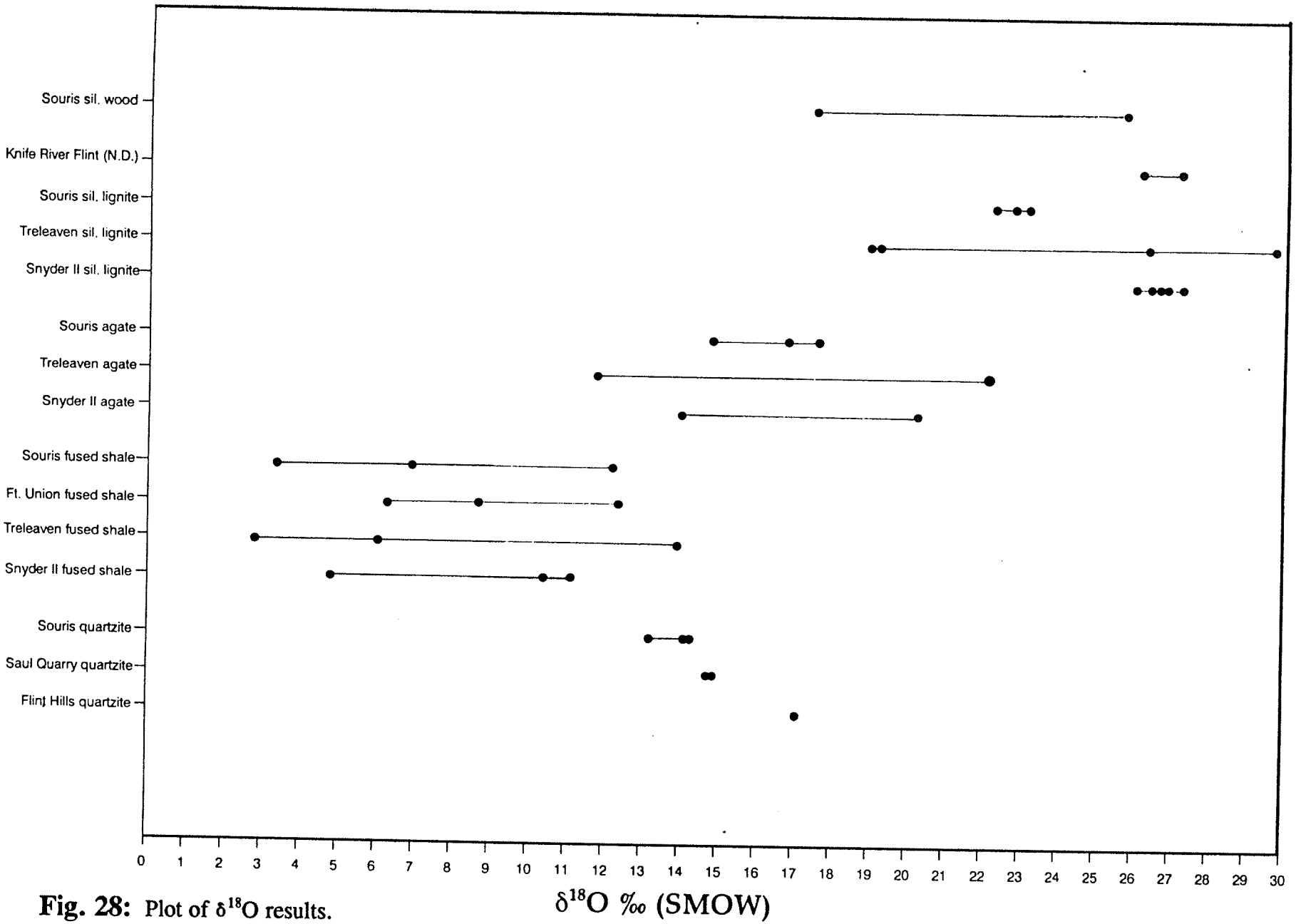


Fig. 28: Plot of $\delta^{18}O$ results.

is exhibited by silicified lignite from the Snyder II North Site, and the relatively tight range of $\delta^{18}O$ values (+26.57 to +27.28 ‰) matches closely those obtained for the two samples of North Dakota KRF, but are higher than determined for the Souris source (Fig.28). If this also held true for a larger sample size, it would lend support to the hypothesis that Native groups occupying the Snyder II Site were utilizing Knife River Flint from North Dakota rather than the closer but generally poorer quality silicified lignite available at Souris.

Although tools made from silicified lignite are present in the artifact assemblage from the Treleaven Site, the majority are of relatively low quality material similar to that found locally at Souris. Microscopic examination of the archaeological waste flakes catalogued as "petrified wood" revealed that all but one (T-5) were actually silicified lignite. Comparison with the other silicified lignites revealed that one (T-6) was microscopically indistinguishable from the North Dakota Knife River Flint, but had significantly lower $\delta^{18}O$ values than the latter. The same comparison confirmed that all three of the Snyder II flakes previously identified as "petrified wood" were also silicified lignite, and that one of the four Snyder II flakes (S-17) was also microscopically indistinguishable from the North Dakota Knife River Flint. Snyder flakes S-16 and S-20 were also very similar but slightly coarser-grained. Interestingly, all $\delta^{18}O$ values for the Snyder flakes occupied a narrow range which closely approximated the spread between North Dakota KRF samples MS-17 and DC-14.

In sharp contrast to the relatively narrow range of $\delta^{18}O$ values for Knife River Flint, the three samples of Treleaven silicified lignite exhibit a very wide range in $\delta^{18}O$

values (+19.23 to +29.79 ‰). The origin of this difference is uncertain. One explanation is simply that an insufficient number of samples has been examined. However, another possibility includes potential difficulty in classification of this material. For example, as discussed earlier, two samples (T-9 and S-23) were initially identified as agate, and one of the three samples initially catalogued as silicified wood (T-4) was subsequently identified as silicified lignite. It is also possible that the silicified lignite examined came from more than one source; the presence of silicified lignite in the Paleocene Fort Union Formation is well-documented, and, as discussed, it is possible that the conditions for the formation of silicified lignite also existed elsewhere (Clayton *et al.* 1970, Porter 1962). The $\delta^{18}O$ values of silicified wood from Souris (+17.47 to +25.71 ‰) also vary widely and include within their range the value obtained for silicified wood fragment T-5 from the Treleaven Site.

The wide range but generally low $\delta^{18}O$ values obtained for the 12 fused shale samples (+2.91 to +14.00 ‰) undoubtedly are a reflection of the high temperature modification that this material has experienced (F. Longstaffe, personal communication 1993). The partitioning of ^{18}O between minerals and water decreases as temperature rises. Hence, oxygen isotope re-equilibration between the fused shale precursor and superheated groundwater (which generally has $\delta^{18}O$ values < 0 ‰) can be expected to produce products with very low $\delta^{18}O$ values. The precise range of values obtained reflects the temperature of the reaction, the exact oxygen isotope composition of the groundwater, and the degree to which oxygen isotope re-equilibration occurred (F. Longstaffe, personal communication 1993).

The ranges in $\delta^{18}O$ values obtained for the Souris and Fort Union sources indicates that the process of fused shale formation was broadly similar for the material found at both localities, and it is therefore not possible to discriminate between sources using the oxygen isotope method. Clearly, however, the close overlap among the $\delta^{18}O$ values of the primary and secondary sources and the archaeological materials from the Treleaven and Snyder II sites supports a common origin for all.

The intermediate range of $\delta^{18}O$ values (+11.78 to +22.08 ‰) obtained for agate samples can be directly related to their origin by crystallization from groundwaters during diagenesis, at higher temperatures than the processes associated with silicification of wood or lignite (F. Longstaffe, personal communication 1993). The small number of samples analyzed produced a wide range in $\delta^{18}O$, precluding any definitive observation concerning the source of the Treleaven or Snyder II agate. No archaeological samples have $\delta^{18}O$ values that fall within the comparatively narrow range (+14.85 to +17.79 ‰) obtained for the Souris agate. The higher $\delta^{18}O$ values obtained for the archaeological agate, however, do overlap with the low end of the range obtained for silicified lignite and silicified wood.

The much tighter range of $\delta^{18}O$ values obtained for the quartzites (+13.39 to +17.16 ‰) reflects differences in their mode of origins when compared to the other silica samples. The $\delta^{18}O$ value of the quartzites is controlled mostly by the provenance of the quartz grains, and to a lesser extent by the isotopic composition and temperature of the formation water (deep groundwater) from which the secondary quartz overgrowths and cements were formed that bind the quartz grains (F. Longstaffe, personal communication

1993). The tight range and unique values obtained for each source, in particular the difference between the Souris-Saul Quarry and Flint Hills localities, indicates that oxygen isotopic analysis has potential as a tracer for archaeological materials of this character.

Chapter 7: Conclusions

7.1 Introduction

The growing emphasis in archaeology upon a multi-disciplinary approach to the reconstruction of past cultures has led to greater recognition of the applications of geological techniques to the study of archaeology. To the author's knowledge, this study represents the first attempt to synthesize, from an archaeological persepective, information on Tertiary gravels on the northern plains and the depositional history of the Souris Gravel and Sand deposit. Geological techniques have also been used to address several issues of archaeological relevance. Chemical and physical techniques have been employed in a preliminary characterization of lithics from gravel deposits exposed in and near Souris, Manitoba, a source of siliceous rocks for precontact Native groups in the area. The four techniques used (thin sections, X-Ray Diffraction, Instrumental Neutron Activation Analysis and Oxygen Isotopic Analysis) have been evaluated on the basis of their ability to differentiate between different lithic types and between material of the same type collected from different sources. Lithic flakes from two archaeological sites were also tested to see if they could be correlated with any of the sources examined.

7.2 The Souris Gravel and Sand Deposit

The stratigraphic unit designated the Souris Sand and Gravel Deposit is made up of material eroded from the newly-formed Rocky Mountains about 65 million years ago during the early Tertiary. This period was one of repeated tectonic unrest along the western margin of North America, as successive episodes of uplift and mountain-building

initiated corresponding cycles of erosion and deposition. By about 38 million years ago, rivers trending northeastward from the Rockies were depositing gravel in the Cypress Hills region of southern Alberta; these gravels were, in turn, carried southward to Flaxville, Montana, before they were later incorporated in lower level valley bottom deposits designated the Saskatchewan Gravels. During a later interglacial period, probably the Aftonian, material from the Saskatchewan Gravels was eroded and redeposited to the north, where it outcrops at Souris, Manitoba. These deposits are made up of the Tertiary gravel originally derived from the Rocky Mountains, as well as a variety of other lithics plucked from the substrate over which the transporting rivers flowed. Several of these redeposited lithic types, not usually found in other glacial gravels in the region, would have been of particular use to precontact peoples occupying the area due to their primarily siliceous composition and corresponding workability. Materials such as fused shale, silicified wood, silicified lignite, agate, chert and quartzite are found in significant quantities on archaeological sites in the region, and, although it is likely that some portion of this material was obtained from the Souris gravel deposit, the extent to which it was utilized has never been evaluated. It is hoped that the baseline data resulting from this initial study will provide the foundations for a complete characterization of this gravel source, which could then serve as the basis for comparison with archaeological material.

7.3 Evaluation of Analytical Techniques

This study represents the first application of physical and chemical techniques in an attempt to characterize lithic material from secondary sources and archaeological sites

in southwestern Manitoba. Each of the analytical techniques used in this analysis yielded information on specific characteristics of each lithic sample. Although each method had its own limitations, all combined to provide a physical and chemical characterization of the samples studied. Thin sections -- at approximately $25 to $30 for an unpolished, uncovered section -- are an inexpensive means of examining a number of physical characteristics, but cannot provide information on chemical composition. Conversely, Instrumental Neutron Activation Analysis and Oxygen Isotopic Analysis provide an exhaustive account of a sample's chemical composition, but do not produce a visual record of grain size, shape, etc. At about $50 per sample for the former and $75 for the latter, they are also considerably more expensive. Therefore, depending upon the material being studied, some combination of physical and chemical analyses is advocated.

7.31 Thin sections

Differences in grain size and shape and the presence or absence of diagnostic features were clearly illustrated in thin sections. Micro- or cryptocrystalline cherts were immediately distinguishable from coarsely-grained quartzites, fibrous agates and opaque fused shale or porcellanite. Souris chert, although similar in external appearance to Chadron chert, lacked the circular mineral staining visible microscopically in the latter (Fig.6). Fossils present in both Chadron and Platte County cherts served to differentiate them from the Souris cherts, in which fossils were comparatively rare. Fossils in chert have also been used to successfully identify the geological formation in which the chert

originated; thus, further research on the fossils observed in the Chadron chert, presently found only as redeposited cobbles, could identify this chert's origins.

Although the X-ray diffraction patterns for agate and quartzite are virtually identical (Figs.11 & 21), thin sections immediately demonstrated the distinction between the equant grains found in quartzite (and the other lithics examined) and the fibrous structure of agate. Similarly, thin sections illustrated the difference between small flakes of agate and silicified lignite, in which light and dark lenses of silica replacing plant tissue are evident. Fused shale, although normally distinctive even in hand specimens, may prove in its more vitreous form difficult to distinguish from jasper. Again, thin sections easily show the difference between porcellanite and the other siliceous rocks examined.

Silicified wood was identified on the basis of extant cell walls. In some cases, a slightly more specific identification (i.e., hardwood or conifer) was possible from a single thin section, although generally several sections cut along different planes are necessary to identify species. Silicified lignite, although macroscopically and structurally very similar to silicified wood, was differentiated on the basis of non-woody plant material present.

7.32 X-Ray Diffraction

XRD analysis also provided a rapid and inexpensive quantification of the minerals in each sample. Although substantial differences were not evident in the XRD patterns for agate, quartzite and silicified lignite due to similarities in the mineralogy of these material types, the XRD patterns for fused shale were distinct. Two samples of fused shale from

the Treleaven Site contained amphibole, likely a by-product of heating to very high temperatures. The absence of amphibole in the other samples of fused shale tested suggests that presence of such distinctive minerals may serve as an additional means of characterizing certain types of archaeological material.

7.33 Instrumental Neutron Activation Analysis

Rocks that form from replacement by or deposition of silica can show tremendous chemical variability, as illustrated by the range in trace elements found in multiple samples taken from the same flake or cobble. In silicified wood or lignite, the concentration of plant remains (which can selectively retain certain trace elements) also varies; results for trace elements may therefore depend on whether the sample had a high or low concentration of plant remains. Nevertheless, some observations can be made regarding the chemistry of the materials examined. Instrumental Neutron Activation Analysis showed fused shale to be chemically distinct from the other rock types studied. Consistent with its origins as a clay sediment, it was invariably higher in Al, K, Na, Ca, V and Ba and lower in Si. Small flakes of silicified wood or silicified lignite could be differentiated from agate on the basis of U and Ba, which are present in greater quantities in the wood and lignite. Uranium in particular has potential for the identification of siliceous rocks which originated as plant material. On the basis of very high levels of Ba and U, two waste flakes recovered from the Treleaven Site and previously identified as agate could be re-identified with some confidence as silicified wood or silicified lignite, although in the absence of thin sections it was not possible to differentiate further.

7.34 Oxygen Isotopic Analysis

Oxygen isotopic analysis also appears to have potential for distinguishing between certain rock types. The broad separation in $\delta^{18}O$ values among silicified wood and silicified lignite, agate and fused shale is of interest, and may be of value if larger populations of samples can be examined. The silicification of lignite and wood likely occurred over a wide geologic period; the redeposition of these materials in secondary gravel deposits could then produce a wide range of values for very similar material. However, $\delta^{18}O$ values for silicified lignite waste flakes from the Snyder II North Site cluster closely and correspond with oxygen isotope values for Knife River Flint from the primary source area in northwestern North Dakota. This suggests that the material tested formed under similar conditions, and may in fact be from the same geological formation. Similarly, oxygen isotopic analysis may be capable of differentiating between sources of quartzite. Samples of quartzite from Souris and Wyoming cluster markedly, and it is possible that further examination of a larger sample size would reveal a similar pattern.

7.4 Archaeological Samples

Waste flakes identified as "petrified wood" were chosen from the artifact assemblages of two southwestern Manitoba sites, the Treleaven Site (DjMb-3) and the Snyder II North Site (DgMg-15) for comparison with silicified wood and silicified lignite from Souris and North Dakota. Microscopic examination indicated that only one of these seven flakes (T-5) was actually silicified wood and that the other six flakes were, in fact, silicified lignite. Based upon INAA and Oxygen Isotopic Analysis, two very translucent

waste flakes (T-9 and S-23) previously identified as agate were also provisionally designated silicified lignite.

Further examination of all material identified as silicified lignite from both sources and sites revealed that one (T-6) was microscopically indistinguishable from the North Dakota Knife River Flint examined, but had significantly lower $\delta^{18}O$ values than the latter. The same comparison confirmed that one of the four Snyder II flakes (S-17) was also microscopically indistinguishable from the North Dakota Knife River Flint. Snyder flakes S-16 and S-20 were also very similar but slightly coarser-grained. Oxygen isotope values for all the Snyder flakes occupied a narrow range (Fig.28) which closely approximated the spread between North Dakota KRF samples MS-17 and DC-14. As noted, this suggests that this material formed at approximately the same geological time and under similar environmental conditions. Although this cannot be considered proof that the Snyder II silicified lignite was obtained from the same North Dakota quarry site as the Knife River Flint tested, it remains a possibility given that the $\delta^{18}O$ values for the Snyder material so closely resemble those of the North Dakota samples, yet are substantially different than those of the Souris silicified lignite examined.

7.5 Implications and Recommendations for Further Research

The results of this analysis suggest that archaeologists should exercise caution in identifying finely-grained, translucent brown silicified lignite as "Knife River Flint". Use of this term immediately implies an origin in deposits in western North Dakota and, as has been demonstrated, silicified lignite occurs in other gravel deposits of glacial and non-

glacial origin across the northern plains. For this reason, identification of "Knife River Flint" based solely upon physical appearance (either macroscopic or microscopic) is discouraged, and use of the more general term "silicified lignite", which does not presume to identify a specific source locale, is encouraged. However, it is recognized that given the present wide usage of the term, it is unlikely that archaeologists will easily relinquish its use. It is hoped that use of the term "Knife River Flint" will at least be tempered by the knowledge that the geological occurrence of this material is not confined to aboriginal quarries in North Dakota. Silicified wood is also found over a wide geographic area, and if replacement of organic material by silica is complete, may have the appearance of Knife River Flint. In addition, silicified lignite occupies a "quality continuum" from poor to excellent. This variation is not always obvious on a macroscopic level, particularly in smaller fragments or artifacts. In such cases, confidence in the identification of KRF in an artifact assemblage would be increased if several of the less "diagnostic" artifacts, i.e., waste flakes, could be sampled for physical and/or chemical analyses.

While the Souris gravels do contain cobbles of silicified lignite, the vast majority are generally of very poor quality, making it unlikely that local precontact peoples would have utilized Souris as an exclusive source of this material if other means of procurement were available, i.e., exchange from the south. Certainly, Souris should not be considered a source of good quality silicified lignite, although isolated cobbles have been found there. Nevertheless, it is reasonable to hypothesize that the silicified lignite found in the Souris gravels was deposited there by northeasterly-flowing Tertiary rivers, sometime prior to the Wisconsinan glaciation.

The issue of whether Knife River Flint from North Dakota was redeposited in the Souris vicinity prior to the last glaciation deserves further investigation. If any of the Souris silicified lignite was from the primary KRF source area, $\delta^{18}O$ values should reflect a common environment of formation. However, $\delta^{18}O$ values for the Souris silicified lignite and the North Dakota KRF do not reflect the relatively close agreement necessary to support such a scenario. This may be interpreted as further support for the hypothesis that the rivers which deposited silicified lignite at Souris did not pass through the area in which Knife River Flint formed, but an adjacent area in which silicified lignite formed under different environmental conditions. It is also possible, however, that further testing of silicified lignite from both Souris and North Dakota would reveal a wider range of isotopic variation and a closer correspondence between the two secondary sources.

This study has provided preliminary data on the characterization of lithics from secondary gravel deposits at Souris, Manitoba and from two southwestern Manitoba archaeological sites. Results indicate that different lithic types can be distinguished through petrographic examination. This includes materials that may bear a superficial resemblance, like silicified wood and silicified lignite, agate and silicified lignite, and chert and fused shale. Misidentifications in artifact assemblages from two archaeological sites have been identified, suggesting that the application of petrographic techniques would decrease the likelihoon of incorrect interpretations based on such mistakes. Continued examination of quarry locales and archaeological sites would no doubt provide further valuable information regarding local vs. non-local procurement of lithics, including silicified lignite or Knife River Flint. Preliminary results indicate that some correlation

may exist between silicified lignite from the Snyder II North Site and aboriginal quarrries in North Dakota. Further sampling from Souris and North Dakota is necessary to provide a more complete picture of the range in the silicified lignite at each source for comparison with archaeological material. Finally, quartzite from Souris and Wyoming was also differentiated geochemically, both by INAA and Oxygen Isotopic Analysis. A single sample from Flint Hills, South Dakota yielded appreciably different trace element and oxygen isotope values than the other quartzites examined. Further testing of a larger sample using these methods would prove whether, as indicated by these preliminary results, they are of value in the characterization of quartzite from various archaeological and quarry sites.

References Cited

Ahlbert, M., R. Akselsson, B. Forkman and G. Rausing

1976 Gold Traces on Wedge-Shaped Artifacts from the Late Neolithic of Southern Scandinavia Analyzed by Proton-Induced X-Ray Emission Spectroscopy. *Archaeometry* 19:39-49.

Ahler, Stanley A.

1977 Lithic Resource Utilization Patterns in the Middle Missouri Subarea. *In* W.R. Wood (ed.) *Trends in Middle Missouri Prehistory: A Festschrift Honoring the Contributions of Donald J. Lehmer.* Plains Anthropologist, Memoir 13:132-150.

1986 *The Knife River Flint Quarries: Excavations at Site 32DU508.* Bismarck: State Historical Society of North Dakota.

Alden, William C.

1924 Physiographic Development of the Northern Great Plains. *Bulletin of the Geological Society of America* vol. 35. Washington: U.S. Department of the Interior. pp. 385-424.

1932 Physiography and Glacial Geology of Eastern Montana and Adjacent Areas. *U.S. Geological Survey Professional Paper* 174. Washington: U.S. Department of the Interior.

Allen, R.O., A.H. Luckenback and C.G. Holland

1975 The Application of Instrumental Neutron Activation Analysis to a Study of Prehistoric Steatite Artifacts and Source Materials. *Archaeometry*, 17(1):69-83.

Allman, M. and Lawrence, D.F.

1972 *Geological Laboratory Techniques.* New York: ARCO Publishing Co. Inc. 335 pp.

Anderson, Duane C.

1978 Aboriginal Use of Tongue River Silica in Northwest Iowa. *Plains Anthropologist* 23(80):149-157.

Asaro, F., H.V. Michel, R. Sidrys and F. Stross

1978 High-Precision Chemical Characterization of Major Obsidian Sources in Guatemala. *American Antiquity* 43(3):436-443.

Bannatyne, B.B.
1970 The Clays and Shales of Manitoba. *Department of Mines and Natural Resources Publication* 67-1. Winnipeg.

Bannatyne, B.B. and J.T. Teller
1984 Geology of Manitoba Before the Ice Age. **In** *Natural Heritage of Manitoba: Legacy of the Ice Age*. James T. Teller (ed.). Winnipeg: Manitoba Museum of Man and Nature and Manitoba Nature Magazine.

Beekly, A.L.
1912 The Culbertson Lignite Field, Valley County, Montana. **In** Contributions to Economic Geology (Short Papers and Preliminary Reports: Part II - Mineral Fuels). *U.S. Geological Survey Bulletin* 471. pp. 319-358.

Behm, J.A. and A. Faulkner
1974 Hixton Quartzite: Experiments in Heat Treatment. *Wisconsin Archeologist* 55:271-76.

Bentor, Y.K., Kastner, M., Perlman, I. and Yellin, Y.
1981 Combustion Metamorphism of Bituminous Sediments and the Formation of Melts of Granitic and Sedimentary Composition. *Geochimica et Cosmochimica Acta* 45:2229-2255.

Bishop, A.C. and A.R. Woolley
1973 A New Technique for Cutting Archaeological Material. *Antiquity*, 47:302-303.

Bissell, H.J.
1957 Combined Preferential Staining and Cellulose Peel Technique. *Journal Sedimentary Petrology*, 27:417-420.

Blatt, Harvey, Gerard Middleton and Raymond Murray
1980 *Origin of Sedimentary Rocks*. Second edition. New Jersey: Prentice-Hall, Inc.

Bleed, Peter and Marlene Meier
1980 An Objective Test of the Effects of Heat Treatment of Flakeable Stone. *American Antiquity* 45(3):502-507.

Bleumle, John P.
1972 Pleistocene Drainage Development in North Dakota. *Geological Society of America Bulletin* 83:2189-2194.

Bonardi, M. and R.J. Traill

1975 Catalogue of X-Ray Diffraction Patterns and Specimen Mounts on File at the Geological Survey of Canada. *Geological Survey of Canada Paper* 75-8. Ottawa.

Brothwell, Don

1983 Petrology and Archaeology: an Introduction. **In** *The Petrology of Archaeological Artifacts*, D.R.C. Kempe and A.P. Harvey (eds). Oxford: Clarendon Press. pp. 1-25.

Broughton, Paul L.

1975 Agate and Agatized-Wood Bearing Gravels of South-Central Saskatchewan. *Blue Jay* 33(1):10-12.

1976 Silicified Lignite from the Tertiary of South-Central Saskatchewan. *Canadian Journal of Earth Science* 13:1719-1722.

Bryson, Robert P.

1952 The Coalwood Coal Field, Powder River County, Montana. *U.S. Geological Survey Bulletin* 973-B. Washington: U.S. Govt. Printing Office.

Buehler, E.J.

1948 The Use of Peels in Carbonate Petrology. *Journal Sedimentary Petrology* 18:71-73.

Butzer, Carl

1971 *Environment and Archaeology: An Ecological Approach to Prehistory.* Chicago: Aldine Publishing.

Caldwell, W.G.E.

1983 The Cretaceous System in the Williston Basin -- a Modern Appraisal. **In** Fourth International Williston Basin Symposium, J.E. Christopher and J. Kaldi (eds.). *Special Publication* 6, Saskatchewan Geological Society. Regina.

Campling, Neil R.

1980 Identification of Swan River chert. **In** *Directions in Manitoba Prehistory: Papers in Honour of Chris Vickers.* L. Pettipas (ed). Winnipeg: Association of Manitoba Archaeologists and Manitoba Archaeological Society.

Cann, J.R., J.E. Dixon and Colin Renfrew
1969 Obsidian Analysis and the Obsidian Trade. **In** *Science in Archaeology*, D. Brothwell and E. Higgs (eds). London: Thames and Hudson.

Christiansen, E.A.
1965 Preglacial Valleys in Southern Saskatchewan. *Saskatchewan Research Council, Geological Division Map* no. 3. Regina.

Clayton, Lee, W.B. Bickley Jr. and W.J. Stone
1970 Knife River Flint. *Plains Anthropologist* 15(50), pt.1, pp.282-290.

Clark, Frances
1984 Knife River Flint and Interregional Exchange. *Midcontinental Journal of Archaeology* 9:173-198.

Clayton, R.N. and T.K. Mayeda
1963 The Use of Bromine Pentafluoride in the Extraction of Oxygen in Oxides and Silicates for Isotopic Analysis. *Geochim. Cosmochim. Acta* 27:43-52.

Coleman, M. and S. Walker
1979 Stable Isotope Identification of Greek and Turkish Marbles. *Archaeometry* 21(1):107-112.

Collier, Arthur J. and W.T. Thom Jr.
1918 The Flaxville Gravel and Its Relation to Other Terrace Gravels of the Northern Great Plains. *U.S. Geological Survey Professional Paper* 108-J. Washington: U.S. Govt. Printing Office.

Crabtree, D.E. and B.R. Butler
1964 Notes on Experiments in Flintknapping. 1: Heat treatment of Silica Minerals. *Tebiwa* 7:1-6.

Craig, Harmon and Valerie Craig
1972 Greek Marbles: Determination of Provenance by Isotopic Analysis. *Science* 176:401-403.

Crawford, G.S.
1955 Pumicite in Saskatchewan. *Department of Mineral Resources Report* no. 16. Regina.

Dake, H.C., Frank L. Fleener and Ben Hur Wilson
1938 *Quartz Family Minerals: A Handbook for the Mineral Collector.* New York: McGraw-Hill Book Company, Inc.

Dana, J.D.
1962 *A System of Mineralogy*, vol. 3. New York: John Wiley and Sons.

Davidson, D.A. and M. Shackley (eds.)
1976 *Geoarchaeology: Earth Science and the Past.* London: Duckworth.

Denner, M.J. and P.L. Reeves
1979 Mineral Resources of Saskatchewan. *Saskatchewan Mineral Resources Miscellaneous Report* 79-11. Regina.

Dickson, J.A.D.
1965 A Modified Staining Technique for Carbonates in Thin Section. *Nature* 205:587.

Dorf, Erling
1964 The Petrified Forests of Yellowstone Park. *Scientific American* 210(4):106-114.

Dunn, C.E., J. Ek and J. Byman
1985 Uranium Biogeochemistry: a Bibliography and Report on the State of the Art. *International Atomic Energy Agency Technical Document* 327, Vienna.

Durrani, S.A., H.A. Khan, M. Taj and C. Renfrew
1971 Obsidian Source Identification by Fission Track Analysis. *Nature* 233:242-45.

Eley, Betty and Peter von Bitter
1989 *Cherts of Southern Ontario.* Toronto: Royal Ontario Museum.

Elson, John A.
1956 Surficial Geology of the Tiger Hills Region. Unpublished PhD dissertation, Yale University, New Haven.

1958 Pleistocene History of Southwestern Manitoba. **In** Guidebook Ninth Annual Field Conference, W.M. Laird, R.W. Lemke and M. Hansen (eds). *North Dakota Geological Survey*, Miscellaneous Series no. 10.

1962 Surficial Geology Virden Manitoba-Saskatchewan. *Geological Survey of Canada Map* 39-1961.

Fladmark, K.R.
1984 Mountain of Glass: Archaeology of the Mount Edziza Obsidian Source, British Columbia, Canada. *World Archaeology* 16(2):139-156.

Folk, R.L and C. Weaver
1952 A Study of the Texture and Composition of Chert. *American Journal of Science* 250:498-510.

Forsman, Nels F.
1983 A Volcanic Airfall Marker Bed in the Upper Fort Union Formation (Paleocene) of Western North Dakota. **In** Fourth International Williston Basin Symposium, J.E. Christopher and J. Kaldi (eds.). *Special Publication* no. 6, Saskatchewan Geological Society. Regina.

Francaviglia, V., M.E. Minardi and A. Palmieri
1975 Comparative Study of Various Samples of Etruscan Bucchero by X-Ray Diffraction, X-Ray Spectrometry, and Thermoanalysis. *Archaeometry* 17(2):223-231.

Fraser, F.J., F.H. McLearn, L.S. Russell, P.S. Warren and R.T.D. Wickenden
1935 Geology of Southern Saskatchewan. *Geological Survey of Canada Memoir* 176. Ottawa.

Fredlund, Dale E.
1976 Fort Union Porcellanite and Fused Glass: Distinctive Lithic Materials of Coal Burn Origin on the Northern Plains. *Plains Anthropologist* 21:207-211.

Frison, George C., Gary A. Wright, James B. Griffin and Adon A. Gordus
1968 Neutron Activation Analysis of Obsidian: an Example of its Relevance to Northwestern Plains Archaeology. *Plains Anthropologist* 13:209-17.

Frison, George C. and Dennis J. Stanford
1982 *The Agate Basin Site: A Record of the Paleoindian Occupation of the Northwestern High Plains.* New York: Academic Press.

Furnival, G.M.
1946 Cypress Lake Map-Area, Saskatchewan. *Geological Survey of Canada Memoir* 242. Ottawa.

Gale, N.H.
1981 Mediterranean Obsidian Source Characterization by Strontium Isotope Analysis. *Archaeometry* 23(1):41-51.

Gladfelter, B.G.
1977 Geoarchaeology: the Geomorphologist and Archaeology. *American Antiquity* 42:519-538.

Goffer, Z.
1980 *Archaeological Chemistry: A Sourcebook on the Applications of Chemistry to Archaeology*. Toronto: John Wiley and Sons. 376 p.

Goldsmith, J.R. and Jenkins, D.M.
1985 The High-Low Albite Relations Revealed by Reversal of Degree of Order at High Pressures. *American Mineralogist* 70:911-923.

Goles, G.G.
1977 Instrumental Methods of Neutron Activation Analysis. In *Physical Methods of Determinative Mineralogy*, J. Zussman (ed). London: Academic Press. pp. 343-370.

Gordus, A.A., W.C. Fink, M.E. Hill, J.C. Purdy, and T.R. Wilcox
1967 Identification of the Geologic Origins of Archaeological Artifacts: an Automated Method of Na and Mn Neutron Activation Analysis. *Archaeometry* 10:87-96.

Gordus, A.A., G.A. Wright and J.B. Griffin
1968 Characterization of Obsidian Sources by Neutron Activation Analysis. *Science* 161:382-84.

Gregg, Michael L.
1987 Knife River Flint in the Northeastern Plains. *Plains Anthropologist* 32(118):367-377.

Hall, E.T.
1960 X-Ray Fluorescent Analysis Applied to Archaeology. *Archaeometry* 3:29-35.

Hall, E.T., M.S. Banks and J.M. Stern
1964 Uses of X-Ray Fluorescent Analysis in Archaeology. *Archaeometry* 7:84-89.

Halstead, E.C.
1959 Ground-Water Resources of the Brandon Map-Area, Manitoba. *Geological Survey of Canada Memoir* 300. Ottawa.

Hanna, Margaret
1982 Pots and Populations. Unpublished PhD dissertation, University of Manitoba, Winnipeg.

Hassan, Fekri A.
1979 Geoarchaeology: The Geologist and Archaeology. *American Antiquity* 44:267-70.

Herz, N.
1987 Carbon and Oxygen Isotopic Ratios: a Data Base for Classical Greek and Roman Marble. *Archaeometry* 29(1):35-43.

Hester, T.R.
1975 X-Ray Fluorescence Analysis of Archaeological Obsidian from the Rio Grande Plain, Southern Texas. *Texas Journal of Science* 26:286-89.

Hickey, Leo J.
1977 Stratigraphy and Paleobotany of the Golden Valley Formation (Early Tertiary) of Western North Dakota. *Geological Society of America Memoir* 150.

Hind, Henry Y.
1971 *Narrative of the Canadian Red River Exploring Expeditions of 1857 and the Assiniboine and Saskatchewan Exploring Expedition of 1858.* Edmonton: Hurtig Reprint (originally published in 1860 by Longman, Green, Longman and Roberts).

Hlady, Walter M.
1965 A Manitoba Source of "Knife River Flint". *Manitoba Archaeological Newsletter* 2(2):3-7.

Horberg, Leland
1952 Pleistocene Drift Sheets in the Lethbridge Region, Alberta, Canada. *Journal of Geology* 60:303-330.

Horberg, Leland and Richard C. Anderson
1956 Bedrock Topography and Pleistocene Glacial Lobes in Central United States. *Journal of Geology* 64(2):101-116.

Howard, A.D.
1960 Cenozoic History of Northeastern Montana and Northwestern North Dakota with Emphasis on the Pleistocene. *U.S. Geological Survey Professional Paper* 326. Washington: U.S. Govt. Printing Office.

Hughes, Richard E. and Fred W. Nelson
1987 New Findings on Obsidian Source Utilization in Iowa. *Plains Anthropologist* 32(117):313-316.

Ingham, K.W. and Z. Dunikowska-Koniuszy
1965 The distribution, character and basic properties of cherts in Southwestern Ontario. Ontario Department of Highways, Report RB106:1-35.

Janusas, S.E.
1984 A Petrological Analysis of Kettle Point Chert and its Spatial and Temporal Distribution in Regional Prehistory. National Museum of Man Mercury Series, *Archaeological Survey of Canada Paper* no. 128. Ottawa.

Johnson, Eldon A.
1986 Properties and sources of some Saskatchewan lithic materials of archaeological significance. Unpublished Master's Thesis, University of Saskatchewan.

Johnston, W.A.
1934 Surface Deposits and Ground-water Supply of Winnipeg Map-area, Manitoba. *Geological Survey of Canada Memoir* 174. Ottawa.

1946 Glacial Lake Agassiz, with Special Reference to the Mode of Deformation of the Beaches. *Geological Survey of Canada Bulletin* 7. Ottawa.

Julig, P.J., L.A. Pavlish and R.G.V. Hancock
1989 Aspects of Late Paleoindians Lithic Technological Organization in the Northwestern Lake Superior Region of Canada. **In** *Eastern Paleoindian Lithic Resource Use*, Christopher J. Ellis and Jonathan C. Lothrop (eds.). Investigations in American Archaeology, Westview Press. pp. 293-322.

1991a INAA Provenance Studies of Lithic Materials from the Western Great Lakes Region of North America. *Archaeometry '90: Proceedings of the International Symposium on Archaeometry*. Ernst Pernicka and Gunter Wagner (eds). Heidelberg: Birkhauser Birlag.

1991b INAA of Lithic Materials from Cummins Site Thunder Bay: Determination of Raw Material Sources. **In** Neutron Activation and Plasma Emission Spectrometric Analysis in Archaeology: Techniques and Applications, *British Museum Occasional Paper* 82. M.J. Hughes, M.R. Cowell and D.R. Hook (eds.). London: British Museum. pp. 155-167.

Julig, P.J., L.A. Pavlish, C. Clark and R.G.V. Hancock
1992 Chemical Characterization and Sourcing of Upper Great Lakes Cherts by INAA. *Ontario Archaeology* 54:37-50.

Katz, A. and G.M. Friedman
1965 The Preparation of Stained Acetate Peels for the Study of Carbonate Rocks. *Journal Sedimentary Petrology* 35:248-249.

Kehew, A.E. and Lee Clayton
1983 Late Wisconsinan Floods and Development of the Souris-Pembina Spillway System in Saskatchewan, North Dakota and Manitoba. **In** Teller, J. and Lee Clayton (eds) Glacial Lake Agassiz. *Geological Association of Canada Special Paper* 26. pp. 187-210.

Kehew, A.E. and Mark Lord
1987 Glacial-Lake Outbursts Along the Mid-Continent Margins of the Laurentide Ice-Sheet. **In** *Catastrophic Flooding*, L. Mayer and D. Nash (eds).

Kempe, D.R.C. and Anthony P. Harvey (eds.)
1983 *The Petrology of Archaeological Artifacts*. Oxford: Clarendon Press.

Kempe, D.R.C. and J.A. Templeman
1983 Techniques. In D.R.C. Kempe and A.P. Harvey (eds) *The Petrology of Archaeological Artifacts*. Oxford: Clarendon Press. pp.26-52.

Keyser, James D. and John L. Fagan
1987 ESP: Procurement and Processing of Tongue River Silicified Sediment. *Plains Anthropologist* 32(117):233-256.

Klassen, R.W.
1965 Surficial Geology Riding Mountain Manitoba-Saskatchewan. *Geological Survey of Canada Map* 16-1965.

1969 Quaternary Stratigraphy and Radiocarbon Chronology in Southwestern Manitoba. *Geological Survey of Canada Paper* 69-27. Ottawa.

1971 Nature, Thickness and Subsurface Stratigraphy of the Drift in Southwestern Manitoba. **In** Geoscience Studies in Manitoba, A.C. Turnock (ed). *Geological Association of Canada Special Paper* no. 9.

1989 Quaternary Geology of the Southern Canadian Interior Plains. **In** Quaternary Geology of Canada and Greenland, R.J. Fulton (ed.). Geological Survey of Canada, *Geology of Canada* no.1 (also Geological Society of America, *The Geology of North America*, vol. K-1). pp. 138-173.

Klassen, R.W. and J.E. Wyder
1970 Bedrock Topography, Buried Valleys and Nature of the Drift, Virden Map-Area, Manitoba. *Geological Survey of Canada Paper* 70-56. Ottawa.

Klassen, R.W., J.E. Wyder and B.B. Bannatyne
1970 Bedrock Topography and Geology of Southern Manitoba. *Geological Survey of Canada Paper* 70-51, Map 25-1970.

Klein, Cornelis and C.S. Hurlbut, Jr.
1985 *Manual of Mineralogy*. 20th edition. Toronto: John Wiley and Sons, Inc.

Knauth, L. Paul and Donald R. Lowe
1978 Oxygen Isotope Geochemistry of Cherts from the Onverwacht Group (3.4 Billion Years), Transvaal, South Africa, with Implications for Secular Variations in the Isotopic Composition of Cherts. *Earth and Planetary Science Letters* 41:209-222.

Kohl, P.L., G.Harbottle and E.V. Sayre
1979 Physical and Chemical Analyses of Soft Stone Vessels from Southwest Asia. *Archaeometry* 21(2):131-159.

Kupsch, W.O.
1956 Geology of Eastern Cypress Hills. *Saskatchewan Department of Mineral Resources Report* 20.

1964 Bedrock Surface and Preglacial Topography of the Regina-Wynyard Region, Southern Saskatchewan. **In** *Third Annual Williston Basin Symposium*. Billings Geological Society. pp. 274-283.

Laird, W.M.
1967 A note on preglacial drainage in the northern Great Plains. **In** Glacial Geology of the Missouri Coteau and Adjacent Areas, Lee Clayton and T.F. Freers (eds). *North Dakota Geological Survey Miscellaneous Series* no. 30, pp. 167-170.

Lavin, Lucianne and Donald R. Prothero
1992 Prehistoric Procurement of Secondary Sources: The Case for Characterization. *North American Archaeologist* 13(2):97-113.

Lazenby, Colleen
1980 Prehistoric Sources of Chert in Northern Labrador: Field Work and Preliminary Analyses. *Arctic* 33(3):628-645.

Lemke, Richard W.
1960 Geology of the Souris River Area, North Dakota. *U.S. Geological Survey Professional Paper* 325. Washington: U.S. Dept. of the Interior.

Lemke, Richard W., W.M. Laird, M.J. Tipton and R.M. Lindvall
1965 Quaternary Geology of Northern Great Plains. **In** *The Quaternary of the United States: A Review Volume for the VII Congress of the International Association for Quaternary Research*, H.E. Wright, Jr. and David G. Frey (eds). Princeton: University Press.

Leonoff, Leslie M.
1970 The Identification, Distribution and Sources of Lithic Raw Materials in Manitoba Archaeological Sites. Unpublished M.A. thesis, University of Manitoba, Winnipeg.

Loendorf, Lawrence L., David D. Kuehn and Nels F. Forsman
1984 Rainy Buttes Silicified Wood: A Source of Lithic Raw Material in Western North Dakota. *Plains Anthropologist* 29(106):335-342.

Luedtke, Barbara E.
1978 Chert Sources and Trace-Element Analysis. *American Antiquity* 43(3):413-423.

1979 The Identification of Sources of Chert Artifacts. *American Antiquity* 44(4):744-757.

MacNeish, R.S.
1958 An Introduction to the Archaeology of southeast Manitoba. *National Museum of Canada Bulletin* 157. Ottawa.

McConnell, R.G.
1886 Report on the Cypress Hills, Wood Mountain and Adjacent Country. *Geological Survey of Canada Annual Report* (New Series), Vol.1 Pt. C. pp. 1-85.

Mandeville, M. and J.J. Flenniken
1974 A Comparison of the Flaking Qualities of Nehawka Chert Before and After Thermal Pre-Treatment. *Plains Anthropologist* 19:146-48.

Manfra, L., U. Masi and B. Turi
1975 Carbon and Oxygen Isotope Ratios of Marbles from some Ancient Quarries of Western Anatolia and their Archaeological Significance. *Archaeometry* 17(2):215-221.

Mayer-Oakes, W.J. (ed.)
1967 Life, Land and Water. *University of Manitoba Department of Anthropology Occasional Paper* 1. Winnipeg.

Meneley, W.A., E.A. Christiansen and W.O. Kupsch
1956 Preglacial Missouri River in Saskatchewan. *Journal of Geology* 65:441-447.

Murata, K.J.
1940 Volcanic Ash as a Source of Silica for the Silicification of Wood. *American Journal of Science* 238(8):586-596.

Nielson, K.K., M.W. Hill, N.F. Mangelson and F.W. Nelson
1976 Elemental Analysis of Obsidian Artifacts Using Proton-Induced X-Ray Emission. *Analytical Chemistry* 48:1947-50.

Nelson, D.E., J.M. D'Auria and R.B. Bennett
1975 Characterization of Pacific Northwest Coast Obsidian by X-Ray Fluorescence Analysis. *Archaeometry* 17:85-97.

Nelson, F.W., K.K. Nielson, N.F. Mangelson, M.W. Hill and R.T. Matheny
1977 Preliminary Studies of the Trace Element Composition of Obsidian Artifacts From Northern Campeche, Mexico. *American Antiquity* 42:209-25.

Nelson, Fred W. and Barbara Voorhies
1980 Trace Element Analysis of Obsidian Artifacts from Three Shell Midden Sites in the Littoral Zone, Chiapas, Mexico. *American Antiquity* 45(3):540-550.

Parkins, W.
1977 Onondaga chert: geological and palynological studies as applied to archaeology. Unpublished M.Sc. thesis, Brock University.

Pettijohn, F.J., P.E. Potter and R. Siever
1987 *Sand and Sandstone*. Second edition. New York: Springer-Verlag.

Porter, James W.
1960 The Value of Lithic Analysis in Archaeological Interpretation. Unpublished M.Sc. thesis, Department of Anthropology, University of Wisconsin.

Prest, V.K.
1970 Quaternary Geology of Canada. **In** R.J.W. Douglas (ed) Geology and Economic Minerals of Canada. *Geological Survey of Canada Economic Geology Report* 1. pp. 676-764.

Price, I.

1975 Acetate Peel Techniques Applied to Cherts. *Journal Sedimentary Petrology* 45:215-216.

Prothero, Donald R. and Lucianne Lavin

1990 Chert petrography and its potential as an analytical tool in archaeology. *In* Lasca, N.P. and J. Donahue (eds.) *Archaeological Geology of North America.* Boulder, Colorado: Geological Society of America, Centennial Special Volume 4.

Rogers, G. Sherburne

1917 Baked Shale and Slag Formed by the Burning of Coal Beds. *U.S. Geological Survey Shorter Contributions to General Geology,* Professional Paper 108A:1-10. Washington: U.S. Govt. Printing Office.

Rogers, G. Sherburne and Wallace Lee

1923 Geology of Tullock Creek, Coal Field, Rosebud and Bighorn Counties, Montana. *United States Geological Survey Bulletin 749-I*:1-181. Washington: U.S. Government Printing Office.

Russell, Loris S.

1934 Revision of the Lower Oligocene Vertebrate Fauna of the Cypress Hills, Saskatchewan. *Transactions of the Royal Canadian Institute* vol. 20, pt. 1, pp. 49-66.

1938 The Skull of a *Hemipsalodon grandis*, a Giant Oligocene Croedont. *Transactions of the Royal Society of Canada*, Series 3, vol. 32, sec. IV, pp. 61-66.

1940 Titanotheres from the Lower Oligocene Cypress Hills Formation of Saskatchewan. *Transactions of the Royal Society of Canada*, Series 3, vol. 34, sec. 4, pp. 89-100.

1948 The Geology of the Southern Part of the Cypress Hills, Southwestern Saskatchewan. *Saskatchewan Department of Mineral Resources Report* 8.

1950 The Tertiary Gravels of Saskatchewan. *Transactions of the Royal Society of Canada* Series 3, vol. 44, sec. 4, pp. 51-59.

Russell, Loris S. and R.W. Landes

1940 Geology of the Southern Alberta Plains. *Geological Survey of Canada Memoir* 221. Ottawa.

Russell, Loris S. and R.T.D. Wickenden
1933 An Upper Eocene Vertebrate Fauna from Saskatchewan. *Transactions of the Royal Society of Canada*, series 3, 27(4):53-65.

Rutherford, R.L.
1937 Saskathcewan Gravels and Sands in Central Alberta. *Transactions of the Royal Society of Canada* Series 3, sec IV, vol. 31, pp. 81-95.

Saul, John M.
1969 Study of the Spanish Diggings, Aboriginal Flint Quarries of Southeastern Wyoming. *National Geographic Society Research Reports*, Paul H. Oehser (ed.). Washington, D.C.

Scurfield, G. and E.R. Segnit
1984 Petrification of Wood by Silica Minerals. *Sedimentary Geology* 39:149-167.

Shackleton, N.J. and C. Renfrew
1970 Neolithic Trade Routes Re-Aligned by Oxygen Isotope Analysis. *Nature* 228:1062-5.

Shotton, F.W. and G.L. Hendry
1979 The Developing Field of Petrology in Archaeology. *Journal of Archaeological Science* 6:75-84.

Sieveking, G. de G., P. Bush, J. Ferguson, P.T. Craddock, M.J. Hughes and M.R. Cowell
1972 Prehistoric Flint Mines and Their Identification as Sources of Raw Material. *Archaeometry* 14(2):151-176.

Skolnick, Herbert
1965 The Quartzite Problem. *Journal of Sedimentary Petrology* 35(1):12-21.

Stalker, A. MacS.
1961 Buried Valleys in Central and Southern Alberta. *Geological Survey of Canada Paper* 60-32. Ottawa.

1963 Quaternary Stratigraphy in Southern Alberta. *Geological Survey of Canada Paper* 62-34. Ottawa.

1968 Identification of Saskatchewan Gravels and Sands. *Canadian Journal of Earth Sciences* 5:155-163.

Stevenson, D.P., F.H. Stross and R.F. Heizer
1971 An Evaluation of X-Ray Fluorescence Analysis as a Method for Correlating Obsidian Artifacts with Source Identification. *Archaeometry* 13(1):17-25.

Stewart, W.N. and T.N. Taylor
1965 The Peel Technique **In** Kummel, B. and D. Raup, *Handbook of Paleontological Techniques*. San Francisco: W.H. Freeman and Co. pp.224-232.

Storer, J.E.
1978 Tertiary Sands and Gravels in Saskatchewan and Alberta: Correlation of Mammalian Faunas. **In** Western and Arctic Canadian Biostratigraphy, C.R. Stelck and B.D.E. Chatterton (eds.). *Geological Association of Canada Special Paper* 18.

Stos-Fertner, Z., R.E.M. Hedges and R.D.G. Evely
1979 The Application of the XRF-XRD Method to the Analysis of the Pigments of Minoan Painted Pottery. *Archaeometry* 21(2):187-194.

Stout, A.M. and A. Hurst
1985 X-Ray Diffraction of Early Iron Age Pottery from Western Norway. *Archaeometry* 27(2):225-230.

Stross, F.H., F. Asaro, H.V. Michel and R. Gruhn
1977 Sources of Some Obsidian Flakes from a Paleoindian Site n Guatemala. *American Antiquity* 42(1):114-118.

Syms, E. Leigh
1977 Cultural Ecology and Ecological Dynamics of the Ceramic Period in Southwestern Manitoba. *Plains Anthropologist* 22(76, part 2).

1979 Settlement Studies in Southwestern Manitoba: A Preliminary Statement. *Archae-Facts* 6(2):8-9.

1980 A Description and Analysis of the Nash Random Survey Sample, Southwestern Manitoba, 1972-73: a Compendium. *Data Log* No.1, Southman Human Adaptation and Paleoenvironmental Explorations. Brandon: Brandon University.

Teller, J.T.
1993 Quaternary Geology of the Eastern Canadian Prairies, Winnipeg to Moose Jaw: An Examination of the Sediments and Geomorphology from the Glacial Lake Agassiz Basin West to Glacial Lake Hind, the Souris River Spillway, and Glacial Lake Regina. Unpublished field guide for the meeting of IGCP 253, "Termination of the Pleistocene", June 29-July 1, 1993. Part I.

Thomas, Marvin
1983 Lithic raw material selection at a number of sites in the Qu'Appelle basin. Unpublished B.A. (Hon.) Thesis, University of Regina.

Tite, M.S.
1972 *Methods of Physical Examination in Archaeology*. London: Seminar Press.

Underwood McLellan and Associates Ltd.
1977 Sand and gravel resources of the Brandon region: Manitoba Department of Mines, Resources and Environmental Management. Open File Report OF77-8, vols. 1 & 2.

VanNest, Julieann
1985 Patination of Knife River Flint Artifacts. *Plains Anthropologist* 30(110) (part 1):325-339.

Vonhof, J.A.
1965a Tertiary Gravels and Sands in Southern Saskatchewan. Unpublished Master's thesis, University of Saskatchewan, Saskatoon.

1965b The Cypress Hills Formation and Its Reworked Deposits in Southwestern Saskatchewan. *Alberta Society of Petroleum Geologists, 15th Annual Field Conference Guidebook*, Part I, Cypress Hills Plateau. pp. 142-161.

Vonhof, J.A.
1969 Tertiary Gravels and Sands in the Canadian Great Plains. Unpublished PhD thesis, University of Saskatchewan, Saskatoon.

Walker, Ernest G.
1974 The Coronach Archaeological Survey Project. Report on file at the Saskatchewan Museum of Natural History, Regina.

Warne, S.
1962 A Quick Field or Laboratory Staining Scheme for the Differentiation of the Major Carbonate Minerals. *Journal of Sedimentary Petrology* 32:29-38.

Warren, P.S.
1939 The Flaxville Plain in Alberta. *Transactions of the Royal Canadian Institute* 22(2):341-349.

Watrall, Charles
1976 A Note on the Souris Gravels. *Archae-Facts* 4(2):21-23.

Wedel, W.R.
1961 *Prehistoric Man on the Great Plains.* Oklahoma: University Press.

Weigand, P.C., G. Harbottle and E.V. Sayre
1977 Turquoise Sources and Source Analysis: Mesoamerica and the Southwestern U.S.A. **In** T.K. Earle and J.E. Ericson (eds) *Exchange Systems in Prehistory.* New York: Academic Press. pp. 15-34.

Westgate, J.A.
1968 Surficial Geology of the Foremost-Cypress Hills Area, Alberta. *Research Council of Alberta Bulletin* 22. Edmonton: Research Council of Alberta.

Westgate, J.A. and L.A. Bayrock
1964 Periglacial Structures in the Saskatchewan Gravels and Sands of Central Alberta, Canada. *Journal of Geology* 72:641-648.

Wettlaufer, B.
1956 The Mortlach Site in the Besant Valley of Central Saskatchewan. *Saskatchewan Museum of Natural History Anthropological Series* no. 1. Regina.

Wettlaufer, B. and Mayer-Oakes, W.J. (eds.)
1960 The Long Creek Site. *Saskatchewan Museum of Natural History Anthropological Series* no. 2. Regina.

Weymouth, J.W. and M. Mandeville
1975 An X-Ray Diffraction Study of Heat-Treated Chert and its Archaeological Implications. *Archaeometry* 17(1):61-67.

Whitaker, S.H. and E.A. Christiansen
1972 The Empress Group in Southern Saskatchewan. *Canadian Journal of Earth Sciences* 9:353-360.

Williams, M.Y.
1929 The Physiography of the Southwestern Plains of Canada. *Transactions of the Royal Society of Canada*, Series 3, section IV, vol. 23, pp. 61-79.

Williams, M.Y. and W.S. Dyer
1930 Geology of Southern Alberta and Southwestern Saskatchewan. *Geological Survey of Canada Memoir* 163. Ottawa: Geological Survey of Canada.

Wilson, Michael C.
1990 Archaeological Geology in western Canada: Techniques, Approaches, and Integrative Themes. **In** Archaeological Geology of North America, N.P. Lasca and J. Donahue (eds.). *Geological Society of America Special Volume* 4. Boulder, Colorado.

Wright, Gary A. and Henry J. Chaya
1985 Obsidian Source Analysis in Northwestern Wyoming: Problems and Prospects. *Plains Anthropologist* 30(109):237-242.

Wright, Gary A., Henry J. Chaya and James McDonald
1990 The Location of the Field Museum Yellowstone (F.M.Y., 90) Group Obsidian Source. *Plains Anthropologist* 35(127):71-74.

Wyder, John E.
1968 Geophysical and Geological Study of Surficial Deposits near Frobisher, Saskatchewan. Unpublished PhD thesis, University of Saskatchewan, Saskatoon.

Young, H.R. and E.L. Syms
1980 The Use of Acetate Peels in Lithic Analysis. *Archaeometry* 22(2):205-208.

Zussman, J.
1977 X-Ray Diffraction. **In** J. Zussman (ed.) *Physical Methods in Determinative Mineralogy*. London: Academic Press. pp.391-474.