PETROGRAPHY AND PROVENANCE OF MISSISSIPPIAN GREENSTONE ARTIFACTS FROM THE MOUNDVILLE SITE, ALABAMA

by

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Daniel G. Gall. Petrography and Provenance of Mississippian Greenstone Artifacts from the Moundville Site, Alabama
(under the direction of Dr. J. Robert Butler, UNC-CH)

ABSTRACT

This is a study of the greenstone artifacts found at the Moundville site, Alabama. The objectives are to determine the greenstone artifact types, their mineralogy and petrography, and their geologic sources.

Greenstone was used almost exclusively for petaloid celts at Moundville. Whole celts and celt fragments comprise 96% of the greenstone artifact inventory. Of the 578 artifacts originally classified as greenstone, 568 are fine- to medium-grained, massive to crudely-foliated metabasites composed of actinolite, epidote, and albite. This was determined by hand-specimen inspection of 578 greenstone artifacts, and petrographic and X-ray diffraction analyses of 28 representative celt fragments. Mineralogy and relict igneous textures indicate that most of the greenstone protoliths were low-potassium tholeiitic basaltic rocks that underwent greenschist-facies metamorphism. Artifact rock chemistry determined using Instrumental Neutron Activation Analysis supports this conclusion.

The Moundville celt greenstones are composed of metabasites obtained from Hatchet Creek valley outcrops located within the central portion of the Hillabee Metavolcanic Complex, and from Gale Creek outcrops located in the southern portion of the Hillabee Metavolcanic Complex. Located in the Northern Piedmont of Alabama, the Hillabee Metavolcanic Complex consists of a discontinuous belt of metabasites, metadacites, and mafic phyllites.

The Moundville site was a major, Mississippian period (A.D. 1000 to 1600), civic-ceremonial center used by Indians of the Black Warrior River valley of west central Alabama. Greenstone outcrops located in the Hatchet Creek valley are approximately 150 km from Moundville in an area that was accessible to the Indians of the Black Warrior River valley. Their proximity to the greenstone outcrops of the Hillabee Metavolcanic Complex afforded them direct access to tough, workable ax-stone. Procurement expeditions were dispatched from the Black Warrior River valley primarily to the upper portions of Hatchet Creek to gather boulders. Boulders were reduced to petaloid celts by the peck-and-abrade method of stone working at individual dwellings; therefore, only finished celts were taken to the Moundville site where they were used primarily as axes and wedges.

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TABLE OF CONTENTS

CHAPTER PAGE

LIST OF TABLES

TABLE PAGE

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

This is a study of the greenstone artifacts found at the Moundville site located in west central Alabama. The objectives of this study are to determine the greenstone artifact types, their mineralogy and petrography, and their geologic sources. Geological and archaeological data will be used to identify greenstone procurement and celt manufacturing methods.

The importance of stone artifacts and provenance studies in archaeology is discussed in this chapter. The geographic setting and prehistory of the Moundville site are also reviewed. The chapter closes with an overview of the dissertation.

Stone Artifacts And Provenance

> *Archaeologists and geologists have long been interested in prehistoric stone implements of all kinds. As our understanding of them has increased, so we have come to appreciate that man was able to take advantage of the great range of naturally available resources to a very much greater degree of sophistication than was once realized. More specifically, the development and application of archaeological petrography have made it easier for the prehistorian to evaluate stone implements as tangible evidence of man's critical powers and technical skill.*
> *(Clough and Woolley, 1985, p. 90)*

Geochemical, mineralogical, and petrographic analyses of stone artifacts can be critical components in archaeological studies because of the importance of rocks and minerals in premetallurgical cultures. Mineralogical and petrographic analyses of stone artifacts provides researchers with proper rock names. Petrographic and geochemical data may be useful in determining the geologic deposits from which raw materials were derived. Identifying the geologic deposits from which the rock materials were obtained also determines the geographic localities from which the rock materials originated. Rapp (1985, p. 353) states, "The archaeometric goal of provenance studies is to be able to specify with confidence the geographic source of the deposit that provides the raw materials for the manufacture of a specific artifact or set of artifacts. Such studies do not address the question of where the artifact was manufactured but only the source of the raw material." Harbottle (1982, p. 16) equates the term *provenience* with *provenance*, and states that provenience means, "where something is found. Thus with a raw material it could be identical with source. For artifacts, the point of excavation or discovery is the provenience (provenance)."

Petrologic analysis of stone artifacts can be challenging for reasons that include: 1) the highly-weathered and/or deeply-stained surfaces of artifacts inhibit hand specimen identification, 2) the small dimensions of an artifact provide little material for geochemical, mineralogical, and petrographic analyses, 3) curators are reluctant to subject artifacts to destructive methods of analysis, and 4) the use of rock names and sources that have not been

correctly identified become entrenched in the literature, making it difficult for curators to recognize a need for additional analysis.

To identify properly the chemical, mineralogical, and petrographic compositions of stone artifacts, archaeologists and geologists must coordinate their efforts to overcome these types of problems. By aligning the geologic terms and descriptive methods used in archaeology with those used in geology, communication among researchers in the two disciplines will be greatly improved; therefore, mineralogical and petrographic terminology should be applied consistently.

Prehistoric lithic exchange networks have been determined by matching petrographic and geochemical profiles of stone artifacts to their geologic sources. One of the earliest successful lithic provenance studies was conducted by W. Stukeley in 1740. Using petrologic data on Stonehenge megaliths, he determined that local and distant sources of rock were exploited (Rapp, 1985). Provenance studies on British Neolithic stone axes conducted during the 1930s and 1940s utilized petrologic data obtained from over 3000 axes to identify 24 geologic sources distributed across the British Isles (Hodder and Lane, 1982). Examples of recently conducted provenance studies that have established the extent of movement of lithic materials include: marbles from the Mediterranean region (Herz, 1990), turquoise artifacts from southwestern United States and Mesoamerica (Harbottle and Weigand, 1992), and native copper and galena artifacts found in the southeastern United States (Goad,

1978; Walthall et al., 1982). Studies such as these are typically conducted according to the following format (Earle and Ericson, 1977): 1) describe a representative sample of the lithic artifact materials using petrographic and other techniques, 2) sample the possible geologic sources of the artifact materials, and develop a petrographic and geochemical profile that is unique for each source, 3) complete the profile on artifact materials and match artifact profiles to those of the geologic sources, and 4) construct a procurement and exchange model based on the available archaeological and geological data.

Goad (1978) states, "Prehistoric exchange has become, in recent years, an important topic in the analysis of prehistoric social systems," and lithic artifact provenance studies have become important topics of research with respect to prehistoric procurement and exchange networks. Sources of lithic artifact materials constitute the initial step in a manufacturing and exchange network which ends at the archaeological sites at which the artifacts were discovered. Goad (1978) concludes, "Before a complete model of exchange in the Eastern United States can be formulated all exotic goods must be identified through quantitative studies of the artifacts and their possible sources. It is only when the actual sources of each good have been established through quantitative means that we may begin to discuss the exchange materials of the Eastern United States."

Prehistoric Indians of the southeastern United States engaged in procurement practices and exchange systems, but few of the

artifact lithologies and sources have been identified. Moundville Indians (Mississippian period: A.D. 1000 - 1600) used a variety of stone items (e.g., celts, disks, gorgets, palettes, pipes, projectile points, spatulates) made from numerous lithologies (e.g., amphibolite, basalt/diabase, chert, diorite/metadiorite, granite, greenstone, limestone, silt- and sandstone, shale/slate). Greenstone was one of the preferred lithologies used for ground-and-polished stone items, and it was commonly fashioned into ungrooved axes (petaloid celts) and included in burials (Peebles, 1970, 1971; Steponaitis, 1989; Welch, 1986). Socially-valued craft items made from greenstones may have been imported into the area as finished goods as a result of long-distance trade, or they may have been produced at or near the Moundville site by part-time craft specialists who used rocks obtained from nearby Piedmont lithologies. Locally manufactured goods would have been used within the Moundville polity and possibly traded abroad (Goad, 1978; Peebles, 1971; Steponaitis, 1989; Welch, 1986). Determining the origins of the various rock types used to make craft items such as celts will provide archaeologists with the data necessary to describe the procurement methods and exchange systems operating at or near Moundville during Mississippian times.

The importance of rocks and minerals in the lives of people who have no more than a rudimentary knowledge of metallurgy cannot be overemphasized. Raw material procurement strategies and knowledge of stoneworking methods were fundamental to the well-being of premetallugical cultures. Directly or indirectly, items made from rocks and minerals have fed, clothed, sheltered,

protected, and decorated most of the world's prehistoric cultures for the greater part of human existence.

Geographic Setting And Prehistory Of The Moundville Site, Alabama

> *In the tenth and eleventh centuries A.D., there developed along the interior river valleys of southeastern North America a number of societies that are now called Mississippian. It is well known that the Mississippian people were sedentary farmers who grew maize and other crops. It is also generally accepted that these people possessed a relatively complex social organization with evidence of internal social ranking and political hierarchies that extended beyond the range of the local community. Societies of this type are often categorized in general evolutionary terms as "chiefdoms," and questions relating to the organization of such societies and how they developed continue to be matters of wide interest and considerable debate.* (Steponaitis, 1983, p. 1)

The Moundville site is located in west central Alabama (33°00'17" N. Lat., 87°37'53"W. Long.) in the northern Coastal Plain situated on top of a river terrace on a bend in the Black Warrior River (Fig. 1). The Black Warrior River drains the northwestern part of Alabama and joins the Tombigbee River, which meanders along a southerly course emptying into the Gulf of Mexico in the southwestern corner of the state. The segment of the Black Warrior River valley that contains the Moundville site has a width of from 5 to 10 km, and it is bounded by low hills that were covered by hardwood forests in late prehistoric times. During this period of time, the Black Warrior River valley and the surrounding uplands contained abundant wild foods, and the floodplain was suitable for intensive farming (Scarry, 1986; Steponaitis, 1989).

The present extent of the Moundville site (Fig. 2) covers approximately 100 ha and consists of 20 earthen, platform mounds that delineate a rectangular plaza of about 32 ha (Steponaitis, 1983,

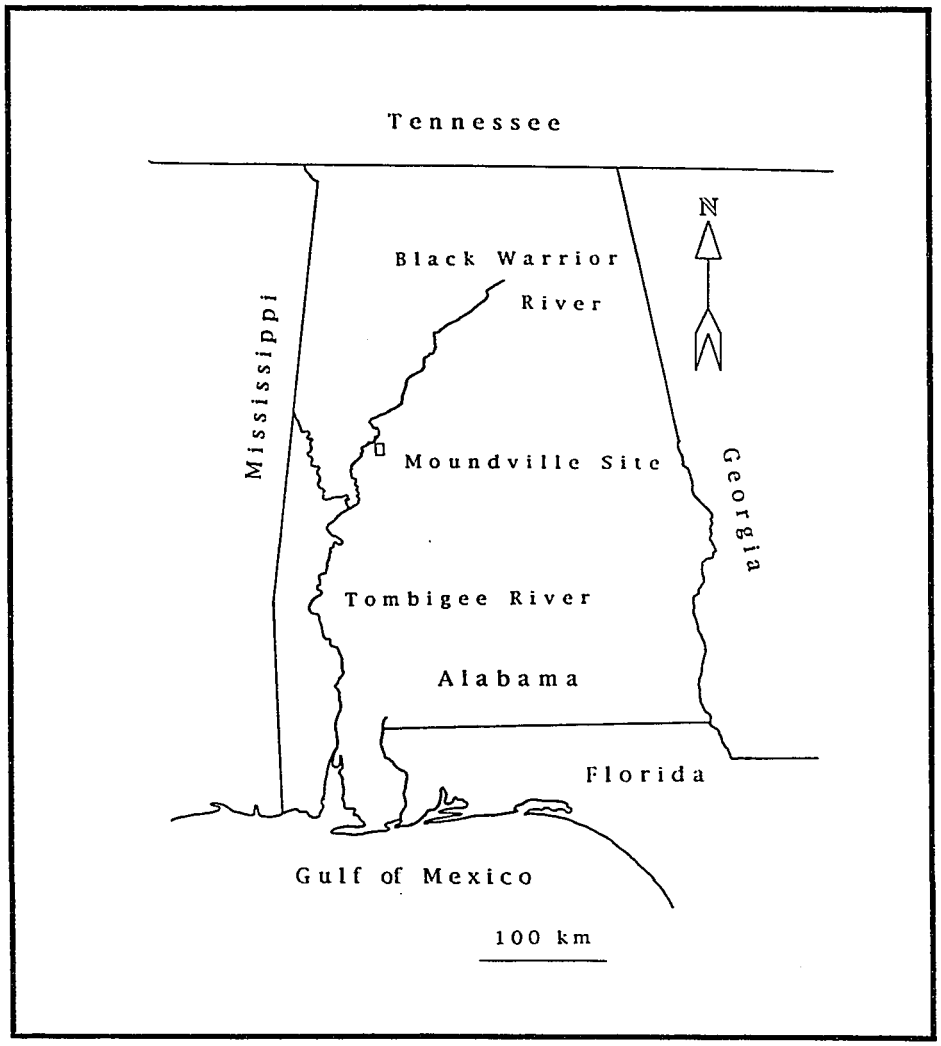

Figure 1. Map of Alabama showing the locations of the Moundville site and the Black Warrior River (after Welch, 1986).

1989). Mound B, the largest mound, is 17 m high and about 75 m square at the base. The remaining mounds are less than 8 m in height. The mounds that contained burials (C, D, Q, F, O, and H) served as substructures for temples, and are located beside (paired with) larger residence mounds (Peebles, 1971; Steponaitis, 1983). The Moundville site contains four artificial ponds, and was protected by a bastion palisade to the east, south, and west, and by the Black Warrior River to the north. With respect to other Mississippian period sites, Moundville is second in size only to the Cahokia site located in Illinois (Steponaitis, 1983).

Smith (1986) views the cultural developments of the prehistoric Indians of eastern North America as changing gradually through the Holocene (10,500 B.C. to the time of contact) from nomadic hunter-gatherers to sedentary farmers; therefore, a regional chronology based on cultural development is somewhat arbitrary. The cultural periods of prehistoric Native Americans of the southeastern United States are as follows according to Steponaitis (1986): Paleo-Indian period (entry date unknown - 8000 B.C.), Archaic period (8000 - 700 B.C.), Woodland period (700 B.C. - A.D. 1000), Mississippian period (A.D. 1000 - 1700).

The development and collapse of chiefdoms during the Mississippian period occurred at different times in different regions throughout the southeastern United States (Peebles, 1986); therefore, the Mississippian period is commonly divided into phases according to the cultural developments within a specific area. Because aspects

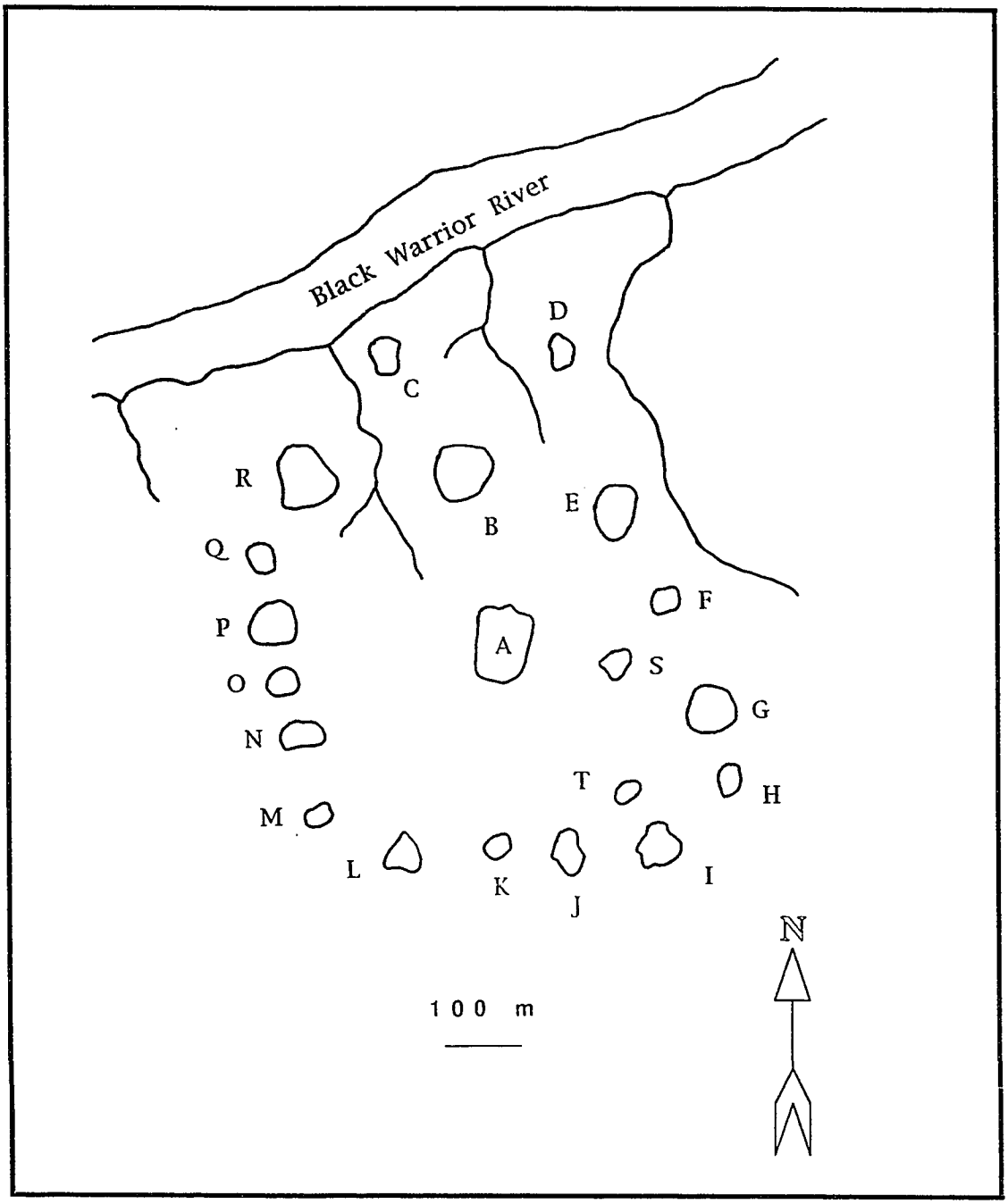

Figure 2. Map of the Moundville site showing the locations of the mounds (A - T) relative to the Black Warrior River (after Scarry, 1986).

of the material culture of the Moundville community, a Mississippian period chiefdom, are the focus of this paper, the chronology of the Moundville site will be defined. Steponaitis (1983, 1989) developed a five-phase late Woodland and Mississippian chronology for the Moundville region based on gravelot seriation and stratigraphic data. The Moundville phases and time spans are as follows (Steponaitis, 1983, 1989):

1) West Jefferson phase, Late Woodland period, A.D. 900-1050;
2) Moundville I phase, Mississippian period, A.D. 1050-1250;
3) Moundville II phase, Mississippian period, A.D. 1250 - 1400;
4) Moundville III phase , Mississippian period, A.D. 1400 - 1550; and
5) Moundville IV phase, Mississippian period, A.D. 1550 - 1650.

West Jefferson Phase (A.D. 900 to 1050) - The West Jefferson phase marked the end of the Woodland period in the Moundville area. Autonomous villages of 50 to 100 people were scattered throughout the Black Warrior River valley. There is no evidence of social stratification or craft specialization among these Woodland societies. Hunting, fishing, and gathering of wild foods were supplemented by gardening. The cultivation of corn increased in importance during this phase. No mounds were constructed and few graves have been located. Grave goods show an increase in marine shell beads (which were probably sewn onto leather garments), shell-drills are a commonly found tool, and greenstone celts make an appearance late in this phase. Conflicts were a common threat to these Indians who possibly intensified exchange in beaded garments, greenstone celts, and corn to build alliances and exchange prestige.

Moundville I Phase (A.D. 1050 - 1250) - Early in the Moundville I phase, the elite separated themselves from the rest of the populace by constructing residence mounds in four centers along the Black Warrior River. The Moundville site, with the highest population, was developed into the major civic-ceremonial center of the region. Planned systematic construction at the Moundville site is strongly supported by the symmetrical arrangement of the earthworks about the plaza, the geometric regularity of the mounds, and the regularity of construction stages. Although wild foods remained important, a shift to corn agriculture occurred accompanied by forest clearance. These developments preceded the centralization of political power into chiefdoms. Nonlocal materials such as marine shell, catlinite, and native copper were fashioned into prestige goods such as ceremonial tools and regalia. Raiding parties and well organized battles occurred as a result of power struggles and tribute extractions. The increase in long-distance exchange as indicated by the contents of graves parallels the development of the Moundville community.

Moundville II Phase (A.D. 1250 to 1400) - By the onset of the Moundville II phase, Moundville had developed into the region's major civic-ceremonial center. Chiefdom-level organization regulated outlying subordinate centers. The elite were supported through a tribute system that provided them with a better diet than the commoner. Warfare was less common, allowing the populace to disperse; therefore, the population density of Moundville decreased during this phase as it became a residence site for the elite, their

relatives, servants, and part-time craft specialists. Burials increased as the site became an important mortuary center with elite burials in or near mounds separated from less important individuals who were interred in a large cemetery. During the Moundville II phase, from 5 to 10 mounds were in the early stages of construction. Early in this phase, trade peaked and continued to be important. Items made by part-time craft specialists included ground-and-polished stone ax-forms (e.g., celts, spatulates, monolithic axes), and regalia fashioned from materials including marine shell, native copper, greenstone, and mica. Sites of manufacturing of nonlocal materials varied but local production of craft items appears to have occurred at the Moundville site.

Moundville III Phase (A.D. 1400 to 1550) - During the Moundville III phase, construction of all 20 pyramids was completed and further development at the site ceased. The mounds were arranged in pairs, large mounds serving as residence platforms and the small mounds functioning as burial and temple sites. Ethnohistoric evidence suggests that the pairing of large and small pyramids distinguishes clans, and the bilateral symmetry of the paired-pyramidal arrangement indicates that the clans may have been part of a moiety alignment (Knight, 1993). Late in the Moundville III phase, mound construction began at the outlying centers indicating a shift in power from Moundville to its subordinate satellite centers. The population which had been dispersed throughout the Black Warrior River valley reformed nucleated villages, indicating an increase in warfare. The collapse of

the Moundville chiefdom also marks a cessation in long-distance trade in exotic goods.

Moundville IV Phase (A.D. 1550 to 1650) - With the onset of the Moundville IV phase, the Moundville site and the surrounding centers were abandoned, and their chiefdoms disintegrated. Long-distance trade in nonlocal materials ceased as did part-time craft specialization. The return to egalitarian polities resulted in the formation of a few small independent farming villages scattered along the Black Warrior River.

In summary, Moundville was a major chiefdom-level, civic-ceremonial center from A.D. 1050 to 1550. It served as the political and religious focal point for the farmsteads, hamlets, villages, and smaller mound centers within a 350 km^2 portion of the Black Warrior River valley (Peebles, 1970, 1986; Scarry, 1986; Steponaitis, 1983, 1989). The circumstances that brought about the collapse of the Moundville chiefdom are unknown. At the time of contact, the Black Warrior River valley had a sparse Indian population that was situated between the Creek Indians to the east and the Choctaws to the west.

Overview of Dissertation

In Chapter Two, I classify the greenstone artifacts in the Moundville collection according to lithologic type and chemical

composition. This chapter will, therefore, focus on a description of greenstone artifact types; the sampling strategy used to obtain a representative sample of the artifacts for destructive analysis; the research methods used to determine greenstone artifact whole-rock chemistry, mineralogy and petrography; the results of the petrographic analysis; and pertinent geochemical data.

Chapter Three deals with the geologic candidates for Moundville artifact greenstones. All other local sources of greenstone are eliminated using petrographic data, except for the greenstones of the Hillabee Metavolcanic Complex; this complex is, therefore, the main subject of Chapter Three. Included in this chapter are explanations of the field work and sampling strategies used to obtain representative samples of Hillabee greenstones, the research methods used to determine whole-rock chemistry, mineralogy and petrography of Hillabee greenstones, the results of the petrographic analysis, and pertinent geochemical data.

I compare the mineralogy, petrography, and chemistry of Moundville artifact greenstones to the greenstones of the Hillabee Metavolcanic Complex in Chapter Four. I use the results of this comparison to identify the geographic localities from which greenstones were obtained for celt production by the Moundville Indians.

In Chapter Five, I conclude the study on Moundville greenstone artifacts with a discussion on greenstone procurement, celt manufacturing, and exchange.

CHAPTER 2

GREENSTONE ARTIFACTS FROM THE MOUNDVILLE SITE

The objective of this chapter is to describe the greenstone artifacts found at the Moundville site. The artifacts are classified according to artifact type and lithology. The frequency of the different types of greenstone artifacts in the Moundville collection indicates how this rock type was used by Moundville Indians. The mineralogical, petrographic, and chemical data obtained from analyses of a representative sample of the artifact greenstone varieties are the criteria used for the selection of geologic source candidates in Chapter Three.

The macroscopic examination of 578 greenstone artifacts and the selection of 28 celt fragments for destructive analysis were assisted by Eugene Futato (Archaeology Division, Alabama State Museum of Natural History) and J. Robert Butler (Department of Geology, University of North Carolina at Chapel Hill).

Artifact Lithologies Of The Moundville Site

Aside from items of chert and greenstone, a variety of other objects made of stone were used during the Moundville period.

> *These include pieces of minerals used for pigments, several kinds of rock used for beads, figurines, and pipes, and a kind of fine-grained sandstone from which most of the circular or rectangular paint palettes were made...the lithic technology of the Moundville culture was focused on locally available raw material.* (Welch, 1986, p. 163)

Over the past 100 years, approximately 50,000 square meters of the Moundville site have been excavated resulting in the recovery of a variety of Mississippian artifacts of various lithologies (Peebles et al., 1981). Some of these artifacts are *exotic* goods because they are composed of nonlocal materials like native copper and catlinite (Goad, 1978; Welch, 1986). These artifacts were used for ornaments and ceremonial purposes, and constitute a small fraction of the artifact inventory; however, because they are special, rare, and composed of rock types from distant sources, they have received a disproportionately large amount of research attention. Most of the lithic artifacts and ceramic containers unearthed at the Moundville site are composed of materials obtained from local or nearby sources (Peebles, 1971; Steponaitis, 1983; Welch, 1986). For the most part, these items were produced and utilized within the region controlled by the Moundville polity. These utilitarian items are composed of the lithic staples that people with only a rudimentary knowledge of metallurgy depended upon for tools and containers, and they were produced in quantity and owned by all members of the society.

Most of the lithic artifacts from the Moundville site are rocks (e.g., chert, greenstone); however, some of the materials are best classified as mineral specimens (e.g., native copper, galena) because they occur as large, single grains, or as mineraloids (e.g., asphalt)

because they do not fulfill the requirements of a mineral. The most common types of rocks, minerals, and mineraloids used by the Moundville Indians (phases I-III) are as follows (Peebles, 1971; Goad, 1978; Walthall, 1981; Steponaitis, 1983; Welch, 1986; Gundersen, 1993): 1) Clay (kaolinite, illite); 2) Glue-Sealant (asphalt); 3) Ground-and-Polished Stone (amethyst, amphibolite, basalt/diabase, bauxite, indurated claystone (catlinite), granite, greenstone, limestone, metadiorite/diorite, silt/sandstone, shale, slate, steatite); 4) Knapping Material (chert, quartzite); 5) Malleable Material (native copper); 6) Nutrient-Preservative-Disinfectant (salt); 7) Paint Pigment (cerussite [white], galena [gray], glauconite [green], graphite [black], hematite/red ochre [red], limonite/yellow ochre [yellow], and psilomelane/wad [black]); and 8) Sectile-Reflective Material (muscovite).

Most of these materials were obtained by the Moundville Indians from nearby geologic sources located in the Coastal Plain, Piedmont, and Valley-and-Ridge Province of Alabama.

Moundville Greenstone Artifact Types

> *The coast tribes from Vancouver island northward to Bering bay - the Kwakiutl, Tsimshian, Haida, and Tlingit - were preeminent among the aboriginal woodworkers of the continent, as attested by their substantial houses, ornamental carvings, totem polls, and canoes dug out of giant cedars - wonders of marine architecture. Before the introduction of iron, all of this work was executed with stone tools, of which the jade celt was the most important. Among the Tlingit, the value of a jade adze-blade two or three inches in length was from one to three slaves. When its*

> *owner used it, his wife should refrain from all frivolity, as any unbecoming conduct on her part might cause the blade to break.*
> *(Emmons, 1923, p. 17 - 18)*

Of the 578 ground-and-polished greenstone artifacts in the Moundville collection (Table 1), 556 artifacts (96%) are whole petaloid celts, petaloid celt fragments, and celt bit chips. A petaloid celt is an ungrooved ax head that has a bifacially abated bit and a tapered body. The flower-petal-shaped (petaloid), tapered body fits into a club-like handle with a tapered socket that accepts the wedge-shaped ax bit (Fig. 3). When used, the force of impact drives the ax bit firmly into the handle's tapered socket, eliminating the need of hafting with cordage. Unhafted celts may also have been used as wedges. This implement was used primarily as a woodworking tool but it would have served also as a weapon.

The remaining 22 greenstone artifacts (4%) consist of disks, polished slabs (palettes), spatulates (spuds), celt preforms/blanks (?), a monolithic ax pendant, and a pin. Because these types of artifacts and whole celts are rare, they were not included in samples utilized in destructive analyses nor were celt bit chips used because they do not provide enough rock material for multi-instrumental analyses.

Table 1. Greenstone artifacts from Moundville in the Alabama Museum of Natural History Collections organized according to function[1].

Catalog Number	Artifact Type									
	Celt Fragment	Celt Chip	Whole Celt	Disk	Slab	Spud	Celt Preform (?)	Pendant	Pin	Total
A930.1	7	1	3							11
A930.2	18	2	4					1		25
A930.3	7	1	3							11
A930.4	3	1	1							5
A930.5	3		1							4
A931.1	7		6	3	1					17
A931.2	32		2		2					36
A932.3	9	2	8	1	1					21
A932.4	3	3	2	1	1		1			11
A936.1	3									3
A939.2	110	94	15	2		2	1		1	225
A940.2	15	1	1	1		1				19
A941.3	86	45	2		1					134
A941.4	28		25	1		2				56
	331	150	73	9	6	5	2	1	1	578

1. Data from Appendix A.

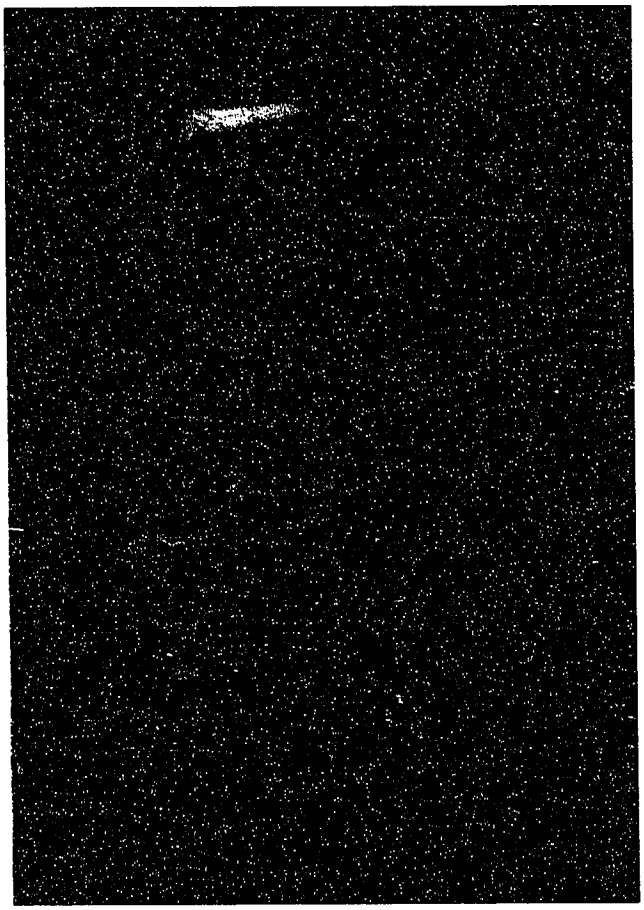

Figure 3. Photograph of a hafted petaloid celt found in the Black Warrior River, Alabama. Courtesy of Moundville Archaeological Park, Alabama Museum of Natural History.

Mineralogy And Petrography Of The Greenstone Artifacts From The Moundville Site

As a utilitarian object the stone axe was extremely important for the survival of primitive people. *(Gay, 1967, p. 23)*

Greenstone was one of the preferred lithologies used by Moundville Indians for ground-and-polished items. It was usually fashioned into petaloid celts (Table 1) which were frequently included in burials (Peebles, 1970, 1971; Steponaitis, 1989; Welch, 1986). *Greenstone* is a very general term used in geology to describe a great variety of lithologies usually formed from the low-grade (e.g., greenschist-facies) metamorphism of mafic and ultramafic igneous rocks (e.g., basalt, dunite) or their sedimentary equivalents. In an archaeological context, these lithologies often share several characteristic features in common which include (Dunning, 1960): they are green in color, they are easily shaped by the peck-and-abrade method of stoneworking, tools made from them take and hold their shape and polish, and they were used by many different prehistoric cultures around the world for utilitarian and ceremonial purposes. The physical properties of toughness (resistance to breakage), high density (>3.0 g/cm^3), and moderate hardness (6 to 7 on Moh's hardness scale) are the primary factors considered in the selection of stone for polished percussion tools such as axes and celts. This combination of physical properties is found in some portions of greenstone belts (metabasite) of folded mountain chains (e.g., the Hillabee Metavolcanic Complex of the Appalachian Mountains). The

mechanical competency of greenstone and its widespread distribution account for its popularity as an ax stone by prehistoric cultures (Heizer, 1959; Burton, 1984; McBryde, 1984).

Of the 578 artifacts originally cataloged as *greenstone*, 568 (98%) of them are composed of minerals typical of the greenschist metamorphic facies; however, the remaining 2% are composed of diabase (A940.2.165 [ax fragment]), granite/diorite (A939.2.442 [celt poll], A941.3.170 [celt], A940.2.296 [celt fragment], A941.3.192 [ax fragment], A941.3.120 [celt fragment], A941.3.216 [celt], A941.3.147 [celt poll]), and gneiss (A930.3.75 [celt bit], A931.2.115 [celt bit]) which are not usually considered to be varieties of greenstone and so they were not part of the sample that underwent petrographic analyses. This determination was made by inspecting the 578 artifacts classified as greenstone under a binocular microscope. With handspecimen observations on texture and mineralogy, diabase, granite, and gneiss are easily distinguished from fine-grained metabasite (greenstone) even without a freshly-broken surface to inspect. Artifact surfaces were studied while they were wet because this treatment substantially improved mineral and texture visibility without harming the artifacts (Fig. 4).

Twenty-three percent of the greenstone artifacts are too small (130 celt bit chips < 1 cm^3) and 29% of the greenstone artifacts (166 artifacts) are too deeply weathered and/or stained to be further classified by nondestructive macroscopic observations on color, texture, and mineralogy. It was possible to determine that these

artifacts are composed of greenstone but it was not possible to assign them to a specific greenstone category with confidence.

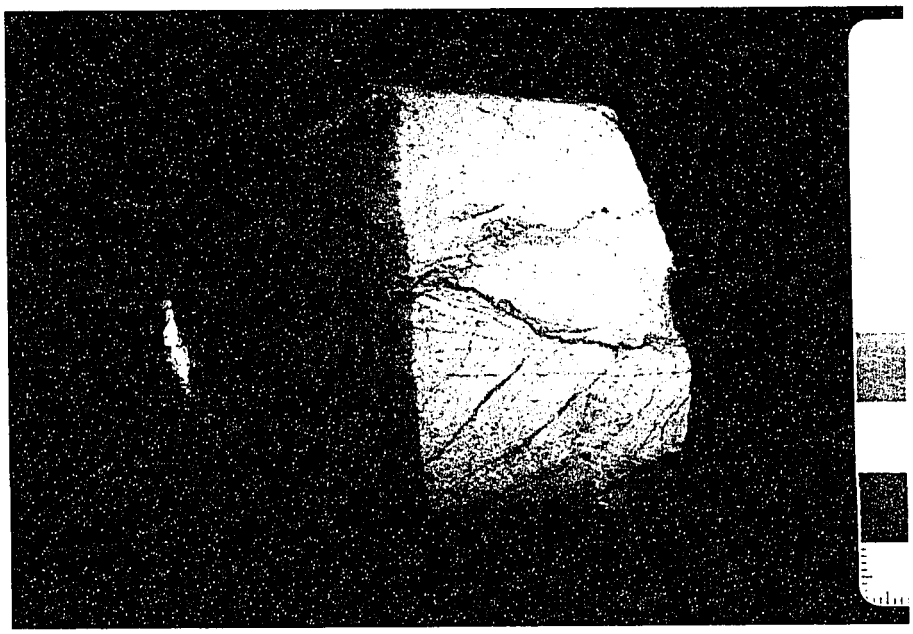

Figure 4. Celt fragment A930.3.51 (catalog number) showing the improvement a wet surface (left side) makes in observations on colors and rock textures. Scale units are in centimeters.

The remaining 48% of the greenstone artifacts (272 artifacts) were subdivided according to color, texture, and other features (e.g., epidote-rich veins) into six groups from which 28 samples were selected for the more detailed (and destructive) mineralogical, petrographic, and chemical analyses (Table 2). The grouping of greenstone artifacts according to color and texture assured that a representative sample of each artifact greenstone variety was obtained for destructive analysis. Once again, the greenstone artifacts were examined under a binocular microscope, and with handspecimen observations on color, texture and other distinguishing features, they were subdivided into six groups (Types A - F). The grouping criteria for the six greenstone varieties (Types A - F) are as follows (Appendix A):

Type A is a fine-grained, light to dark greenish- to bluish-gray, massive metabasite with dark veins and zones (Figs. A-1 to A-9);

Type B is a medium-grained, greenish-gray to gray mottled, massive to slightly foliated metabasite with distinct to indistinct, equigranular to slightly elongate grains (Figs. A-10 to A-17);

Type C is a fine-grained, massive, speckled, greenish-gray metabasite with dark and light colored veins (Figs. A-18 to A-20);

Type D is a fine- to medium-grained, bluish-gray to grayish-black metabasite with medium gray bands delineating foliation, and dark and light colored veins (Figs. A-21 to A-25);

Type E is a fine-grained, massive grayish-black metabasite (Figs. A-26 and A-27); and

Type F metabasite has relict phenocrysts that produce a

distinctly bimodal grain-size assemblage (Fig. A-28). Artifact colors vary from greenish (5GY6/1) to bluish gray (5B5/1), and from medium gray (N3) to grayish black (N2) according to the Munsell color system.

Table 2. Artifact greenstone types from Moundville in the Alabama Museum of Natural History Collections[1].

Greenstone Type	Total Artifacts		Sampled Artifacts	
	Count	Percentage of Total	Count	Percentage within Type
A	108	39.7	9	8.3
B	68	25.0	8	11.8
C	28	10.3	3	10.7
D	41	15.1	5	12.2
E	23	8.5	2	8.7
F	4	1.5	1	25.0
	272	100.0	28	

1. Data from Appendix A.

The 28 greenstone celt fragments selected for petrographic analyses were prepared into petrographic thin sections and examined using a petrographic microscope. The petrographic microscope was used to make observations on rock textures and other rock features, mineralogy, and take photomicrographs.

Macroscopic textural types (Types A - F) identified by handspecimen examination of the greenstone artifacts were not reproduced when petrographic thin-sections of the celts were examined using a petrographic microscope (Table 3). Microscopic analysis yields a different (and more definitive) set of textural categories (Types 1 - 4) which cannot be discerned in handspecimen because of the fine-grained textures and weathered surfaces of most of the artifacts.

Table 3. Cross-tabulation of handspecimen types (Types A - F) and microscopic textural types (Types 1 - 4)[1].

Microscopic Textural Types[2]	Handspecimen Textural Types						
	A	B	C	D	E	F	Total
1	4	3	2	3	2		14
2	5	4	1				10
3		1	1	1			3
4						1	1
	9	8	4	4	2	1	28

1. Data from Appendix B.
2. Key: Type 1 - fine-grained, relict diabasic texture; Type 2 - fine-grained granoblastic texture; Type 3 - medium-grained, granular to crudely-foliated texture; and Type 4 - relict porphyritic texture

The textures of the celt greenstones vary from very-fine- to medium-grained. The fine-grained rocks have relict diabasic (Type 1) or granoblastic (Type 2) textures (Figs. 5-8). The coarser-grained

Figure 5. Photograph of a fine-grained celt fragment (catalog number - A931.1.184). Scale units are in centimeters.

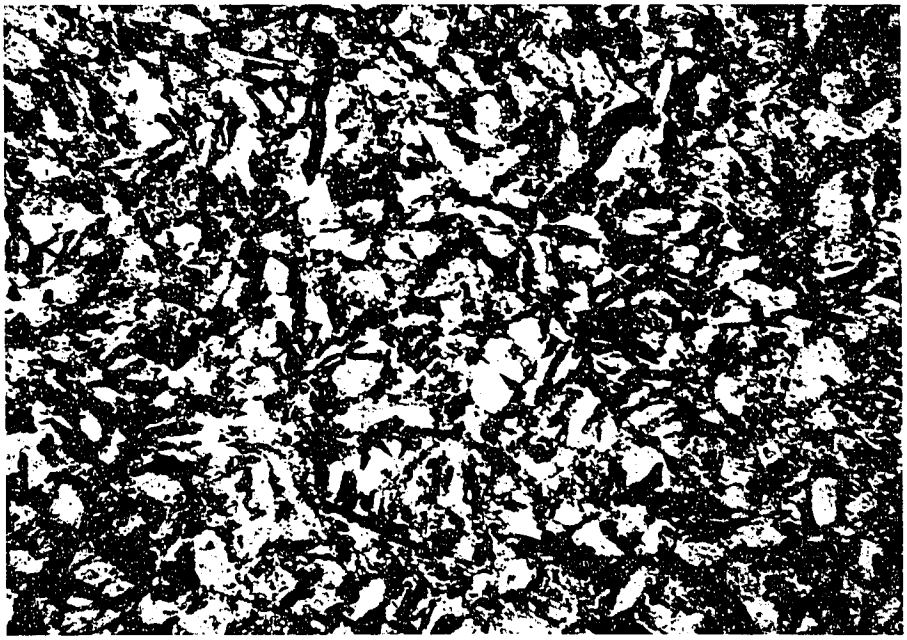

Figure 6. Photomicrograph of celt fragment A931.1.184 showing fine-grained diabasic texture (Type 1). The length of the photomicrograph corresponds to 5 mm; the photograph was taken using plane-polarized light.

Figure 7. Photograph of a fine-grained celt fragment (catalog number - A931.2.90). Scale units are in centimeters.

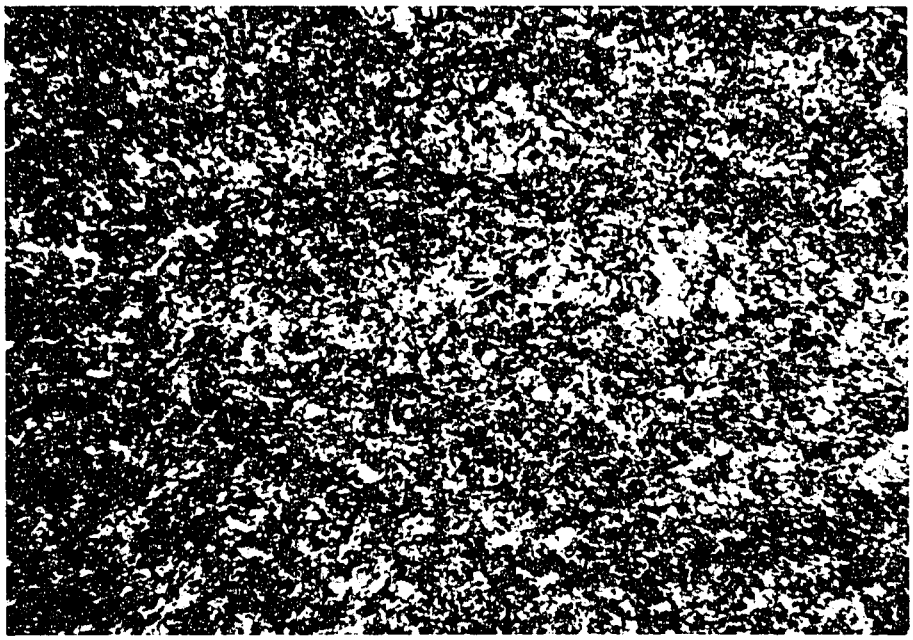

Figure 8. Photomicrograph of celt fragment A931.2.90 showing fine-grained, massive, granoblastic texture (Type 2). The length of the photomicrograph corresponds to 5 mm; the photograph was taken under crossed nicols.

greenstones (Type 3) often have distinct grains which impart a granular to crudely-foliated appearance to the celts (Figs. 9 and 10). Relict phenocrysts produce textures (Type 4) with distinctly bimodal grain-size assemblages (Fig. 11) and deformed porphyroclasts develop fibrous grain boundaries (Figs. 12 and 13). Pyrite and its alteration products often add distinctive features to the celt rock types as do dark-colored veins (Figs. 14 and 15) and aggregates of epidote, and fine-grained aggregates of chlorite (Figs. 16 and 17). Rock texture frequencies among the celt samples are as follows: Type 1 (relict diabasic texture) - 14 celt fragments (50% of sample); Type 2 (very fine-grained to fine-grained granoblastic texture) - 10 celt fragments (35.7% of sample); Type 3 (medium-grained, granular to crudely-foliated texture) - 3 celt fragments (10.7% of sample); Type 4 (relict porphyritic texture) - 1 celt fragment (3.6% of sample).

Even though the artifact greenstone types vary in color and texture, they are almost identical in mineral composition. They are all composed of approximately equal amounts of actinolite, epidote and albite, and contain minor amounts of chlorite, quartz, and pyrite. The major mineral components of the greenstones were identified using X-ray diffraction data and by examining petrographic thin-sections of the greenstone celt fragments. The relative proportions of minerals in the greenstones could not be obtained by point-counting petrographic thin-sections because of the fine-grained texture of most of the samples. The relative abundances of actinolite, epidote, and albite, the three most abundant minerals comprising the greenstones, were approximated by comparing the whole rock

Figure 9. Photograph of a medium-grained celt fragment (catalog number - A930.2.148). Scale units are in centimeters.

Figure 10. Photomicrograph of celt fragment A930.2.148 showing crudely-developed foliation due to grain alignment (Type 3). The length of the photomicrograph corresponds to 5 mm; the photograph was taken using plane-polarized light.

Figure 11. Celt fragment A939.2.487 (catalog number) showing relict phenocrysts that produce a distinctly bimodal grain-size assemblage. Scale units are in centimeters.

Figure 12. Fine - grained celt fragment (catalog number - A930.5.21). Scale units are in centimeters.

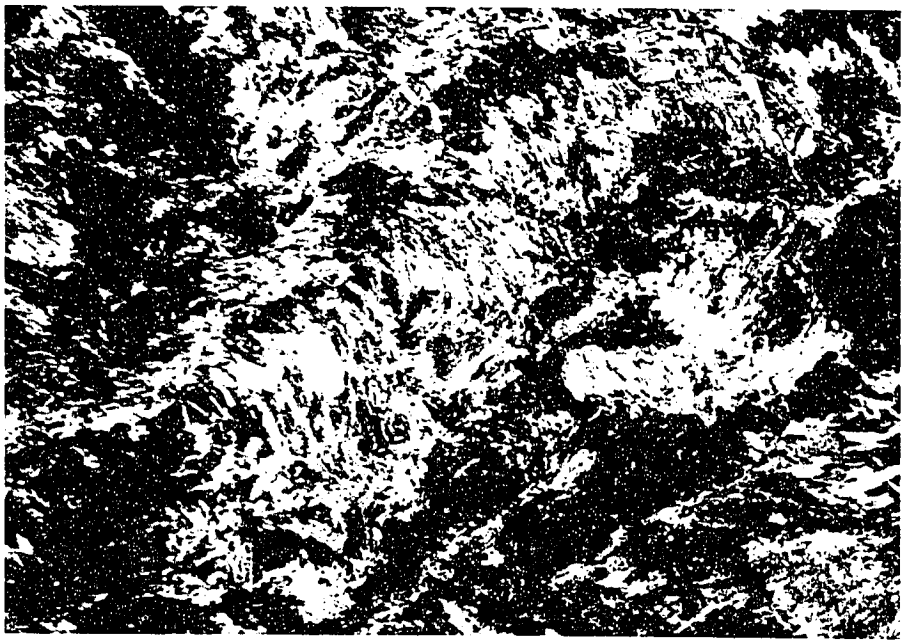

Figure 13. Photomicrograph of celt fragment A930.5.21 showing deformed porphyroblasts (light areas in a fine-grained, darker groundmass) composed of actinolite which have fibrous grain boundaries. The length of the photomicrograph corresponds to 1 mm; the photograph was taken under crossed nicols.

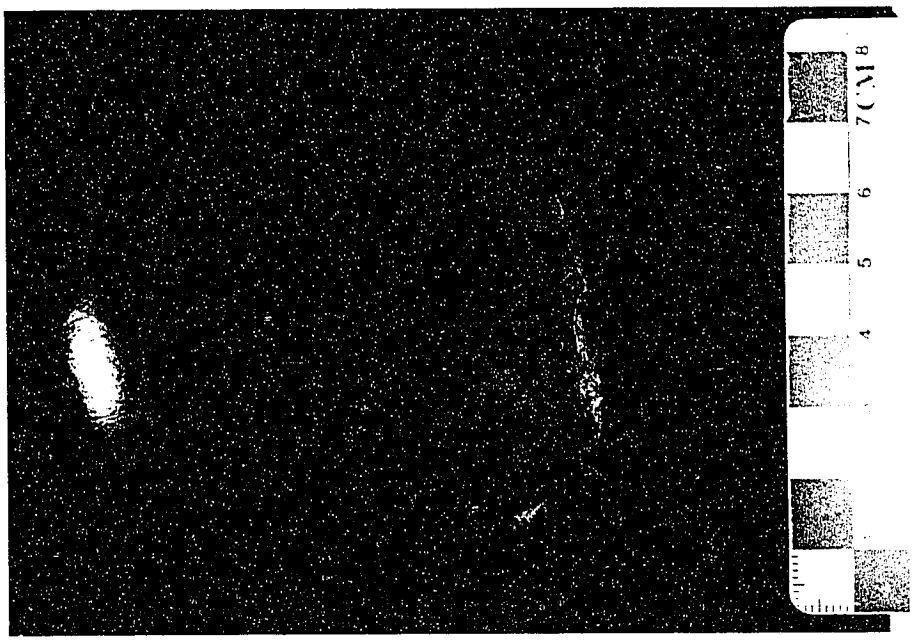

Figure 14. Greenstone celt fragment (catalog number - A930.3.51) showing dark-colored veins in a fine-grained groundmass. Scale units are in centimeters.

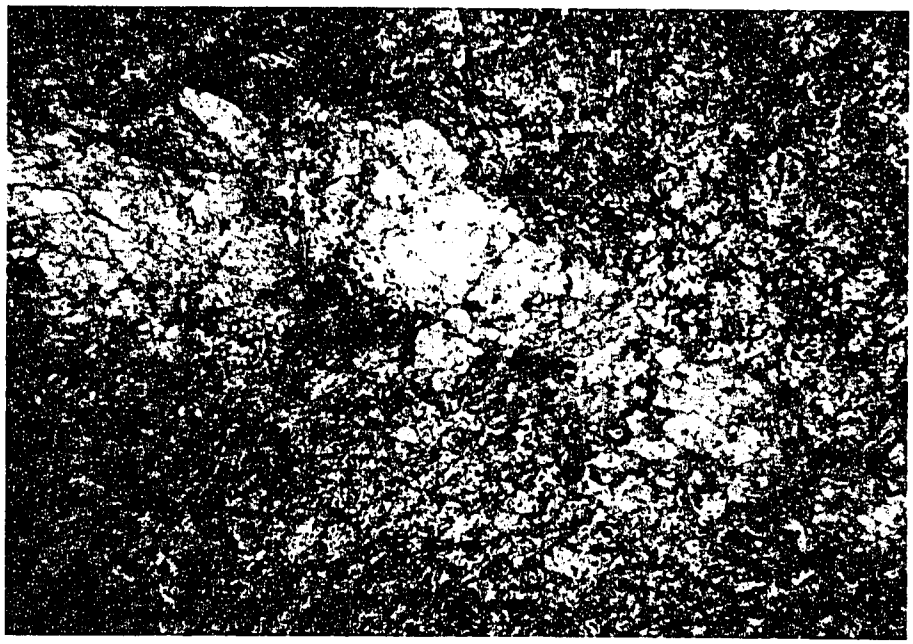

Figure 15. Photomicrograph of celt fragment A930.3.51 showing a coarser-grained vein of epidote with minor amounts of albite, actinolite, and pyrite in a fine-grained groundmass. The length of the photomicrograph corresponds to 5 mm; the photograph was taken using plane-polarized light.

Figure 16. Photograph of a fine-grained celt fragment with a distinctly speckled appearance (catalog number - A930.2.149). Scale units are in centimeters.

Figure 17. Photomicrograph of celt fragment A930.2.149 showing elongate, parallel aggregates of microscopic chlorite (white, lens-shaped areas) in a fine-grained, darker groundmass. The length of the photomicrograph corresponds to 5 mm; the photograph was taken using plane-polarized light.

densities of the celt greenstones with the reported densities of actinolite, epidote, and albite. Whole rock densities of the celt samples were determined using the immersion technique and a hydrologic balance constructed from a Harvard Trip Balance. The samples' weights in air and water were measured, and density values were calculated using the following formula (Mason and Berry, 1968):

$$\text{Density} = \left(\text{Weight}_{air}/[\text{Weight}_{air} - \text{Weight}_{water}]\right) \text{ X Density}_{water}.$$

Whole-rock densities for all 28 of the celt samples are between 3.0 and 3.1 g/cm^3 (Appendix B). The density of actinolite varies from 3.1 to 3.3 g/cm^3 , the density of epidote varies from 3.35 to 3.45 g/cm^3 , and the density of albite is 2.62 g/cm^3 (Klein and Hurlbut, 1985). Equal amounts of actinolite (3.20 g/cm^3), epidote (3.40 g/cm^3), and albite (2.62 g/cm^3) in a compact aggregate would result in a greenstone with a density of 3.07 g/cm^3. This figure is between 3.0 and 3.1 g/cm^3 which is the relatively narrow density range of the celt greenstones. Similar mineralogy and approximately equal proportions of the same three minerals accounts for the similarities in ax-stone whole-rock density values and X-ray diffraction data.

The X-ray diffractometer (XRD) was used to identify the major mineral components in powdered samples of the celt greenstones. Mineral Powder Diffraction File Cards and results from mineral standards were used to interpret XRD data. XRD results confirm that all of the celt greenstones are composed of actinolite, epidote, and

albite with minor amounts of chlorite. Minor amounts of quartz occur in the following artifacts: A930.5.21, A941.3.167, A941.3.107, A939.2.651, A939.2.487, A941.4.244, A939.2.546. The absence or presence of quartz in detectable amounts is the only significant mineralogic difference between the celt samples: 75% of the samples (21 out of 28 samples) do not contain quartz in detectable amounts, and 25% (7 out of 28 samples) do contain enough quartz for it be detected. The amount of quartz present, however, is relatively small because the strongest diffraction line (d-spacing = 3.343 angstroms, *hkl* = 101) is just discernible above the background and no other quartz diffraction lines are readable.

Microscopic and X-ray diffraction analyses established that even though artifact greenstone varieties differ in color and texture, they do not differ significantly in mineralogy. The ax stones are all composed of approximately equal amounts of actinolite, epidote, and albite. Relict igneous textures (e.g., diabasic, porphyritic) occur in approximately 60% of the sample, affirming their igneous origin. The uniformity of greenstone celt mineralogy indicates that the remaining 40% of the sample also had a protolith with a similar initial composition. The mineral components of the greenstones and their fine-grained textures indicate metamorphism of basalt under greenschist-facies conditions at temperatures of about 300-400°C and pressures probably no greater than 0.5 Gigapascals. Epidote and albite form from the decomposition of calcium-rich plagioclase feldspar (e.g., labradorite: An_{50-70}), and actinolite forms from the breakdown of augite (Philpotts, 1990). An igneous rock composed of

labradorite and augite is basaltic in composition; therefore, the artifact greenstone varieties formed from a basaltic parent rock that experienced greenschist-facies metamorphism. Relict igneous features and mineralogy support this conclusion.

Based on rock texture, mineralogy, and protolith, the Moundville greenstone celt lithologies can be classified as very-fine- to medium-grained, massive to crudely-foliated, actinolite-epidote-albite metabasites. The toughness of the celt greenstones results from the low abundance of platy minerals (e.g., chlorite), and from the intergrown and interlocking network of grains, not from a lack of foliation. The fine-grained, interlocking network of grains is also responsible for the occurrence of sub-conchoidal fracture instead of rock cleavage.

Chemistry Of The Greenstone Celts From Moundville

> *With the diffusionist interests of early archaeologists, the aim of research on exchange was to document contact between two culture areas. The qualitative nature of this research resulted from the methods that relied on gross cultural, biological, and geological differences. ... Although such evidence is still employed, quantitative research based on the chemical characterization of raw materials is rapidly becoming the primary approach used to identify prehistoric exchange.*
> *(Earle and Ericson, 1977, p. 4)*

The chemical analysis of the 28 Moundville celt fragments was greatly constrained by sample size. Each celt fragment contains a small and finite amount of material, all of which was not available

for analysis. Because both the broken and shaped ends were not to be used, only the mid-sections of the celt fragments were available for analysis. The celt fragments have weathered and stained exteriors which were also removed when samples were prepared for analysis. Removing the weathered rinds from the celt fragments provides the best preserved material for analysis but significantly reduces the volume of the sample. After trimming, the amount of sample available for analysis was typically no more than 3 cm^3. This small volume of rock was used to construct a petrographic thin section, and provide material for X-ray diffraction and whole-rock chemical analyses.

Rock powders were analyzed by XRAL Laboratories of Ann Arbor, Michigan. The results of the 33-element quantitative chemical analyses determined using Instrumental Neutron Activation Analysis (INAA) are listed in Appendix B. The 33 elements of the analysis with element symbols and lower detection limits are as follows:

Ag (silver)	5.0 ppm	As (arsenic)	2.0 ppm
Au (gold)	5.0 ppb	Ba (barium)	100 ppm
Br (bromine)	1.0 ppm	CaO (lime)	1.399 wt. %
Ce (cerium)	3.0 ppm	Co (cobalt)	5.0 ppm
Cr (chromium)	10.0 ppm	Cs (cesium)	3.0 ppm
Eu (europium)	0.2 ppm	Fe_2O_3 (iron oxide)	0.143 wt.%
Hf (hafnium)	1.0 ppm	Ir (iridium)	20.0 ppb
La (lanthanum)	1.0 ppm	Lu (lutetium)	0.05 ppm
Mo (molybdenum)	5.0 ppm	Na_2O (soda)	0.0674 wt.%
Nd (neodymium)	10.0 ppm	Ni (nickel)	100.0 ppm

Rb (rubidium)	30.0 ppm	Sb (antimony)	0.2 ppm
Sc (scandium)	0.1 ppm	Se (selenium)	5.0 ppm
Sm (samarium)	0.5 ppm	Sr (strontium)	500.0 ppm
Ta (tantalum)	1.0 ppm	Tb (terbium)	0.5 ppm
Th (thorium)	0.5 ppm	U (uranium)	0.5 ppm
W (tungsten)	4.0 ppm	Yb (ytterbium)	0.2 ppm
Zn (zinc)	50.0 ppm		

The celt greenstones contain such small quantities of the following 17 elements that their amounts fell below the INAA detection limits listed above: antimony, arsenic, barium, bromine, cesium, gold, iridium, molybdenum, neodymium, nickel, rubidium, selenium, silver, strontium, tantalum, thorium, and uranium. The data for tungsten were not used because the samples were powdered in a rock mill with tungsten carbide grinding surfaces. The following 15 elements are present in large enough quantities in the greenstone samples to be detected by INAA: calcium, cerium, cobalt, chromium, europium, iron, hafnium, lanthanum, lutetium, samarium, scandium, sodium, terbium, ytterbium, and zinc. The relative abundances of these 15 elements are used to identify similarities and differences among the celt greenstones.

Remarkably, there is no significant difference in the 15-element chemical compositions of the following 19 greenstone samples (identified by catalog number): A930.1.52, A930.2.149, A930.3.51, A931.2.106, A931.2.90, A936.1.112, A939.2.441, A939.2.546, A939.2.556, A939.2.626, A940.2.289, A941.3.107,

A941.3.108, A941.3.122, A941.3.126, A941.3.75, A941.3.86, A941.4.244, and A941.4.250. The remaining 9 greenstone samples (identified by catalog number) differ from the 19 samples listed above in the following ways: A930.2.145, low cobalt value; A930.2.148, high sodium value, and low calcium and chromium values; A930.5.21, high iron, terbium, and lutetium values, and low chromium value; A931.1.184, high zinc value; A931.2.91, high zinc value; A939.2.487, low iron and scandium values; A939.2.651, low chromium value; A941.3.167, high iron, chromium, hafnium, lanthanum, cerium, samarium, europium, terbium, ytterbium, and lutetium values; and A941.3.74, low calcium value. Histograms depicting the chemical similarities and differences for celt greenstones are located in Appendix B. Scatter plots will be used in the following portion of the chapter to illustrate the chemical similarities and differences of the artifact greenstone varieties.

Calcium and Sodium

The amount of lime (CaO) in the artifact greenstones ranges from 7.79 to 12.59 wt.%, a difference of 4.8 wt.%. The amount of lime in the samples averages 11.13 wt.% and the median value of the group is 11.19 wt.% (Appendix B). The amount of soda (Na_2O) in the greenstone samples varies from 1.35 to 3.78 wt.%, a difference of 2.43 wt.%. The amount of soda in the samples averages 2.25 wt.% and the median value of the group is 2.09 wt.% (Appendix B). These compositional variations appear substantial but an examination of the CaO-Na_2O graph (Fig. 18) reveals that the ranges for 26 of the 28 samples are much smaller. The small range in CaO and Na_2O values

for 26 of the 28 samples produces the cluster of points in the CaO-Na2O graph (Fig. 18) and accounts for the slight difference between the compositional averages and the median values given above.

An inverse relationship exists between calcium and sodium which is also illustrated in the CaO-Na2O graph (Fig. 18). As calcium values in the samples increase, sodium values decrease. This trend is delineated by 27 of the 28 celt samples.

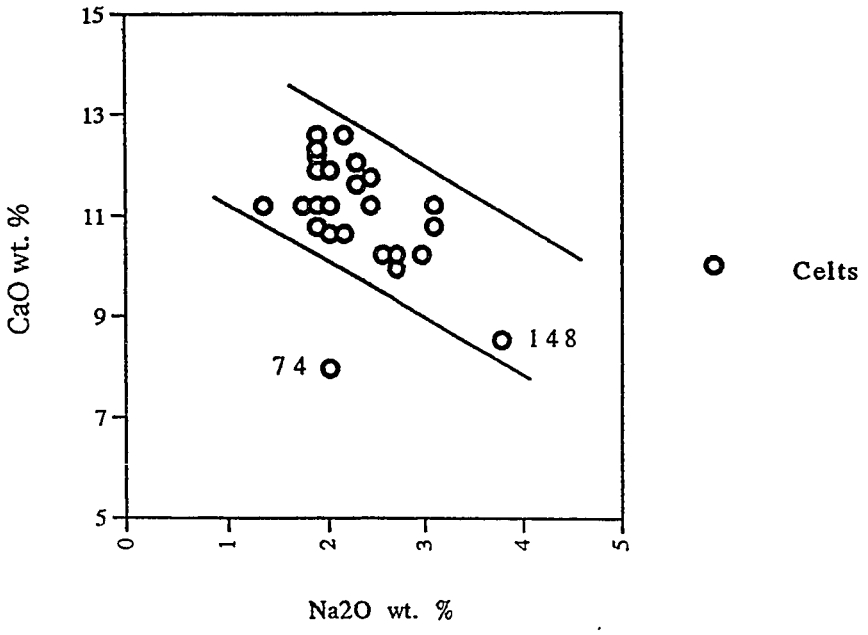

Figure 18. Scatter plot showing the variations in the calcium and sodium contents of the Moundville celt greenstones. The two cluster outliers are celt fragments A930.2.148 (148) and A941.3.74 (74).

In summary, 26 of the 28 celt samples have a relatively narrow range of values for CaO and Na_2O. Sample A930.2.148 falls outside of the CaO-Na_2O cluster formed by 26 celt samples; however, it does conform to the CaO-Na_2O trend produced by the linear relationship between calcium and sodium that exists for the samples within the cluster. Sample A941.3.74 falls outside of the cluster because of a low calcium value. Sample A941.3.74 does not conform the CaO-Na_2O trend because its low calcium value is not accompanied by a correspondingly high sodium value.

Iron and Chromium

Total iron (as Fe_2O_3) values range from 8.01 to 14.16 wt.% (a difference of 6.15 wt.%), and the group averages 10.85 wt.% with a median value of 10.87 wt.% (Appendix B). Chromium values vary from 20 to 350 ppm (a difference of 320 ppm), and the group averages 279 ppm with a median value of 300 ppm. These compositional variations also appear substantial but an examination of the Cr-Fe graph (Fig. 19) reveals that the Cr-Fe value ranges for 23 of the 28 samples are much smaller. The close similarities in the iron and chromium values for 23 of the 28 samples produces the cluster of points in the Cr-Fe graph (Fig. 19) and accounts for the slight difference between the compositional averages and the median values given above.

In summary, total iron (as Fe_2O_3) and chromium values are similar for 23 of the 28 greenstone samples. Their iron values range from 9 to 12 wt.% and their chromium values range from 250 to 350

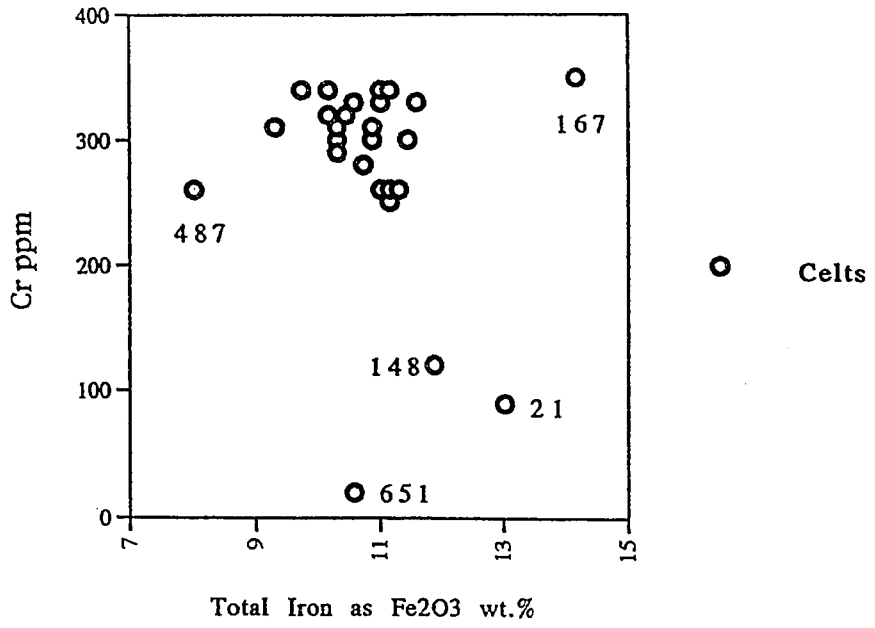

Figure 19. Scatter plot showing the variations in the chromium and total iron (as Fe_2O_3) contents of the Moundville celt greenstones. The five cluster outliers are celt fragments A930.2.148 (148), A930.5.21 (21), A939.2.487 (487), A939.2.651 (651), and A941.3.167 (167).

ppm. Only one of the Cr-Fe cluster outliers (A930.5.21) had both iron and chromium values that fell outside of the group's Cr-Fe range of values. The other four Cr-Fe cluster outliers did not group because of the amount of chromium or iron.

Hafnium and the Rare Earth Elements (Cerium, Europium, Lanthanum, Lutetium, Samarium, Terbium, and Ytterbium)

A direct relationship exists between the hafnium, cerium, europium, lanthanum, lutetium, samarium, terbium, and ytterbium values for all of the samples (Figs. 20 and 21). Higher values for one element correspond with higher values for the other 7 elements. The solitary cluster outlier, Sample A941.3.167, still conforms to this

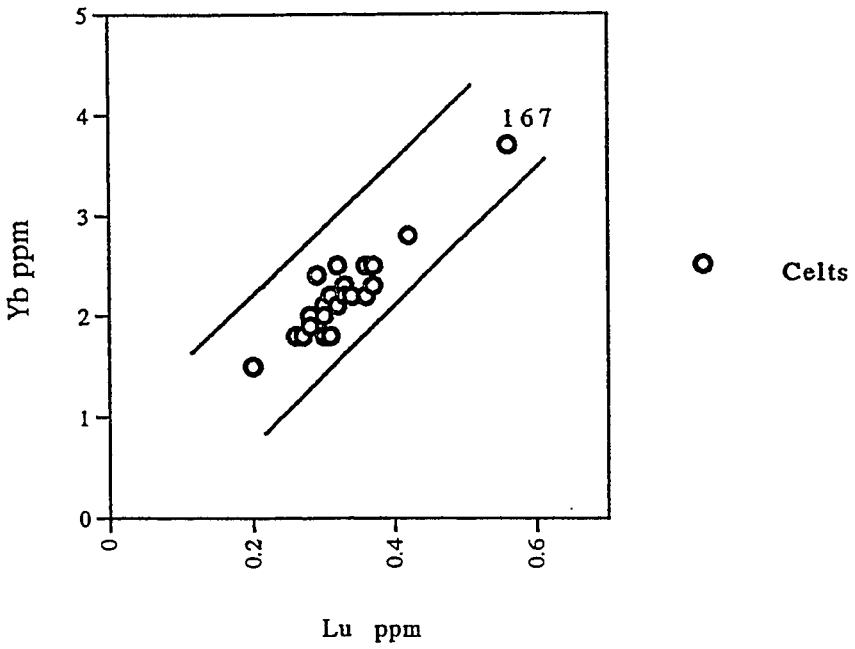

Figure 20. Scatter plot showing the variations in the ytterbium and lutetium contents of the Moundville celt greenstones. The cluster outlier is celt fragment A941.3.167 (167).

trend. The Yb-Lu and Sm-Ce graphs (Figs. 20 and 21) show the general pattern produced by comparing any two of the eight elements. Sample A941.3.167 lies outside of the Yb-Lu and Sm-Ce clusters because it has the highest values for all of these elements.

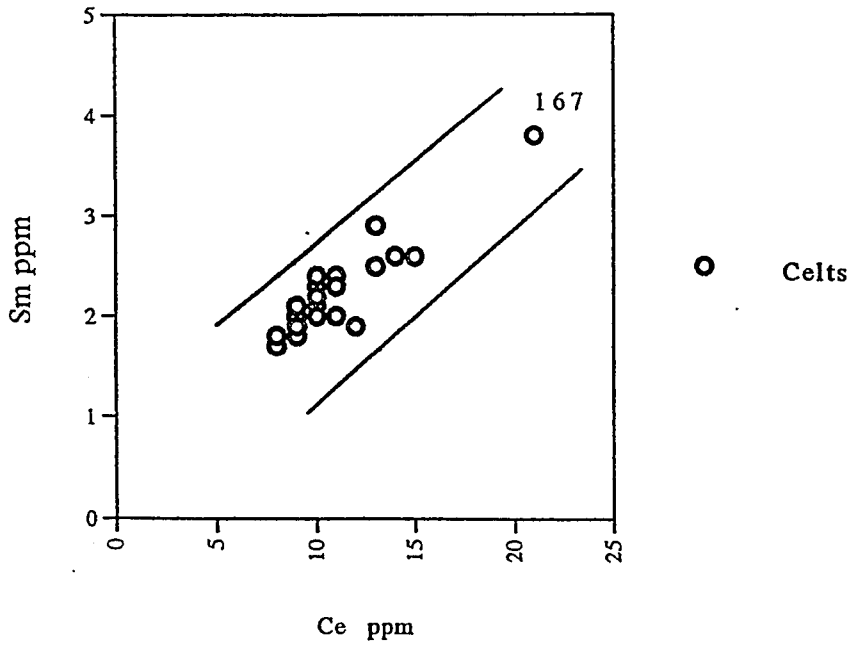

Figure 21. Scatter plot showing the variations in the samarium and cerium contents of the Moundville celt greenstones. The cluster outlier is celt fragment A941.3.167 (167).

Conclusions: Artifact Greenstone Petrography and Chemistry

The relict igneous textures and mineralogy of the greenstone celt samples indicate that their protoliths were basaltic in composition. Chemical data support this conclusion. For example, the average calcium value (CaO wt.% = 11.19), the average sodium value (Na_2O wt.% = 2.25), and the average iron content (total iron as Fe_2O_3 wt.% = 10.85) of the celt greenstones agree well with the reported values (e.g., 11.51, 2.53, and 10.78 wt.%, respectively) for low-potassium tholeiite basalts (Wilkinson, 1986). The potassium quantities of the celt greenstone samples were not determined by INAA; however, the very low abundance of potassium minerals (e.g., potassium feldspar, muscovite) and the relatively large quantity of albite (sodium feldspar) in the celt greenstones indicate that the potassium content of the samples must be significantly lower than the sodium content. The linear relationship between the calcium and sodium values for the greenstone samples (Fig. 18) is also similar to the inverse relationship of calcium and sodium in igneous rocks of basaltic compositions.

Nineteen of the 28 greenstone samples have chemical values that are very similar for all of the elements determined using INAA. The single atypical chemical value that is responsible for most of the cluster outliers is not considered significant because an occasional anomalous result is to be expected when working with metamorphic rocks. Two of the samples (A930.2.148 and A931.3.167), however, do vary in noteworthy but unrelated ways. The high value for

sodium and the correspondingly low value for calcium set celt fragment A930.2.148 apart from the other samples (Fig. 18). The consistently higher values for hafnium, lanthanum, cerium, samarium, europium, terbium, ytterbium, and lutetium of celt fragment A941.3.167 differentiates it from the other artifacts (Figs. 20-21).

The striking similarities in artifact greenstone mineralogy, whole-rock density, and chemistry suggest that the greenstones came from a single geologic source (single source hypothesis). The striking differences in rock textures and the cluster outliers in the chemical data suggest that the greenstones may have come from several geologic sources (multiple source hypothesis). The differences and similarities among the celt greenstones can be accounted for if they formed from similar parent rocks which underwent similar geologic processes (multiple source hypothesis), or if they formed from a group of related lithologies experiencing the same geologic events as a single unit (single source hypothesis). In both cases, rocks will occur with different textures but similar mineralogy and chemistry. In Chapter Four, I present data which supports the single source hypothesis.

CHAPTER 3

HILLABEE METAVOLCANIC COMPLEX

The objectives of Chapter Three are to identify the locally-available geologic sources of greenstone which may have been used for celt-stone by the Moundville Indians, and to describe the mineralogy, petrography, and chemistry of the greenstone candidates. In Chapter Four, the mineralogy, petrography, and chemistry of the possible geologic sources of greenstone will be compared to the mineralogy, petrography, and chemistry of the greenstone celts to establish celt-stone provenance.

The only locally-available sources of metamorphic rocks that were accessible to the Indians of the Black Warrior River valley are located in the Northern, Inner, and Southern Piedmonts of Alabama; therefore, if usable greenstone lithologies occur in the Alabama Piedmont, they are probably the sources of celt stone used by the Moundville Indians. Conclusions based on the mineralogical, petrographic, and chemical data on the Moundville greenstone celts have established that source-rock candidates must be fine- to medium-grained, massive to crudely-foliated metabasite composed of actinolite, epidote, and albite. The geologic-source candidates must have relict diabasic, porphyritic, granoblastic, granular, and

crudely-foliated textures, and show chemical similarities with low-potassium tholeiitic basalts. The candidates' protoliths must have experienced regional greenschist-facies metamorphism. The candidates must be tough and dense, break with sub-conchoidal to hackly fracture, and be greenish gray to gray in color. All of these requirements are met by only one locally-available geologic source, which is the Hillabee Metavolcanic Complex located in the Northern Piedmont of Alabama.

If the greenstone celts from the Moundville site are composed of greenstones from any source other than the Hillabee Metavolcanic Complex, then that material could not have been obtained through direct procurement by Moundville Indians because all of the other sources of this type of greenstone located within the southeastern United States occur far beyond the limits of the Moundville polity (> 500 km). If the Hillabee Metavolcanic Complex is the source of celt greenstones, then celts are locally-manufactured goods produced from locally-available materials; however, if the Hillabee Metavolcanic Complex is not the source of greenstone for Moundville celts, then greenstone celts are *exotic* goods whether manufactured locally or not because the celt material would have been obtained from a source that was beyond the limits of the Moundville polity. The determination as to whether the Moundville celt greenstones were made from local and/or nonlocal material is made in Chapter Four.

Greenstones Of The Alabama Piedmont

The (Tuman) quarry complex (Papua New Guinea highlands) consists of a 2 km line of pits...the tool stone is an actinolite-epidote-albite hornfels. This is a hard, fine-grained, tough rock that takes an extremely good edge. *(Burton, 1984, p. 236)*

The greenstone (e.g., metabasite, serpentinite) belts of the southeastern United States typically occur as isolated, long, narrow outcrops in the Piedmont Province (Fig. 22). Even though there are several localities in the eastern United States from which greenstones can be obtained, there are not many of them and they are separated by relatively large distances.

A survey of the geologic literature (e.g., Griffin, 1951; Higgins et al., 1988; Pallister, 1955; Stow et al., 1984; Tull et al., 1978), inspection of geologic maps (e.g., Larrabee, 1966; Osborne et al., 1989), and field work established that there were three sources of greenstone within 500 km of Moundville: 1) the metabasites of the Hillabee Metavolcanic Complex of the greenschist-facies lithologies of the Northern Piedmont of Alabama (Tull et al., 1978; and Tull, 1979), 2) the slates of the Talladega Group (Tull, 1982) which are also part of the greenschist-facies lithologies of the Northern Piedmont of Alabama, and 3) the amphibolite schists which are part of the amphibolite-facies lithologies of the Inner and Southern Piedmonts of Alabama (Stow et al., 1984).

The slates and amphibolites are very different petrographically from the Moundville celt greenstones. The greenstones of the

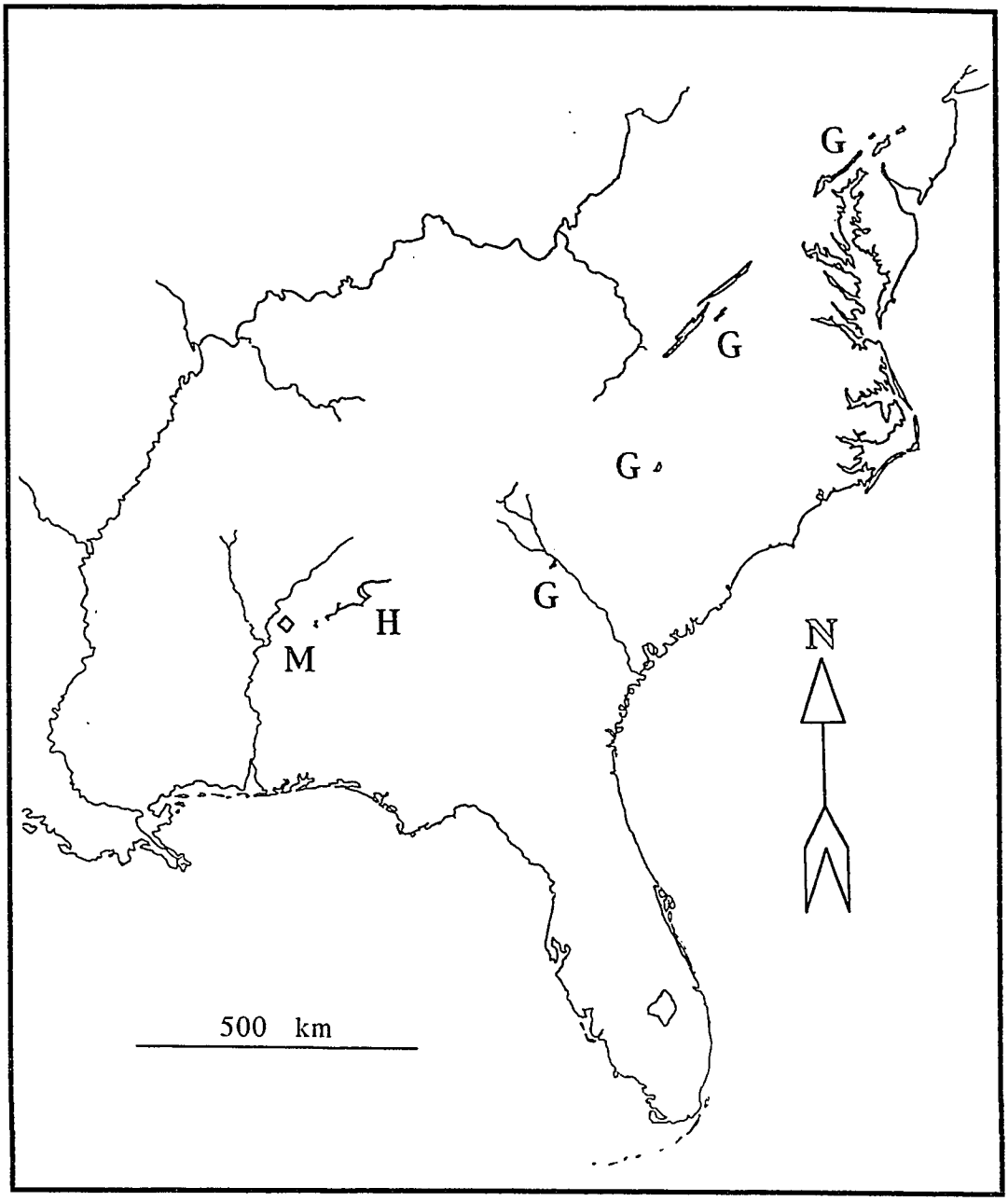

Figure 22. Map of eastern North America showing the locations of the Hillabee Metavolcanic Complex (H), the metamorphosed mafic and ultramafic rocks units (G) that may contain greenstones similar to the Hillabee greenstones, and the Moundville site (M) (Larrabee, 1966).

Talladega Group are very-fine-grained pelitic slates and sericite phyllites with well-developed rock cleavage (Tull, 1982). The amphibolites of the Inner and Southern Piedmonts formed from basaltic rocks that experienced amphibolite-grade metamorphism, not greenschist-facies metamorphism like the Moundville celt greenstones. The amphibolites are medium-grained schists composed of hornblende and plagioclase feldspar, and they also have well-developed rock cleavage (Stow et al., 1984). Metamorphic grade, mineralogy, and schistosity eliminate these lithologies as possible celt-stone candidates.

The mineralogy, petrography, and chemistry of the Moundville celt greenstones match descriptions of the actinolite-epidote-albite metabasites found in the erosionally-resistant portions of the Hillabee Metavolcanic Complex as reported by Griffin (1951) and Tull et al. (1978). Field investigations conducted in the Alabama Piedmont and examination of handspecimens support this conclusion. In summary, the only accessible sources of actinolite-epidote-albite metabasite similar to the Moundville artifact greenstones are the Hillabee Metavolcanic Complex; therefore, the remainder of this chapter will focus on the mineralogy, petrography, and chemistry of the Hillabee lithologies.

Hillabee Metavolcanic Complex

> *All of the diverse information (stratigraphic, petrologic, geochemical, and structural) which have been accumulated in this study appears to be most compatible with a volcanic origin for the great bulk of the Hillabee sequence. The basaltic nature is unquestionable on chemical and petrographic grounds.*
> *(Tull et al., 1978, p. 84)*

The best characterization of the Hillabee Metavolcanic Complex is based on the stratigraphic, petrologic, geochemical, and structural data of Tull et al. (1978); however, descriptions of the Hillabee greenstone date back as far as the mid-1800's and are based on mineralogy, rock textures, and structural considerations. Toumey (1858) described the Hillabee greenstone as a light-green hornblende rock formed from the alteration of basalt. Hitchcock (1885) and others considered the Hillabee greenstone to be a chlorite schist and that it was similar to the greenstones of the Green Mountains in Vermont. Phillips (1892) described the rocks of the Hillabee Metavolcanic Complex as schists composed of various combinations of chlorite, epidote, and actinolite, and concluded that the protolith was a basaltic rock. Prouty (1923) published the first report that included a map showing the outcrop traces of the Hillabee greenstone. Adams (1933) described the Hillabee greenstone as a chlorite schist, and stated that it was an igneous sill that intruded along the thrust fault that separates Ashland lithologies from rocks of the Talladega Slate Belt. Griffin (1951) described the Hillabee as a chlorite-epidote-hornblende-albite schist formed by the alteration of a mafic sill that was injected between the Talladega Slate Belt and Ashland Formation lithologies along the Whitestone fault. He

believed that the thrust faulting, intrusion, and metamorphic alteration took place at the end of the Paleozoic Era during the Appalachian Revolution.

Tull et al. (1978) conducted an detailed geologic survey of the Hillabee Metavolcanic Complex utilizing petrographic, mineralogical, stratigraphic, structural, and chemical data to interpret its geologic history. They recognize three major lithologies described as 1) mafic phyllite and 2) massive greenstone both composed of actinolite (40-60%), albite (20-30%), and epidote (10-40%), and 3) a hornblende-bearing siliceous phyllite/gneiss (hornblende-bearing quartz-sericite schist). Tull et al. (1978) examined the regional stratigraphy and structure, and concluded that the Hillabee greenstone rests conformably on top of the Talladega metasedimentary rocks and ends abruptly at the Hollins Line thrust fault, above which lies the Ashland Supergroup lithologies. Supported by chemical and petrographic data, they concluded that the protoliths for the mafic lithologies were low-potassium tholeiitic and spilitic basalt flows (80 %), and that the parent rock of the more siliceous member was an ignimbritic dacite formed from the fractionation of a basaltic magma. Tull et al. (1978) concluded that these rocks were part of a continental-bound volcanic arc or a volcanic mountain chain that was in place by the middle of the Ordovician Period, the basaltic rocks experienced low-grade regional metamorphism which changed them to greenschist-facies greenstones during the Acadian Orogeny of the Devonian Period, and that imbricate thrust faulting occurred during the Alleghanian Orogeny of late Permian age. To date, this

interpretation of the geologic history of the Hillabee Metavolcanic Complex is generally accepted to be the best explanation based on the available petrographic, mineralogical, stratigraphic, structural, and chemical data.

Higgins et al. (1988) disagreed with the petrologic interpretations of Tull et al. (1978) in several significant ways. They believe that the term *Hillabee* should only be used in an informal context because it is actually three different greenstone belts. Higgins et al. (1988) concluded that the Hillabee lithologies are not stratigraphic members of the Talladega Group; instead, they are parts of three different thrust sheets (Ropes Creek, Paulding, and West Point) that have been thrust over the Talladega metasediments, and over which was thrust the Ashland lithologies. They believe that the Hillabee greenstones show no evidence of continental crustal influence and that they were island-arc and ocean-floor low-potassium tholeiitic basalts and ignimbritic dacites that experienced low-grade regional metamorphism and imbricate thrusting during the closing of the Iapetus Ocean from late Precambrian times to the close of the Paleozoic Era.

Interpretations of the geologic history of the Hillabee Metavolcanic Complex have changed through the last 100 years, and they are still subject to change. The differences between the recent interpretations by Tull et al. (1978) and Higgins et al. (1988) are not based, however, on a difference in mineralogical and chemical data but on a difference in their regional interpretations of

paleogeography. The research on the Hillabee Metavolcanic Complex compiled by Tull et al. (1978) is still the most comprehensive treatment on the subject and is cited extensively in this chapter.

The Hillabee Metavolcanic Complex occurs as a long, narrow, discontinuous belt (Fig. 23) composed of metamorphosed basalt flows and associated volcaniclastic rocks (metabasite), and differentiates (metadacite) that emerge from beneath the Coastal Plain sediments in Chilton County, Alabama, trend in a northeasterly direction for approximately 170 km, and end abruptly at the Goodwater-Enitachopco-Allatoona fault system in Cleburne County, Alabama (Tull et al., 1978; Tull, 1979).

The Hillabee Metavolcanic Complex is considered by Tull and others (Tull, 1979, 1982; Tull et al., 1978; Tull and Stow, 1982) to rest conformably on top of the Talladega Slate Belt lithologies. A conformable stratigraphic contact occurs, therefore, between the foliated Devonian Jemison Chert (and its lateral facies) of the Talladega Group and the overlying mafic phyllites of the Hillabee Metavolcanic Complex (Fig. 24). The uppermost limit of the Hillabee Metavolcanic Complex is marked by the Hollins Line thrust fault that separates the greenschist metamorphic-facies metavolcanic rocks of the Hillabee lithologies from the overlying Ashland Supergroup lithologies of amphibolite metamorphic facies (Tull, 1979; Tull et al., 1978; Tull and Stow, 1982). The Hollins Line fault, therefore, forms a discordant contact between the Hillabee Metavolcanic Complex and Ashland Supergroup lithologies (Fig. 24). The Hillabee lithologies are

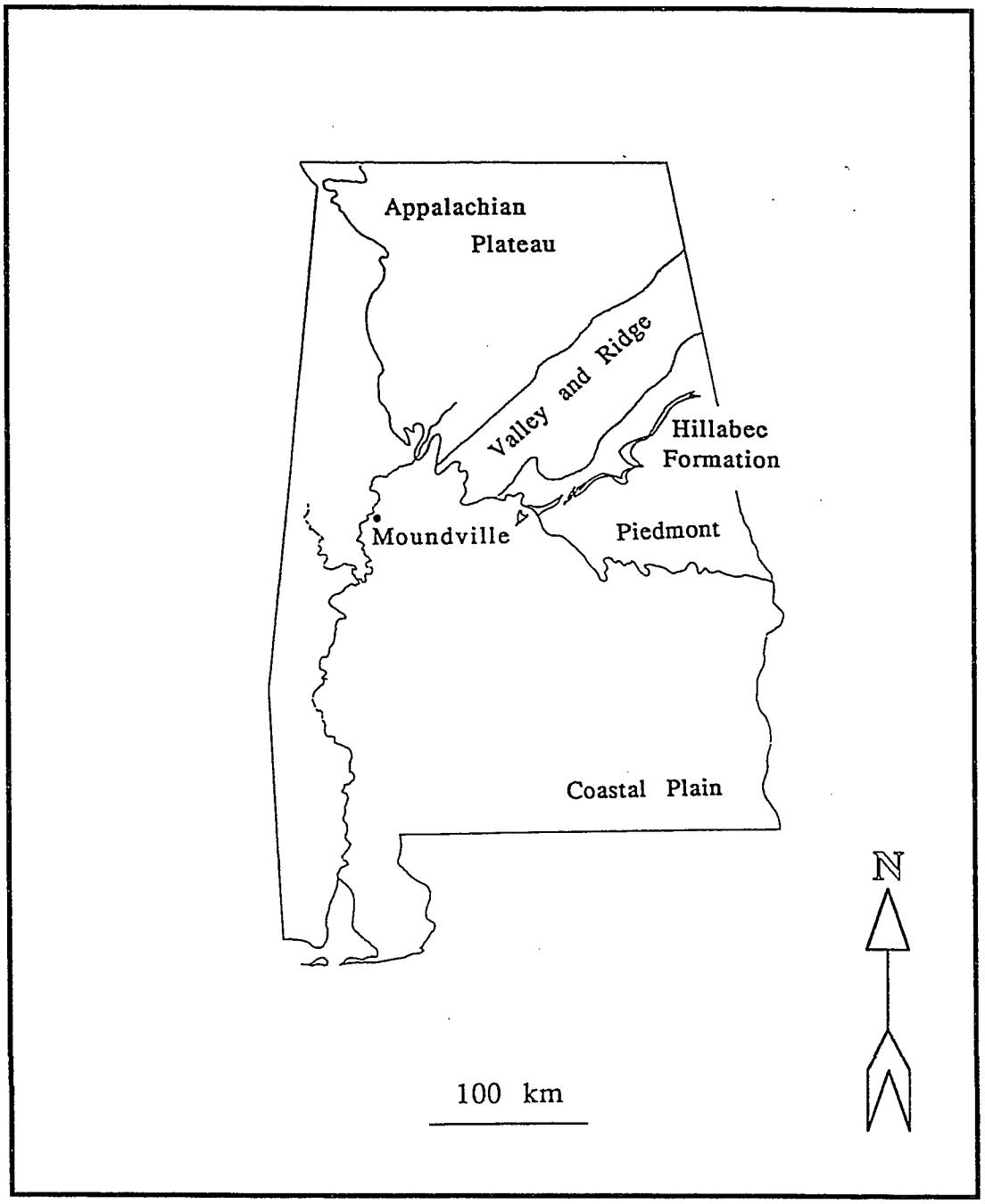

Figure 23. Map showing the locations of the Moundville site, the outcrop trace of the Hillabee Metavolcanic Complex, and the physiographic provinces of Alabama (Osborne et al., 1989).

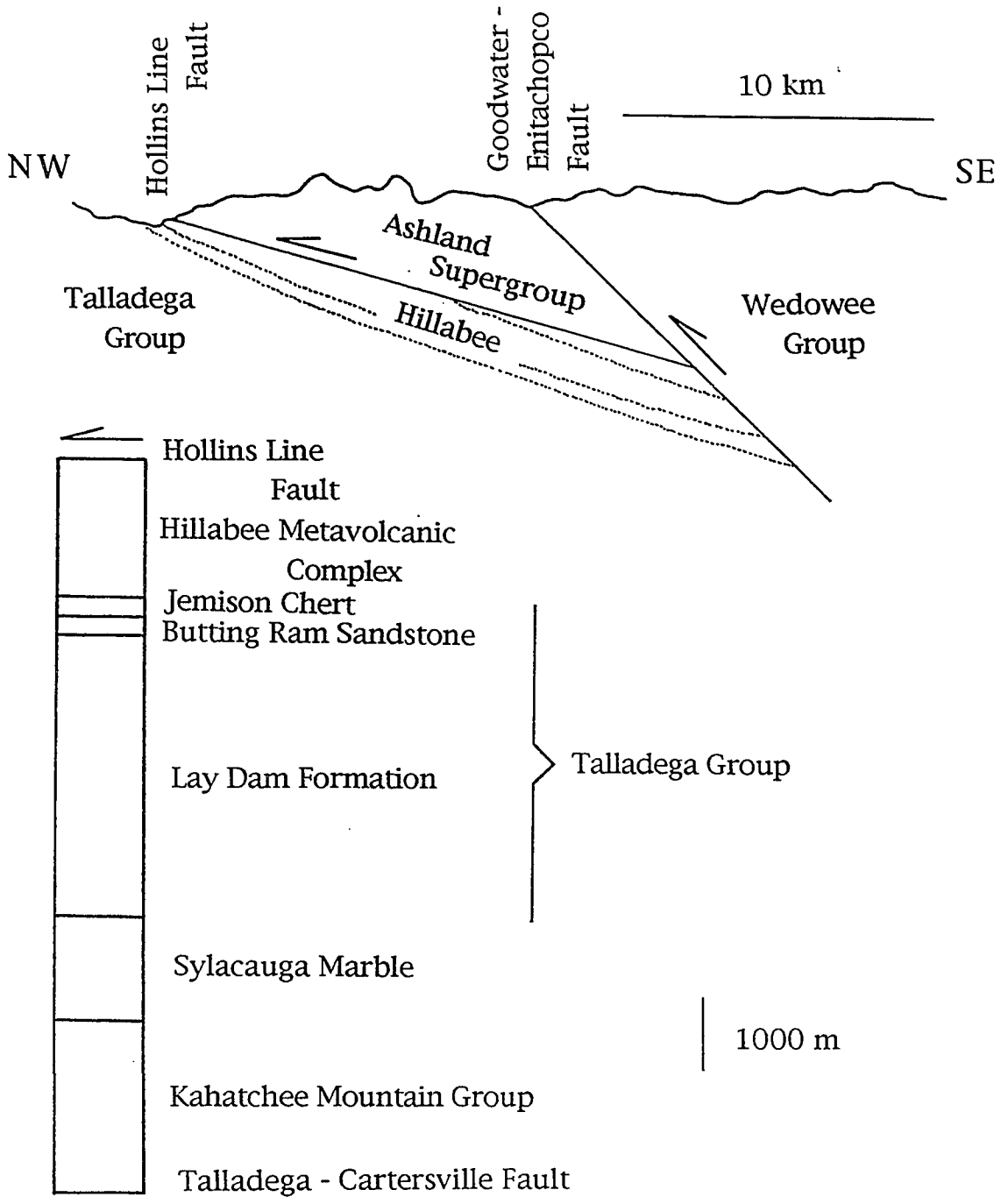

Figure 24. Generalized stratigraphic cross-sections of the Talladega Group, Hillabee Metavolcanic Complex, Ashland Supergroup, and Wedowee Group (Tull et al., 1978; Tull and Stow, 1982).

absent where the Hollins Line fault cuts down into Talladega Group lithologies placing them directly under Ashland Supergroup amphibolites. For the greater part of the outcrop length of the Hillabee Metavolcanic Complex, the Hollins Line fault is located in the basal mafic phyllite forming narrow belts (outcrop widths of less than 0.5 km) of easily-weathered phyllite. Mafic phyllites weather to red clay, which is easily eroded, forming elongate valleys between erosionally-resistant rocks of the Talladega Group to the northwest and the Ashland Supergroup to the southeast (Fig. 24). Parallel valleys separated by narrow ridges of Talladega Group lithologies occur where imbricate faulting along the Hollins Line fault has produced a series of slices that contain narrow belts of Hillabee phyllite that also erode to produce valleys (Tull, 1979). Griffin (1951) states, "Over the greater part of its area of outcrop the Hillabee sill is deeply weathered and is expressed topographically as a valley belt."

At several localities (e.g., Millerville area), the Hollins Line fault cuts upward in the stratigraphic section, increasing the section thickness of the Hillabee Metavolcanic Complex to a maximum of 2.7 km and resulting in outcrop widths of up to 4 km (Tull et al., 1978). In these areas of thicker section, erosionally-resistant lithologies of the Hillabee Metavolcanic Complex form low hills and ridges, and small waterfalls and rapids in stream channels. In summary, most of the Hillabee Metavolcanic Complex is composed of mafic phyllite that erodes to form long, narrow valleys. Within these long, narrow

valleys are small hills and ridges of erosionally-resistant greenstone and metadacite.

The three primary lithologies of the Hillabee Metavolcanic Complex are mafic phyllites composed of actinolite, epidote, and albite; massive to crudely-foliated metabasites composed of actinolite, epidote, and albite; and metadacites composed of quartz, sericite, and hornblende. The mafic phyllites have well-developed rock cleavage which eliminates them as celt-stone candidates because they lack the toughness required for percussion tools. The metadacites were eliminated as celt-stone candidates because they are very different mineralogically. The only lithologies of the Hillabee Metavolcanic Complex that are tough enough to serve as celt stone and that are compositionally similar to the Moundville celts are what Tull et al. (1978, p. 16 - 19) refer to as "massive greenstones." They are, in fact, massive to crudely-foliated, fine- to medium-grained, actinolite-epidote-albite metabasites that exhibit sub-conchoidal to hackly fracture because of the interlocking mosaic of grains and the low abundance of platy minerals like chlorite. Based on textural and mineralogical considerations, the greenstone celts of Moundville are composed of rock types similar to the tough, erosionally-resistant, actinolite-epidote-albite metabasites (massive greenstones) of the Hillabee Metavolcanic Complex. Because the mafic phyllites and metadacites have been eliminated as celt-stone candidates, the remainder of the chapter will be used to describe the mineralogy, petrology, and chemistry of only the massive greenstones of the Hillabee Metavolcanic Complex.

The Mineralogy And Petrography Of The Hillabee Greenstones

> *Massive greenstone tends to be the most resistant lithology within the Hillabee and commonly forms ridges and hills with relief of 30 to 100 m within the Hillabee valleys. (Tull, 1979, p.7)*

Hillabee metabasite samples that resemble the Moundville celt greenstone varieties were collected during field investigations. Sixty-three greenstone samples were collected along the 170-km length of the Hillabee outcrop trace (Appendix C).

Handspecimen examination of the Hillabee greenstone samples determined that they are fine- to medium-grained, massive to crudely-foliated greenstones which vary in color from greenish gray (5G6/1) to dark greenish gray (5G4/1) to medium dark gray (N4) according to the Munsell color system. Whole rock densities were determined for 26 of the Hillabee greenstone samples using the immersion technique and a hydrologic balance according to the proceedure decribed in Chapter 2. The 26 samples have densities that range from 2.8 to 3.2 g/cm^3, and their average density is 3.0 g/cm^3 (Appendix C).

The 62 greenstone samples were examined using a binocular microscope, and twenty-seven petrographic thin sections were constructed and examined using a petrographic microscope. Data obtained from the microscopic examination of petrographic thin-sections and hand specimens were used to place the mafic rocks of

the Hillabee Metavolcanic Complex into the following 5 textural categories:

1. Massive Greenstone - fine-grained (≤0.1 mm), massive, granoblastic texture, 16 of 62 samples (25.8%), 12 thin-sections (Fig. 25);
2. Crudely-Foliated Greenstone - fine- to medium-grained (≤1.0 mm), granular to crudely-foliated texture, 14 of 62 samples (22.6%), 2 thin-sections (Fig 26);
3. Relict Diabasic Texture - fine-grained (< 1.0 mm), lath-shaped relict plagioclase phenocrysts in a fine-grained matrix, 5 of 62 samples (8.1%), 2 thin-sections (Fig. 27);
4. Mylonite - fine-grained (< 1.0 mm), flinty, banded, granulated texture, 8 of 62 samples (12.9%), 10 thin sections;
5. Phyllite - very fine-grained, foliated texture with sheen on foliation surface, 19 of 62 samples (30.6%), 1 thin-section.

Pyrite and its alteration products, dark-colored veins and aggregates of epidote, and fine-grained aggregates of chlorite also occur frequently in the Hillabee greenstone samples.

Rock powders prepared from the samples selected for thin-sectioning were used for X-ray diffraction analysis and multi-instrumental quantitative chemical analysis (Appendix C). The X-ray diffractometer (XRD) was used to identify the major mineral components of the greenstones. Mineral Powder Diffraction File Cards and results from mineral standards were used to interpret XRD data. XRD results confirm that all of the Hillabee greenstone samples are composed of actinolite, epidote, and albite with minor

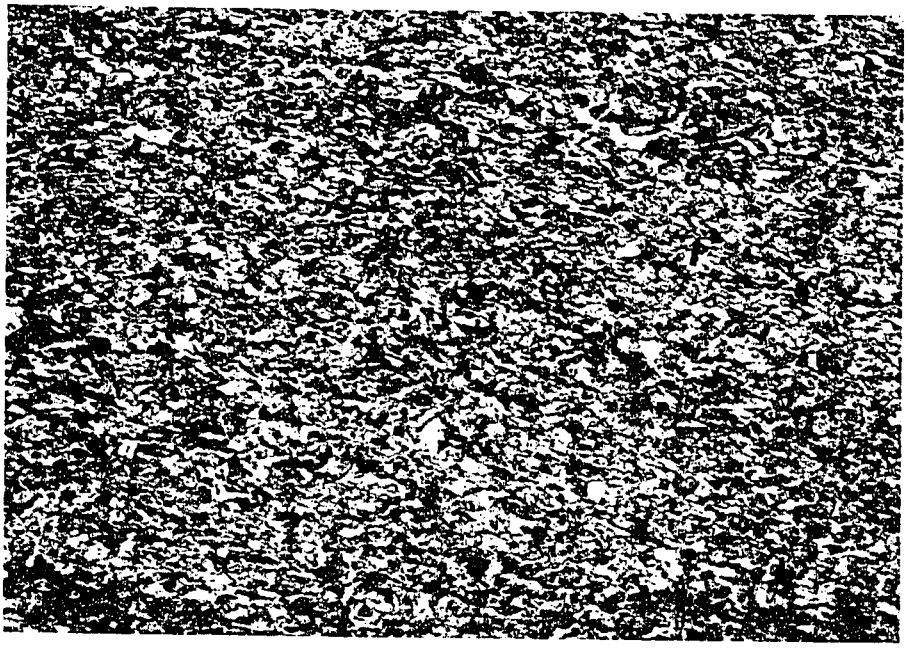

Figure 25. Photomicrograph of Hillabee greenstone sample GS-23 showing fine-grained, massive, granoblastic texture. The length of the photomicrograph corresponds to 5 mm; the photograph was taken using plane-polarized light.

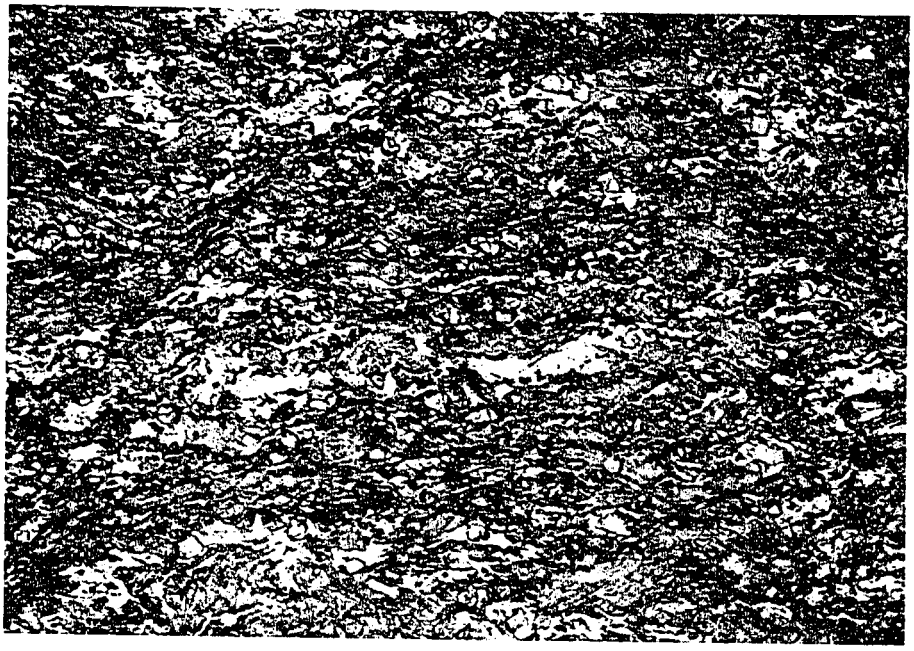

Figure 26. Photomicrograph of Hillabee greenstone sample B-GS-100.5 showing crude foliation. The length of the photomicrograph corresponds to 5 mm; the photograph was taken using plane-polarized light.

Figure 27. Photomicrograph of Hillabee greenstone sample B-GS-104 showing fine-grained diabasic texture. The length of the photomicrograph corresponds to 1 mm; the photograph was taken using plane-polarized light.

amounts of chlorite, and quartz occurs in detectable amounts in 6 of the greenstone samples. The absence or presence of quartz in detectable amounts is the only difference between the samples: 77.9% of the samples (20 out of 26 samples) do not contain quartz in detectable amounts, 23.1% (6 out of 26 samples) do contain enough quartz for it be detected. The amount of quartz present, however, is very small because the strongest diffraction line (d-spacing = 3.343 angstroms, *hkl* = 101) is just discernible above background and no other quartz diffraction lines are present. Because only very small amounts of quartz are present in the greenstone samples, the range in greenstone densities (2.8 to 3.2 g/cm^3) must be due to variations in the relative abundances of albite, actinolite, and epidote.

An evaluation of the microscopic and X-ray diffraction data has established that even though Hillabee greenstone lithologies differ in color and texture, they do not differ significantly in mineralogy. The greenstones are all composed of approximately equal amounts of actinolite, epidote, and albite. The relict igneous textures (e.g., diabasic) of some of the Hillabee greenstones positively confirm their protoliths' igneous mode of origin. The uniformity of greenstone mineralogy indicates that the different types of greenstones without relict igneous features had a protolith with a similar initial composition. The mineral assemblage of the greenstones and their fine-grained textures are indicators of greenschist-facies metamorphism. Under greenschist-facies metamorphic conditions, epidote and albite form from the alteration of calcium-rich plagioclase feldspar (e.g., labradorite: An50-70), and actinolite forms

from the alteration of augite (Philpotts, 1990). An igneous rock composed of labradorite and augite is basaltic in composition; therefore, the Hillabee greenstone lithologies formed from a basaltic parent rock that experienced greenschist-facies metamorphism. Relict igneous features, mineralogy, and published geologic reports (e.g., Tull et al., 1978; Griffin, 1951) support this conclusion.

Based on rock texture, mineralogy, and protolith, the Hillabee greenstone celt lithologies can be classified as very-fine- to medium-grained, massive to crudely-foliated, actinolite-epidote-albite metabasites. The toughness of these greenstones results from the low abundance of platy minerals (e.g., chlorite), and from the interlocking network of grains. The fine-grained, interlocking network of grains is responsible for the occurrence of sub-conchoidal to hackly fracture instead of rock cleavage.

Chemistry of the Hillabee Greenstones

> *The geochemical data were examined to determine if there were chemical variations along strike among the northern, central and southern study areas of the Hillabee...The trend for decreasing total iron is consistent from north to south, and the increasing Na_2O is a consistent trend for only the (massive) greenstones.* *(Tull et al., 1978, p. 55 - 56)*

Eleven samples of Hillabee greenstone were selected for chemical analysis (Appendix C). The selection criteria were based on the mineralogical and petrographic characteristics of the Moundville celt-stones (tough; dense, fine- to medium-grained, massive to

crudely-foliated metabasites composed of actinolite, epidote, and albite). The eleven greenstone samples are from well-exposed, naturally-occurring outcrops (Fig. 28) that are eroding and releasing boulders (Fig. 29); therefore, they are also good candidates based on their potential to be exploited (accessible and abundant resource).

The 11 greenstone samples selected for chemical analysis came from the northern, central, and southern parts of the Hillabee Metavolcanic Complex; however, sample localities are not uniformly spaced along its length because along most of the strike of the Hillabee Metavolcanic Complex, only mafic phyllites occur (approx. 80%). These large segments of the Hillabee contain no celt-stone grade Hillabee lithologies for analysis (or for ax making). Five of the Hillabee greenstone samples came from the southern study area, four of the samples came from the central study area, and two of the samples came from the northern study area (Fig. 30). The small number of Hillabee samples that meet the Moundville celt-stone criteria reflects the limited number of outcrops that are composed of celt-stone grade material.

Rock powders were analyzed by XRAL Laboratories of Ann Arbor, Michigan (Appendix C). The 50-element quantitative analyses used multi-instrumental techniques [X-Ray Fluorescence (XRF), Instrumental Neutron Activation Analysis (INAA), Inductively Coupled Plasma Emission Spectrometry (ICP), and Direct Current Plasma Emission Spectrometry (DCP)] to provide the best possible

Figure 28. Photograph of an outcrop of Hillabee greenstone forming rapids in Gale Creek, Chilton County, Alabama.

Figure 29. Photograph of Gale Creek alluvium containing greenstone cobbles and boulders, Chilton County, Alabama. The hammer in the center of the photograph measures 27 cm in length.

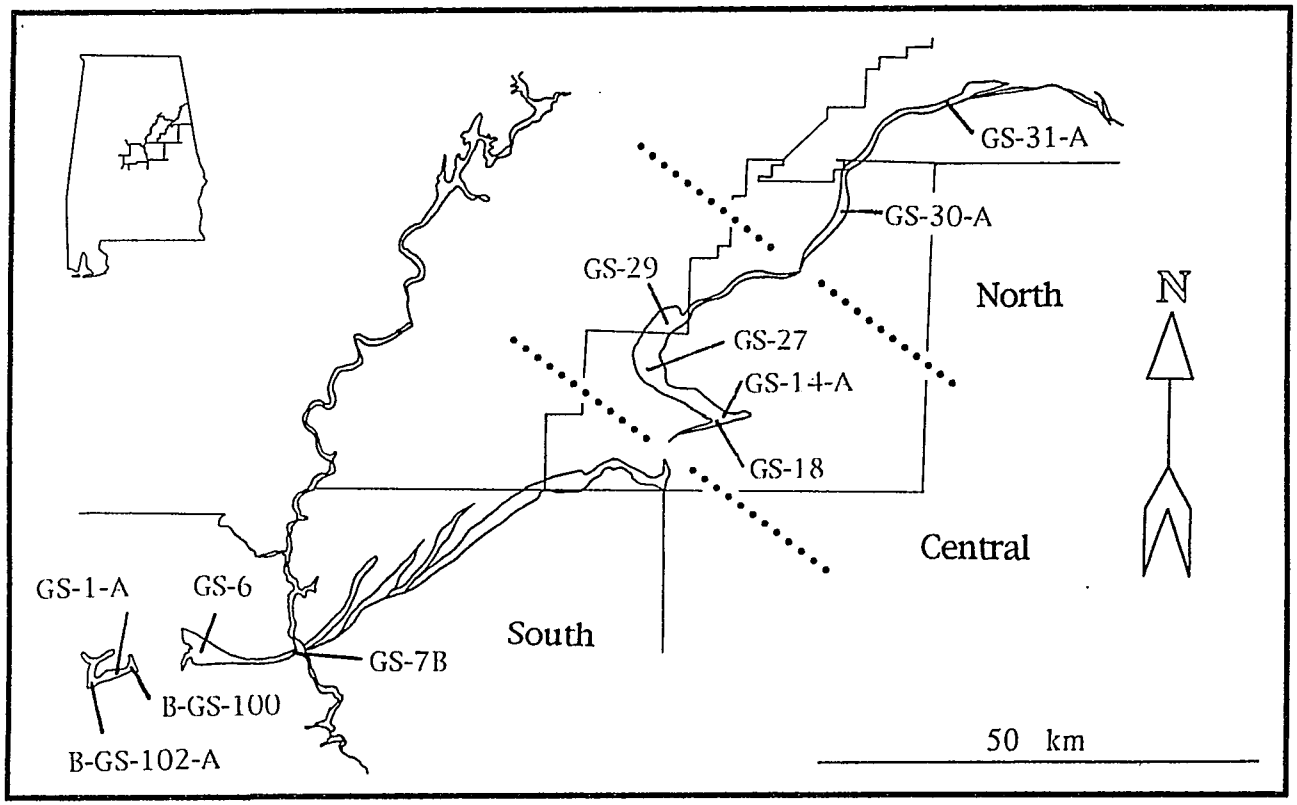

Figure 30. Map showing the location of the outcrop trace of the Hillabee Metavolcanic Complex (Tull,1979); the northern, central, and southern study areas (Tull et al., 1978); and the localities of greenstone samples that were used for chemical analysis.

data for each element. The elements, lower detection limits, and analysis instruments are as follows:

XRF: SiO_2 - 0.01 wt.%, Al_2O_3 - 0.01 wt.%, CaO - 0.01 wt.%, MgO - 0.01 wt.%, Na_2O - 0.01 wt.%, K_2O - 0.01 wt.%, Fe_2O_3 - 0.01 wt.%, MnO - 0.01 wt.%, Cr_2O_3 - 0.01 wt.%, TiO_2 - 0.01 wt.%, P_2O_5 - 0.01 wt.%, LOI - 0.01 wt.%, Ba - 10.0 ppm, Nb - 10.0 ppm, Rb - 10.0 ppm, Sr - 10.0 ppm, Y - 10.0 ppm, Zr - 10.0 ppm;

INAA: As - 1.0 ppm, Au - 2.0 ppb, Br - 0.5 ppm, Ce - 1.0 ppm, Co - 0.5 ppm, Cr - 0.5 ppm, Cs - 0.5 ppm, Eu - 0.05 ppm, Hf - 0.2 ppm, Ir - 5.0 ppb, La - 0.1 ppm, Lu - 0.01 ppm, Mo - 2.0 ppm, Nd - 3.0 ppm, Sb - 0.1 ppm, Sc - 0.05 ppm, Se - 1.0 ppm, Sm - 0.01 ppm, Ta - 0.5 ppm, Tb - 0.1 ppm, Th - 0.2 ppm, U - 0.1 ppm, W - 1.0 ppm, Yb - 0.05 ppm;
ICP: Ag - 0.1 ppm, Cd - 1.0 ppm, Cu - 0.5 ppm, Ni - 1.0 ppm, Pb - 2.0 ppm, Zn - 0.5 ppm;

DCP: B - 10.0 ppm, Be - 1.0 ppm, Ge - 10.0 ppm, Mn - 2.0 ppm, V - 2.0 ppm.

The following 13 elements were not detected in most of the samples: As, B, Cd, Cs, Ge, Mo, Pb, Rb, Se, Ta, Th, U, and Ir. The data for tungsten were not used because the samples were powdered in a rock mill with tungsten carbide grinding surfaces. The remaining 37 elements and ignition losses (LOI) were generally above the lower detection limits. The results of the multi-instrumental, quantitative

chemical analysis of the 11 Hillabee greenstone samples are reported in Appendix C.

The 11 Hillabee samples are basaltic in composition because their SiO_2 contents are between 45% and 52%, and because their soda and potassium (potash) contents ($Na_2O + K_2O$) are less than 5% (Le Bas et al., 1986). The 11 Hillabee greenstone samples have chemical compositions that match those of basalts (Table 3) according to the chemical analyses of basalts reported by Wilkinson (1986) and Le Maitre (1976). The average silica (SiO_2, 47.62 wt.%) and average alumina (Al_2O_3, 14.38 wt.%) contents of the Hillabee samples are reasonable values for low-aluminum (Al_2O_3 < 16 wt.%) tholeiitic basalts according to Wilkinson (1986). The reported quantities of lime, soda, and potash in low-Al tholeiites are 11.51 wt.%, 2.53 wt.%, and 0.14 wt.%, respectively (Wilkinson, 1986). The average lime content of the Hillabee greenstones is 12.03 wt.%, their average soda content is 2.65 wt.%, and their average potash content is 0.18 wt.% which agree well with the expected values for low-Al tholeiites given above (Table 3). The Hillabee samples have an average K_2O/Na_2O ratio of 0.06; therefore, because the K_2O/Na_2O ratio is less than 0.5, the protolith can be further classified as low K/Na basalt (Wilkinson, 1986). Mid-ocean ridge basalts (MORB-type) are very low-potassium tholeiites (K_2O < 0.3 wt.%) according to Wilkinson (1986). Only 2 of the 10 Hillabee samples have K_2O values that exceed 0.3 wt.%; therefore, 8 of the Hillabee samples are similar to MORB-types. Hillabee greenstone samples from the southern study area have

Table 4. Average[1] chemical compositions of the greenstone samples from the northern, central, and southern portions of the Hillabee Metavolcanic Complex[2] and selected tholeiitic basalts (tholeiite)[3].

	Average Abundance (weight %)					
Oxide	North Hillabee	Central Hillabee	South Hillabee	Total Hillabee	Low K-Al Tholeiite	Tholeiitic Basalt
SiO_2	43.30	48.28	48.82	47.62	50.08	49.58
Al_2O_3	15.15	13.80	14.54	14.38	15.07	14.79
CaO	15.65	11.57	10.95	12.03	11.51	10.36
Na_2O	0.70	2.18	3.81	2.65	2.53	2.37
K_2O	0.08	0.36	0.07	0.18	0.14	0.43
Total Fe	13.6	12.35	10.25	11.62	10.78	11.41
MgO	6.67	7.36	5.98	6.63	8.12	7.30
TiO_2	1.20	1.21	0.87	1.05	1.55	1.98
MnO	0.19	0.21	0.26	0.23	0.10	0.18
P_2O_5	0.10	0.12	0.10	0.11	0.13	0.24
LOI	2.13	2.03	3.40	2.67	- -	1.44
	98.84	99.44	99.06	99.16	100.01	100.08

1. Number of samples: North Hillabee, 2; Central Hillabee, 4; South Hillabee, 5; Total Hillabee, 11; Low K-Al Tholeiite, 1; and Tholeiitic Basalt, 202.
2. Data from Appendix C.
3. Data for low-K, low-Al (low K-Al) tholeiitic basalt reported by Wilkinson (1986); and the average chemical compositions of 202 tholeiites reported by Le Maitre (1976).

greater amounts of soda (average Na_2O = 3.81 wt.%) and correspondingly lower amounts of lime (average CaO = 10.95 wt.%).

This fact led Tull et al. (1978) to conclude that the Hillabee greenstones from the southern study area are more closely affiliated with spilitic basalts than with tholeiitic basalts. The "extreme chemical variability" of spilites (Vallance, 1960, p.35) makes this differentiation somewhat tentative. In summary, the average chemical compositions of the 11 Hillabee greenstone samples match those of low-potassium, low-aluminum tholeiitic basalts.

Scatter plots will be used in the following portion of the chapter to illustrate some of the chemical similarities and differences for elements that were evaluated for Moundville celt greenstones (calcium, sodium, iron, chromium, selected rare earth elements).

Calcium and Sodium

As the lime contents in the greenstone samples decrease, their soda contents increase; therefore, an inverse relationship exists between lime and soda, which is illustrated in the CaO-Na_2O graph (Fig. 31). The identification of data-point localities reveals that this change in chemistry correlates to a change in position along the strike of the Hillabee outcrop from north to south (Fig. 31). It is this change in the chemistry of the Hillabee Metavolcanic Complex that led Tull et al. (1978) to the conclusion that the Hillabee's protolith changed from tholeiites in the northern and central parts, to spilites in the southern part.

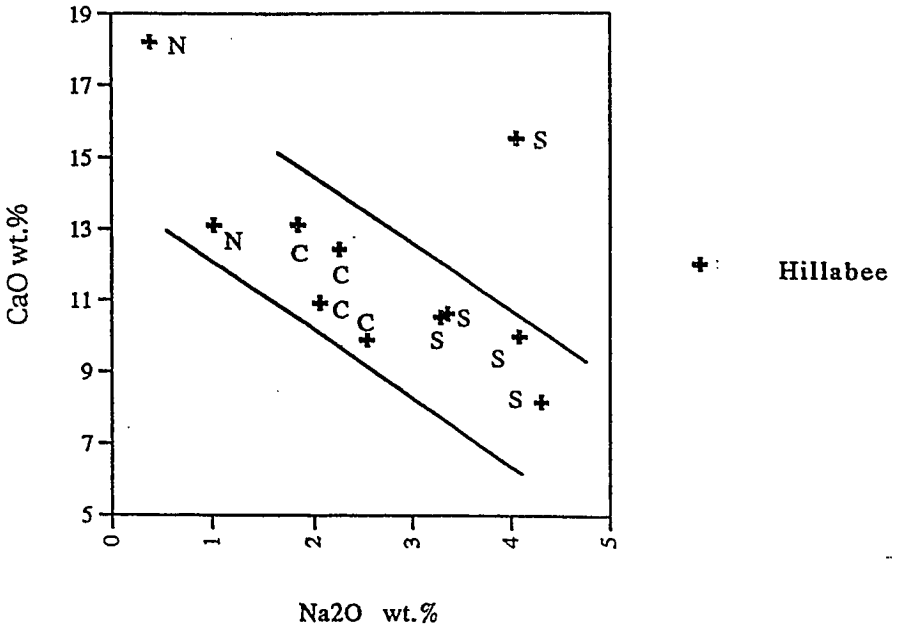

Figure 31. Scatter plot showing the relationship between sodium and calcium for the greenstone samples from the northern (N), central (C), and southern (S) portions of the Hillabee Metavolcanic Complex.

Iron and Chromium

There is a substantial amount of variation in the iron and chromium contents of the greenstones within each study area; however, the iron and chromium values also tend to decrease from north to south along the length of the Hillabee Metavolcanic Complex (Fig. 32). Stow (1979) attributes the decrease in elements such as iron and chromium to magmatic fractionation.

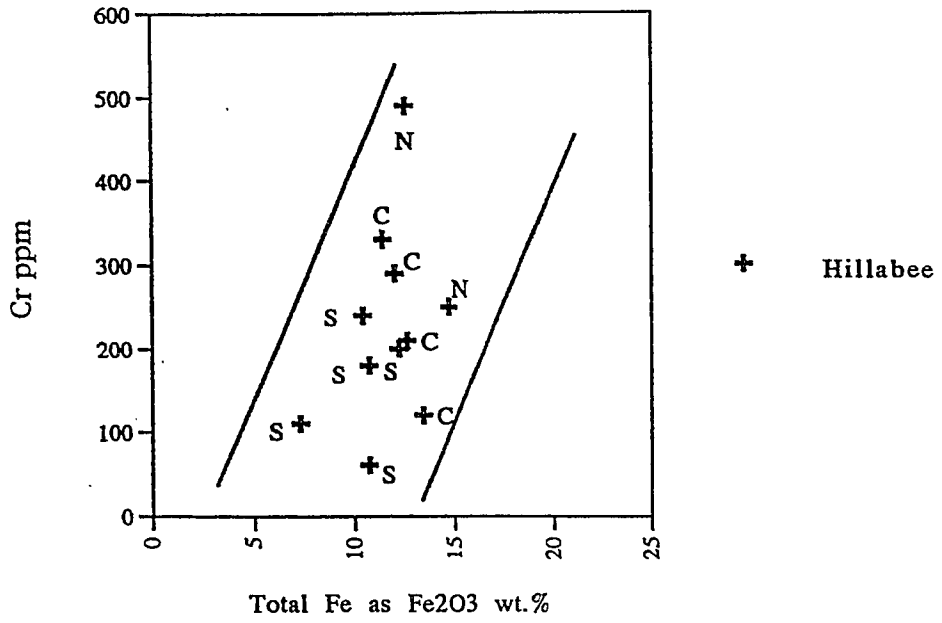

Figure 32. Scatter plot showing the relationship between iron and chromium for the greenstone samples from the northern (N), central (C), and southern (S) portions of the Hillabee Metavolcanic Complex.

Rare Earth Elements: Cerium, Lutetium, Samarium, Ytterbium

A direct relationship exists between the cerium, lutetium, samarium, and ytterbium values for the Hillabee greenstone samples. Higher values for one element signal an increase in the values of the other elements. If fractionation is responsible for the decrease in the iron and chromium contents from north to south among the Hillabee lithologies (Stow, 1979), then the values for the incompatible rare earth elements (REE) should increase from north to south (Davis,

1977). In some instances, the values for the REE appear to decrease from north to south (Fig. 33); in other instances, the changes in REE values do not correlate with changes in position along the length of the Hillabee (Fig. 34). In summary, the direct relationship among the rare earth elements does not correlate well with a change in position along the length of the Hillabee Metavolcanic Complex.

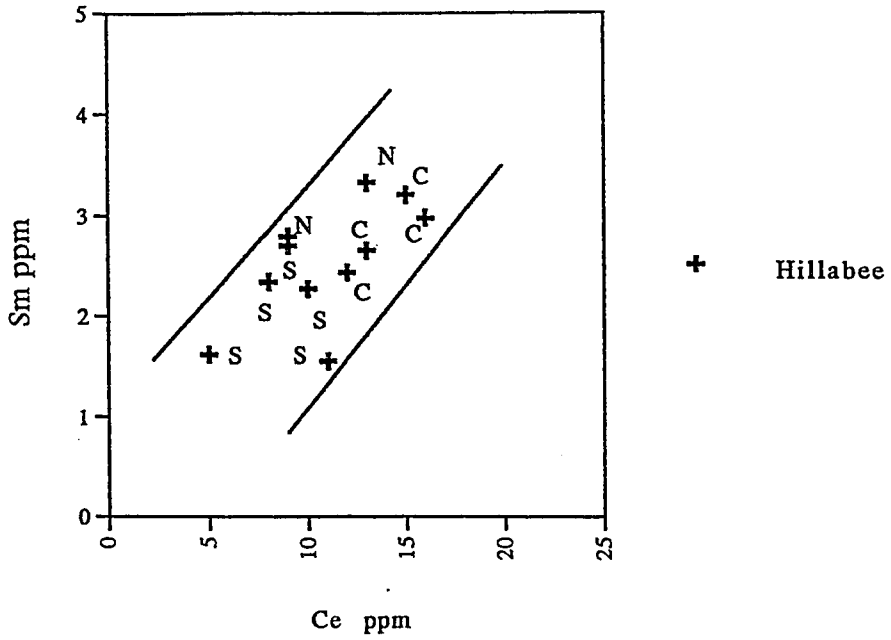

Figure 33. Scatter plot showing the relationship between cerium and samarium for the greenstone samples from the northern (N), central (C), and southern (S) portions of the Hillabee Metavolcanic Complex.

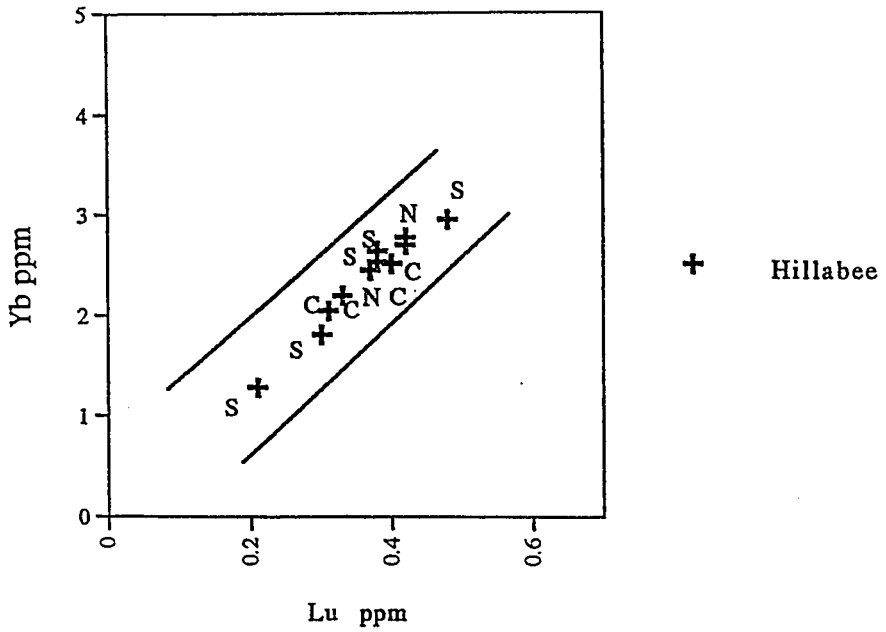

Figure 34. Scatter plot showing the relationship between lutetium and ytterbium for the greenstone samples from the northern (N), central (C), and southern (S) portions of the Hillabee Metavolcanic Complex.

Summary

The greenstones of the Hillabee Metavolcanic Complex are chemically similar to low-potassium, low-aluminum tholeiitic basalts. Mineralogical, petrographic, and chemical data support this conclusion. Within the Hillabee Metavolcanic Complex, chemical trends occur that correlate with changes in position along the length of the Hillabee outcrop belt (e.g., calcium, sodium). Relationships occur among some elements of the Hillabee greenstones that do not

correlate with changes in geographic position (e.g., REE). The chemical trends, differences, and similarities of the Hillabee Metavolcanic Complex will be compared to those of the Moundville celt greenstones in Chapter Four. Mineralogical, petrographic, and chemical comparisons of the outcrop and celt greenstones will determine if the Indians of Moundville used locally-available Hillabee greenstone or metabasite imported from distant sources. Comparisons between the chemical analyses of Tull et al. (1978) and this study are contained in Appendix C.

CHAPTER 4

PROVENANCE OF MOUNDVILLE GREENSTONE ARTIFACTS

The objectives of Chapter Four are to compare the data on the Moundville celt greenstones with the data on the ax-grade greenstones from the Hillabee Metavolcanic Complex. The results of this comparison will be used to determine if the artifact greenstones were obtained from the Hillabee Metavolcanic Complex or from nonlocal geologic sources. Once it has been established that the Hillabee lithologies were the sources of Moundville celt stone, then petrographic and chemical data will be used to determine intraformational provenance. The potential to procure greenstone boulders from alluvial sources will also be considered.

Chapter Four concludes with information that attributes the origin of the name *Hatchet Creek* to the celt-stone sources that occur in the upper parts of the Hatchet Creek valley located in the central part of the Hillabee Metavolcanic Complex.

Mineralogical, Petrographic, And Chemical Comparisons Between The Moundville Celt Greenstones And The Greenstone Lithologies Of The Hillabee Metavolcanic Complex

> *An examination of several hundred sections of greenstone from various igneous areas in the British Isles led the sub-committee (Southwestern Group of Museums and Art Galleries) to the conclusion that the peculiar characteristics of the group (Group I, Neolithic stone axes) could best be matched by the greenstones of Devon and Cornwall. Collecting and examination of rocks in these greenstone areas has been carried out, but unfortunately an exact match still eludes the sub-committee.*
>
> *(Heizer, 1959, p. 452)*

The identification of the chemical trends along the strike of the Hillabee Metavolcanic Complex by Tull et al. (1978) utilized chemical data from all of the different Hillabee lithologies (e.g., mafic phyllite, massive greenstone, metadacite). Most of the chemical variability among the 97 samples is due to changes in lithologies (Tull et al., 1978); however, variations in the values for certain elements (e.g., Ag, Rb) within an outcrop can be as great as variations between outcrops kilometers apart. Based on this observation, Tull (personal communication, 1991) advised me to use combinations of mineralogical, petrographic, and chemical data to determine Moundville greenstone artifact provenance

Mineralogical Comparisons of the Moundville Celt Greenstones and the Greenstones of the Hillabee Metavolcanic Complex

Celt and Hillabee greenstones are composed of actinolite, epidote, and albite with minor amounts of chlorite, pyrite, and quartz. In both greenstone groups, fibrous, microscopic actinolite grains and microscopic aggregates of granular epidote are bound by

interstitial albite, forming an interlocking network of grains (Fig. 15). In both the celt and Hillabee greenstones, compositional layering which results from mineral segregations is poorly-developed if at all, and foliations, where discernible, are delineated by sub-parallel veins and fractures, and by the orientation of elongate actinolite grains. Actinolite, epidote, and albite exhibit intragranular cleavage; however, cleavage traces typically terminate at grain boundaries because of a lack of preferred grain orientation. Greenstone toughness (resistance to breakage) results, in both sets of greenstones, from an interlocking network of sub-parallel to felted, fibrous, fine-grained actinolite; randomly orientated, fine-grained, granular epidote; and randomly orientated, fine-grained, irregularly-shaped albite grains; and from the low abundance of platy minerals like chlorite. Moundville artifact greenstones and Hillabee greenstones have similar whole-rock densities and colors because both sets of greenstones are composed of approximately equal proportions of actinolite, epidote, and albite.

In conclusion, the mineralogy of the Moundville celt greenstones matches the mineralogy of the Hillabee greenstones.

Petrographic Comparisons of the Moundville Celt Greenstones and the Greenstones of the Hillabee Metavolcanic Complex

Based on rock textural types, mineralogy, and protoliths, the Moundville celt greenstones and the Hillabee greenstone lithologies are very-fine- to medium-grained, massive to crudely-foliated, actinolite-epidote-albite metabasites.

The Moundville celt greenstones and the Hillabee greenstones share in common the same types of rock textures and rock features like dark-colored veins and aggregates of epidote. Samples from both sets of greenstones exhibit fine-grained granoblastic texture (Figs. 6 and 25); fine-grained relict-diabasic texture (Figs. 8 and 21); and fine- to medium-grained, granular to crudely-foliated textures (Figs. 12 and 20).

The Moundville celt greenstone protoliths, like the Hillabee greenstone protoliths, were low-potassium tholeiites that have experienced regional, greenschist-facies metamorphism. Ax-grade greenstones of this type only occur in the Northern Piedmont of Alabama as small hills and outcrops forming rapids in Hillabee stream valleys.

In conclusion, the petrographic data of the Moundville celt greenstones match those of the Hillabee greenstones.

Chemical Comparisons Of The Moundville Celt Greenstones and the Greenstones of the Hillabee Metavolcanic Complex

Because of the similar mineralogy in the Moundville artifact greenstones and the Hillabee lithologies, one would expect them to be chemically similar. The discussion in this section on the chemical similarities between the celt and Hillabee greenstones will focus on the chemical relationships and trends of lime, soda, total iron, chromium, and selected rare earth elements (cerium, samarium,

lutetium, ytterbium) as was done in the preceding sections that dealt with celt and Hillabee greenstone chemistry.

Calcium and Sodium

The linear relationship between lime and soda follows the same general trend for both the celt and Hillabee greenstones (Fig. 35). The importance of this trend is that changes in lime and soda values in the Hillabee greenstone lithologies correlate with a change in

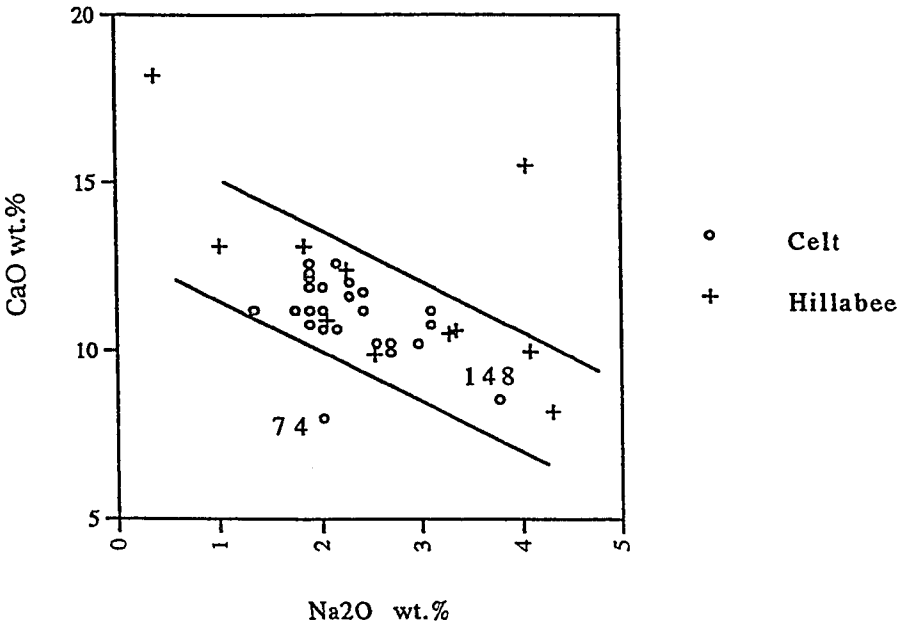

Figure 35. Scatter plot showing the calcium (CaO wt.%) and sodium Na2O wt.%) values for Moundville celt greenstones and Hillabee Metavolcanic Complex greenstones. Celt fragments A 930.2.148 (148) and A 941.3.74 (74) are labeled because they are the cluster outliers in the CaO-Na2O graph for Moundville celt greenstone (Fig. 18).

position along the length of the Hillabee Metavolcanic Complex (Fig. 31). A comparison of lime and soda values reveals that most of the celt greenstones are similar to the greenstone samples from the central portion of the Hillabee (Fig. 36).

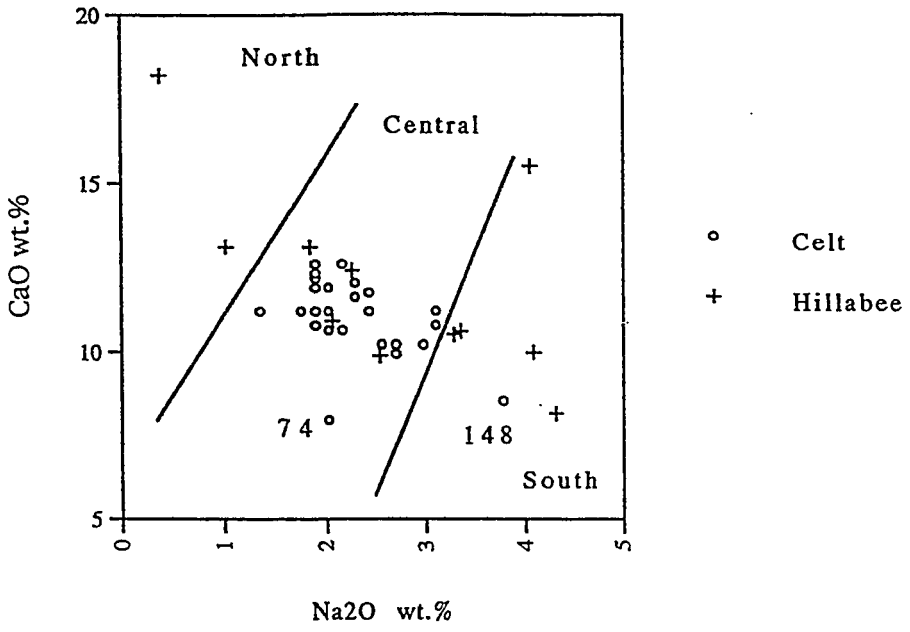

Figure 36. Scatter plot showing the calcium (CaO wt.%) and sodium Na2O wt.%) values for Moundville celt greenstones and Hillabee Metavolcanic Complex greenstones. Division lines divide the field such that Hillabee greenstones from the northern, central, and southern portions fall into groups. Celt fragments A 930.2.148 (148) and A 941.3.74 (74) are labeled because they are the cluster outliers in the Moundville celt greenstone CaO-Na2O graph (Fig. 18).

Iron and Chromium

The range of values for iron and chromium varies less among the Moundville celt greenstones than among the Hillabee greenstone lithologies; therefore, celt greenstone values cluster more tightly than do the iron and chromium values of Hillabee greenstones (Fig. 37).

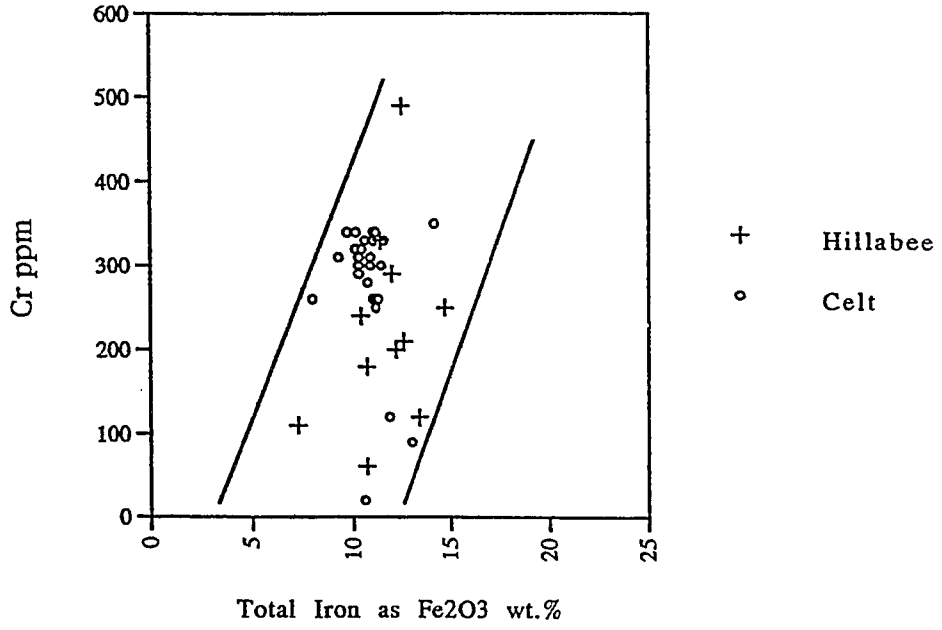

Figure 37. Scatter plot showing the total iron as Fe_2O_3 wt.% and chromium (Cr ppm) values for Moundville celt greenstones and Hillabee Metavolcanic Complex greenstones.

As with calcium values, the Hillabee greenstone values for iron and chromium tend to decrease from north to south (Tull et al., 1978).

Although poorly defined, the Fe-Cr trend is still important because changes in the values of iron and chromium in the Hillabee greenstone lithologies correlate with a change in position along the length of the Hillabee Metavolcanic Complex (Fig. 38). A comparison of the iron and chromium values reveals that most of the celt

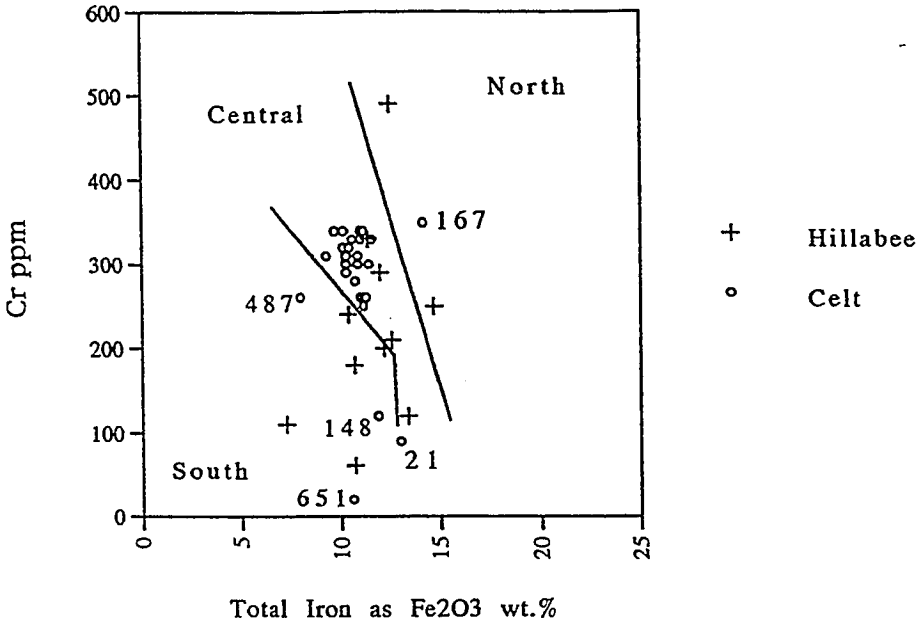

Figure 38. Scatter plot showing the total iron as Fe_2O_3 wt.% and chromium (Cr ppm) values for Moundville celt greenstones and Hillabee Metavolcanic Complex greenstones. Division lines divide the field such that Hillabee greenstones from the northern, central, and southern portions fall into groups. Celt fragments A 930.2.148 (148), A 930.5.21 (21), A 939.2.487 (487), A 939.2.651 (651), and A 941.3.167 (167) are labeled because they are the cluster outliers in the Moundville celt greenstone Fe-Cr graph (Fig. 19).

greenstones are similar to the greenstone samples from the central portion of the Hillabee Metavolcanic Complex (Fig. 38).

Rare Earth Elements: Cerium, Lutetium, Samarium, Ytterbium

A direct relationship exists between the cerium, lutetium, samarium, and ytterbium values for the Moundville celt greenstones and for the Hillabee greenstone samples. Higher values for one element correspond to an increase in the values of the other elements. In some instances, the values for the rare earth elements (REE) appear to decrease from north to south (Fig. 33); in other instances, the changes in REE values do not correlate with changes in position along the length of the Hillabee Metavolcanic Complex (Fig. 34); therefore, the direct relationship among the rare earth elements does not apparently correlate with a change in position along the length of the Hillabee Metavolcanic Complex. These relationships are important nonetheless because of the good correlation in the range of values between the celt and Hillabee rare-earth element quantities (Figs. 39 and 40).

Moundville Celt-Stone Provenance

The mineralogy, petrography, and chemistry of the celt greenstones match the mineralogy, petrography, and chemistry of the erosionally-resistant greenstones of the Hillabee Metavolcanic Complex; therefore, the Moundville celts are composed of Hillabee greenstones. The Hillabee outcrops are the only locally-available sources of celt-grade greenstone lithologies that occur in the Alabama Piedmont, and metamorphic rocks do not occur elsewhere

in the state. Because the Hillabee Metavolcanic Complex is the source of Moundville celt greenstones, celts were locally-manufactured goods produced from locally-available materials.

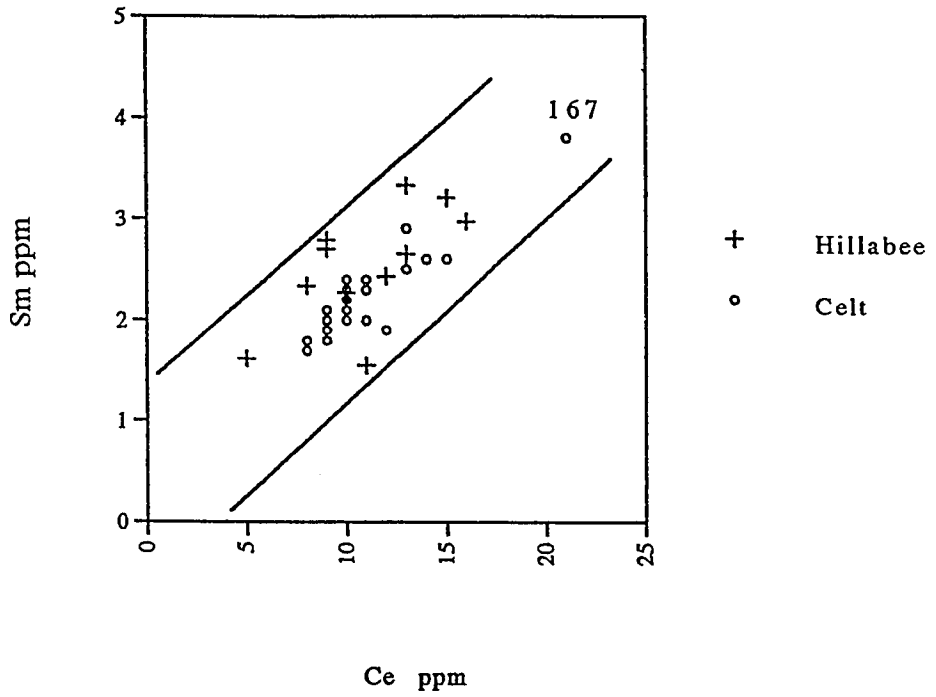

Figure 39. Scatter plot showing the cerium (Ce ppm) and samarium (Sm ppm) values for Moundville celt greenstones and Hillabee Metavolcanic Complex greenstones. Celt fragment A 941.3.167 (167) is labeled because it is the cluster outlier in the Moundville celt greenstone Ce-Sm graph (Fig. 21).

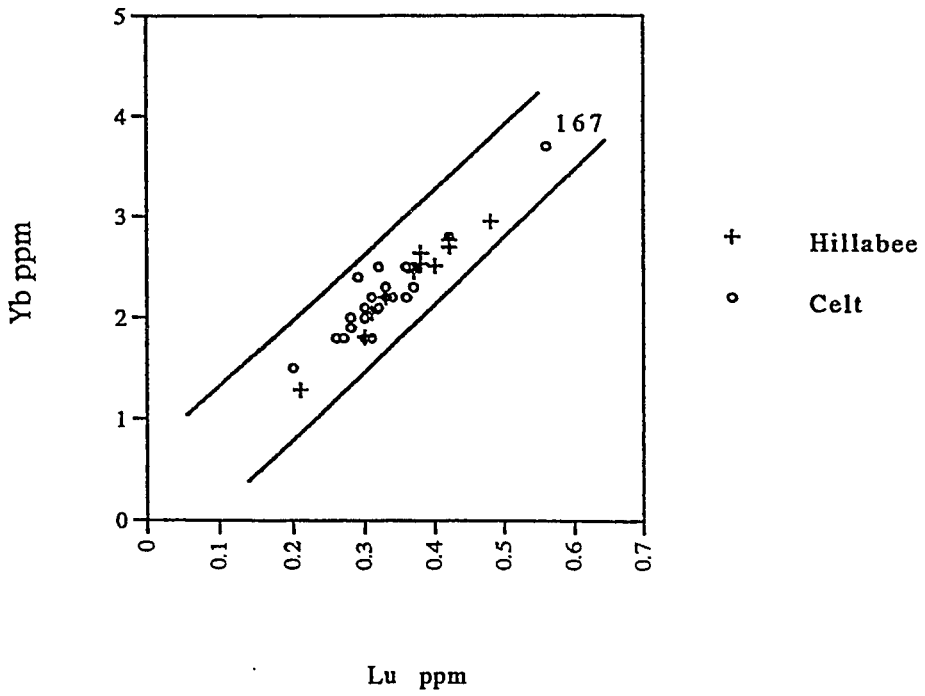

Figure 40. Scatter plot showing the lutetium (Lu ppm) and ytterbium (Yb ppm) values for Moundville celt greenstones and Hillabee Metavolcanic Complex greenstones. Celt fragment A 941.3.167 (167) is labeled because it is the cluster outlier in the Moundville celt greenstone Ce-Sm graph (Fig. 22).

Intraformational Provenance

> *Creek Pochushachi is syncopated either from pochuswuchi hachi, "hatchet creek," or from pochuswa hachi, "ax creek." The (Creek) Indian name of this stream is no longer used.*
>
> *(Read, 1984, p. 35)*

The source of greenstone for Moundville celts is the Hillabee Metavolcanic Complex. The greenstone provenance study is not complete, however, until specific localities along the 170 km-long outcrop trace of the Hillabee are identified. Once again, petrographic and chemical data provide information on intraformational provenance.

Type 1: Greenstone Celts with Fine-Grained, Relict Diabasic Texture

The following 14 celt fragments (50% of sample) selected from the Moundville collection for destructive analysis have fine-grained, relict diabasic texture (Fig. 6): A930.3.51, A931.2.106, A941.3.75, A941.3.86, A930.5.21, A941.3.107, A941.4.244, A939.2.626, A941.3.74, A930.1.52, A931.1.184, A939.2.556, A931.2.91, and A939.2.546. Five of the 62 Hillabee samples (7.9%) that were collected during field investigations also have fine-grained, relict diabasic texture (Fig. 27). Of the 5 Hillabee greenstone samples collected with relict diabasic texture, 4 came from the central part of the Hillabee, 1 came from the northern part of the Hillabee, and no examples of this textural type were located in the southern area. All 14 of the celt samples with relict diabasic texture except for celt sample A941.3.74 (74) have lime and soda values that agree well with those of greenstones from the central area; therefore, they

group together with them in the CaO-Na_2O graphs (Figs. 35 and 36). Celt fragment A941.3.74 does not group with the other members of its textural type because its lime value is too low; however, its soda value is similar to that of the other celts with relict diabasic texture and to the greenstones from the central portion of the Hillabee. Celt fragment A941.3.74 is also probably from the central portion of the Hillabee because its soda, iron, and chromium values match those of this greenstone group. The assignment of celts with fine-grained, relict diabasic texture to the central portion of the Hillabee Metavolcanic Complex is also supported by the data for iron and chromium. All of the celts with relict diabasic texture except A930.5.21 (21) have iron and chromium values that agree well with those of greenstones from the central Hillabee area; therefore, they group together with them in the Fe-Cr graphs (Figs. 37 and 38). Because the correlation between chemistry and intraformational location is better for calcium and sodium than for iron and chromium, celt fragment A930.5.21 is also probably from the central part of the Hillabee. In conclusion, all of the celts with fine-grained, relict diabasic texture are from the central portion of the Hillabee Metavolcanic Complex.

Type 2: Greenstone Celts With Fine-Grained, Massive, Granoblastic Texture

The following 10 celt fragment (35.7% of sample) selected from the Moundville collection for destructive analysis have fine-grained, massive, granoblastic texture (Fig. 8): A931.2.90, A936.1.112, A939.2.441, A940.2.289, A941.3.122, A930.2.145, A939.2.651,

A941.3.108, A941.3.167, and A941.4.250. Sixteen of the 62 Hillabee samples (25.4%) that were collected during field investigations also have fine-grained, massive, granoblastic texture (Fig. 25). Of the 16 Hillabee greenstone samples collected with granoblastic texture, 15 came from the central part of the Hillabee, 1 came from the northern part of the Hillabee, and no examples of this textural type were located in the southern area. All 10 of the celt samples with granoblastic texture have lime and soda values that agree well with those of greenstones from the central area; therefore, they group together with them on the CaO-Na_2O graphs (Figs. 35 and 36). The assignment of celts with fine-grained, massive, granoblastic texture to the central portion of the Hillabee Metavolcanic Complex is also supported by the data for iron and chromium. All of the celts with granoblastic texture except A941.3.167 (167) have iron and chromium values that agree well with those of greenstones from the central area; therefore, they group together with them on the Fe-Cr graphs (Figs. 37 and 38). Because celt fragment A941.3.167 has lime and soda values similar to greenstones from the central part of the Hillabee Metavolcanic Complex and because the correlation between chemistry and intraformational location is better for lime and soda than for iron and chromium, celt fragment A941.3.167 is probably from the central part of the Hillabee, too.

Type 3: Greenstone Celts with Medium-Grained, Granular to Crudely-Foliated Texture

The following 3 celt fragments (10.7% of sample) selected from the Moundville collection for destructive analysis have medium-

grained, granular to crudely-foliated texture (Fig. 10): A930.2.148, A930.2.149, and A941.3.126. Fourteen of the 62 Hillabee samples (22.6%) that were collected during field investigations also have medium-grained, granular to crudely-foliated texture (Fig. 26). Of the 14 Hillabee greenstone samples collected with crudely-foliated texture, 10 came from the southern part of the Hillabee, 4 came from the central part of the Hillabee, and no examples of this textural type were located in the northern area. Celt fragments A930.2.149 and A941.3.126 have lime and soda values that agree well with those of greenstones from the central area; therefore, they group together with them in the CaO-Na_2O graphs (Figs. 35 and 36). Celt fragment A930.2.148 does not group with the other members of its textural type and the greenstones from the central part of the Hillabee because its lime value is too low and its soda value is too high. Instead, the lime and soda values for celt fragment A930.2.148 more closely resemble those of greenstones from the southern portion of the Hillabee; therefore, it groups with them (Fig. 36). The assignment of celt fragments A930.2.149 and A941.3.126 to the central portion of the Hillabee Metavolcanic Complex is also supported by the data for iron and chromium because these celts have iron and chromium values that agree well with those of greenstones from the central area; therefore, they group together with them in the Fe-Cr graphs (Figs. 37 and 38). The assignment of celt fragment A930.2.148 to the southern portion of the Hillabee Metavolcanic Complex is also supported by the data for iron and chromium because its iron and chromium values agree well with those of greenstones from the southern area; therefore, it groups together with them in the Fe-Cr

graph (Fig. 38). Medium-grained greenstones like that of celt fragment A930.2.148 were observed only in the Gale Creek valley in Chilton County which is where 10 of the 14 Hillabee greenstones with granular to crudely-foliated textures were collected.

Type 4: Greenstone Celt With Relict Porphyritic Texture

Only one celt fragment, A939.2.487 (487), selected from the Moundville collection (3.6% of sample) for destructive analysis has relict porphyritic texture (Fig. 11), and no examples of this textural type were located during field investigations. Celt fragment A939.2.487 has lime and soda values that agree well with those of greenstones from the central area; therefore, it groups together with them in the CaO-Na_2O graphs (Figs. 35 and 36). The chromium value of celt fragment A939.2.487 does not agree well with the greenstones from the central part of the Hillabee; therefore, it does not group together with them in the Fe-Cr graphs (Figs. 37 and 38). Celt fragment A939.2.487 is probably from the central part of the Hillabee because its values for lime, soda, and iron agree well with those of greenstones from the central portion of the Hillabee.

Conclusion

The main sources of greenstone used by the Moundville Indians are located in the central portion of the Hillabee Metavolcanic Complex. The Gale Creek valley outcrops located in the southern portion of the Hillabee Metavolcanic Complex are the sources of a small amount of Moundville greenstone, and no greenstones were used from the northern section of the Hillabee.

This conclusion is supported by mineralogical, petrographic, and chemical data. This conclusion is also supported by the fact that the central part of the Hillabee contains the largest amount of ax-stone grade greenstone. All of the localities in the northern and southern areas combined do not come close to offering the opportunities for greenstone exploitation that the central part of the Hillabee offers with respect to the abundance of readily-available material.

Within the central portion of the Hillabee Metavolcanic Complex, most of the celt-grade greenstone outcrops occur in the vicinity of the confluence of the east and west forks of Hatchet Creek located in the uppermost part of the Hatchet Creek valley. Moundville Indians made practically all of their celts (hatchets) out of greenstones that came from outcrops located in the Hatchet Creek valley. Although Moundville Indians had vanished prior to the time of contact with Europeans, the upper portions of the Hatchet Creek valley were occupied by Creek Indians during early historic times (Read, 1984). Historic documents record that the name *Hatchet Creek* was derived from a translation of the Creek Indian word *Pochushachi* which is short for *Pochuswuchi Hachi* (Hatchet Creek) or *Pochusma Hachi* (Ax Creek). This information was provided by the inhabitants of the Creek Indian village named *Pochushatchee* which was located in the Hatchet Creek valley at the time when the area was being settled (Read, 1984). The upper reaches of the Hatchet Creek valley are drained by the east and west forks of Hatchet Creek which are separated by a greenstone divide composed of erosionally-resistant Hillabee greenstone. Evidently, Hatchet Creek owes its

name to the prehistoric Indians who for centuries exploited its greenstone outcrops for celt stone par excellence. In summary, the place name *Hatchet Creek* is itself a line of ethnographic evidence that supports the conclusion that localities the upper parts of the Hatchet Creek valley were the major sources of celt stone for prehistoric Indians.

No evidence of prehistoric quarrying or mining activity was found anywhere along the strike of the Hillabee greenstone; however, small pits (Fig. 41) and well-like openings were frequently encountered that probably date to historic times (Dunning, 1960). Quarrying and mining would not have been necessary to obtain celt blanks since erosion produces boulders of mechanically-competent greenstone at low waterfalls and rapids (Figs. 28 and 29). Celt blanks were, therefore, properly-proportioned boulders obtained at stream sites where downcutting has been effectively halted by erosionally-resistant deposits of greenstone. Removed from channel deposits, greenstone boulders were then reduced into celts by chipping, pecking, and abrasion. The outcrops of Hillabee greenstone that are mechanically competent enough to serve as celt stone are incredibly tough. Typically, blows with a sledgehammer are deflected and hammer falls ring like a bell. It would have been very difficult to mine the Hillabee greenstone without the benefit of steel tools which the prehistoric Indians of the Southeastern United States did not possess.

Figure 41. Small pit with spoils near Gale Creek , Chilton County, Alabama. The pit is approximately 4 m in length by 3 m in width.

Because the greenstone outcrops of the Hillabee Metavolcanic Complex are eroding, another possible source of greenstone is from river bed downstream from the sources. Hatchet Creek empties into the Coosa River which is a tributary of the Alabama River. Gale

Creek empties into Mulberry Creek which is also a tributary of the Alabama River. Therefore, it is possible that greenstone boulders could have been obtained from the Alabama River or any of its tributaries that cross Hillabee lithologies. No greenstone boulders occur in the Black Warrior River because its drainage basin is underlain by Coastal Plain sedimentary rocks, and sedimentary rocks of the Appalachian Plateau and the Valley-and-Ridge Province (Figs. 23 and 42).

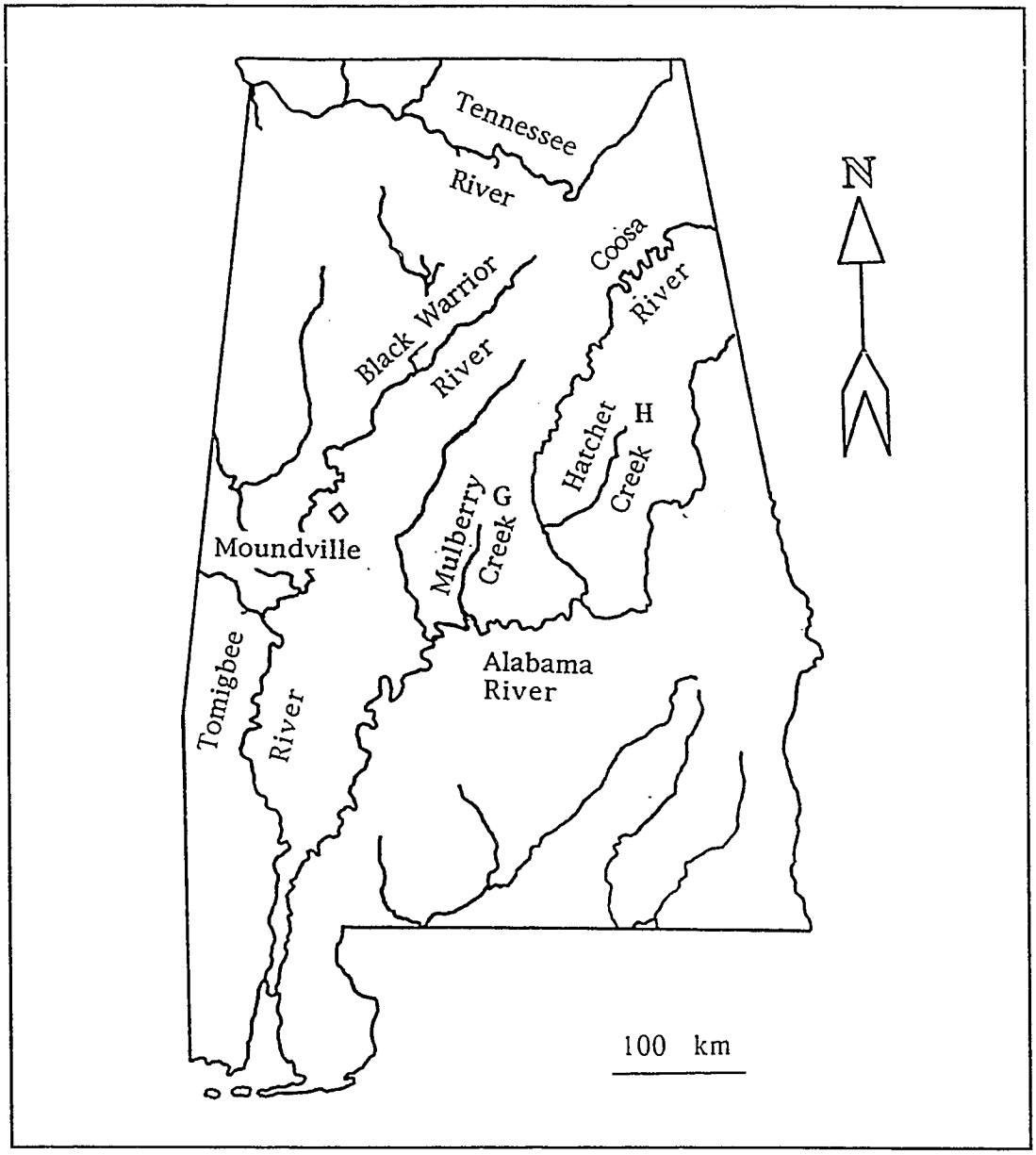

Figure 42. Map of Alabama showing the locations of the Black Warrior River, Hatchet Creek, and Mulberry Creek. Gale Creek empties into the upper part of Mulberry Creek from the northeast but its course is not identified because it is too small. The locations of ax-grade Hillabee greenstone outcrops are shown for Gale Creek (G) and Hatchet Creek (H).

CHAPTER 5

SPECULATIONS ON THE NATURE OF GREENSTONE PROCUREMENT AND EXCHANGE

Chapter Five will conclude this investigation on the petrography and provenance of Moundville greenstone artifacts with speculations on the nature of greenstone procurement, and with comments regarding exchange-system nomenclature used in archaeology as it relates to locally-available and nonlocal materials.

Most of the lithologies utilized by the prehistoric Indians who occupied the Moundville site during Mississippian times occur in geologic deposits within a distance of 150 km of the Moundville site (Pallister, 1955). The lithic materials not available from within a distance of 150 km of the Moundville site include indurated claystone (e.g., catlinite) and native copper from the Great Lakes area; and chert, cerussite, and galena from the lead-zinc ore deposits of the upper Mississippi valley (Goad, 1978; Walthall, 1981; Gunderson, 1993). The presence of rocks and minerals from distant sources in the artifact inventory of the Moundville collection indicates that some sort of *exchange system* was in operation at Moundville during the Mississippian period; however, it does not appear necessary to invoke such mechanisms to account for the vast

majority of lithic artifact materials recovered at the Moundville site (Welch, 1986).

Local and Nonlocal Materials, and Exchange Systems

> *Tungei informants (Papua New Guinea highlands) attribute their success in obtaining stone from (greenstone) axe quarries to ritual purity and the correct axe-making magic. Quarrying was perceived to be dangerous and, as in warfare and other hazardous activities, the main theme of the quarrymen's beliefs was segregation from women and all 'female' things.*
>
> *(Burton, 1984, p. 240)*

The terms *local* and *nonlocal* are usually used to describe the wide range of materials that traveled various distances into a specified territory or polity. Harbottle (1982, p. 16) states, "*Local* is generally taken to mean near or associated with the production center. *Imported* (nonlocal) is usually everything else, at least operatively." With respect to Moundville lithic artifacts, Welch (1986) and others consider artifacts composed of lithologies from the Piedmont of Alabama (e.g., greenstone) and materials from the Great Lakes area (e.g., catlinite, native copper) to all be *nonlocal* materials. Obviously, researchers do not consider Piedmont greenstone and native copper from the Great Lakes region to be equivalent, but general terms such as *local* and *nonlocal* do not differentiate between the two and, therefore, do not adequately describe the procurement situation. The use of the terms *local* and *nonlocal* also implies that the geographic locations of the quarry sites and production centers, and boundaries of the polity exploiting the raw material are known.

The expression *long-distance exchange* is also used when discussing procurement of *nonlocal* artifact materials by prehistoric cultures. When discussing the procurement of *nonlocal* materials (i.e., native copper and marine shell) among Mississippian chiefdoms, Goad (1978) considers both native copper and marine shell to have been acquired by means of *long-distance exchange*. The actual distance, difficulty and limitations in transportation, and the number of transactions are not indicated by such terms, nor has the *exchanging* of items been proven to have occurred. Furthermore, the movement of a relatively common, low-density substance like marine shell several hundred kilometers from the south or east between similar cultures can not be equated to the movement of rare and dense substances like native copper and galena from northern sources more than 1000 km away. As before, researchers do not consider marine shell obtained from nearby coastal sources and native copper from the Great Lakes region to be equivalent, and the general term *exchange system* also does not adequately describe the procurement situation.

The concepts embodied in the terms *local* and *nonlocal*, and the phrase *long-distance exchange* could be better conveyed if lithic sources were considered with respect to proximity to the site, availability of the material (rare or plentiful), and control of access to the resource (Stone, 1994). The following categories can be defined when proximity, availability, and control are considered:

1) Within-Polity Procurement. In the simplest of cases, the lithic resource is close to the site, the resource is plentiful, and it is under the undisputed control of the polity. With respect to Moundville artifacts, substances that are in this category include kaolinite-illite clays, silt- and sandstones, some varieties of chert, quartzite, hematite, and limonite. These materials would have been available upon demand and easily procured since geologic sources are located close to the Moundville site. The Moundville Indians probably got these materials directly from nearby sources with no risk, relatively little expense of time and energy, and without invoking transferal mechanisms; therefore, this is the simplest means of procuring lithic materials.

2) Procurement Expedition. In this case, the lithic resource is in the vicinity of the site, it is plentiful, but the geologic deposit is located in a buffer zone (no-man's land) that separates neighboring polities. Lithic materials found at Moundville that possibly belong in this category are amphibolite, basalt/diabase, graphite, granite, greenstone, metadiorite/diorite, muscovite (sheet mica), shale/slate, and steatite (Pallister, 1955). Although resources are plentiful, procurement is made difficult due to the lack of an allied-resident population near the lithic resource. Lithic procurement would be achieved by expeditions into the buffer zone to collect lithic materials. Overland expeditions into the Piedmont of Alabama undertaken by Indians of the Black Warrior River valley would have required a great deal of time and expenditure of manpower. Since these expeditions would not be assured of success, supply shortfalls

and the potential of periodic shortages would inflate the value and importance of the lithic material, possibly require periodic recycling of heavily-used items or substitutions of less desirable materials, and thus create administrative crises. Procurement expeditions into buffer zones might also create confrontations between neighboring polities that might otherwise not have occurred, thereby creating military crises.

3) Simple Transferal. In this case, the lithic resource is in the vicinity of the site, it is plentiful, but it is under the control of an independent ally. Lithic materials of Moundville that could be placed in this category include native asphalt, some varieties of chert, glauconite, limestone, psilomelane/wad, and salt. These materials were relatively easy to acquire and plentiful. A mechanism for procurement (e.g., trade, tribute extraction) and transferal (e.g., portage, canoe cargo) would have been required; therefore, there would be a greater expense of time and energy expended on the procurement of these types of materials, possibly a debt or obligation created, or an exchange of goods might have occurred.

4) Complex Transferal. In this instance, the material does not occur near the site and/or it is not plentiful, it is in great demand, and acquisition may require transferal from distant sources. Lithic artifacts from Moundville that can be placed in this category are amethyst, catlinite, native copper, cerussite and galena, and some varieties of chert. These materials would be of greatest value with respect to time and energy expended in procurement, and because

supplies may be frequently curtailed due to breakdowns in the transferal mechanisms. Ownership of these materials would probably be indicators of status, wealth, and power, or their use may be restricted to applications of ceremonial significance.

Within-polity procurement, procurement expeditions, and simple and complex transferal better define procurement situations, and alleviate the ambiguities and implications caused by the use of terms such as *local* and *nonlocal goods*, and *long-distance exchange*. With respect to Moundville, within-polity procurement, procurement expeditions, and simple and complex transferal of lithic materials all occurred. Apparently the Moundville Indians and the Indians to the north, south, and west of the territory controlled by the Moundville polity engaged in simple transferal. This is indicated by the presence of Moundville ceramics in sites that border Moundville to the north, south, and west, and the presence of lithologies in the artifact inventory of the Moundville collection from these areas. Access to sources of lithic materials to the east of the Moundville site was probably by direct procurement only and not by the transferal of material from the Indians of northeastern Alabama and northwestern Georgia (Welch, 1986; Harry Holstein, personal communication, 1994). The lack of settlements in the buffer zone that separates Moundville and its neighbors to the east, and the lack of characteristic ceramic types in artifact inventories support this conclusion. The lack of transferal interactions between the Indians of Moundville and the Indians of northeastern Alabama and northwestern Georgia is also supported by celt greenstone

compositions. Moundville celts are composed of Hillabee metabasite lithologies most of which were obtained from outcrops exposed in the upper portions of the Hatchet Creek valley. Indians that occupied northeastern Alabama and northwestern Georgia during Mississippian times not only used Hillabee metabasite for ax bits, but they also used phyllite (metasiltstone) from the Heflin Formation (Vaughn, 1993). None of the Moundville greenstone artifacts are composed of metasiltstone or phyllite. The lack of Heflin metasiltstone celts in the Moundville celt inventory indicates that the Indians of northeastern Alabama were not supplying celts to Moundville Indians.

Prestige Goods Economy and Complex Transfer: An Assessment of Lithic Procurement for Moundville

> *Ground-stone artifacts constitute a broad class of formal tools with relatively long use lives in the lithic technology of many societies, both modern and prehistoric...The impact of raw-material scarcity and transport cost for this class of tools has not been considered systematically.* *(Stone, 1994, p. 680)*

An evaluation of the use of native copper indicates that most of it was used as a precious metal in jewelry (e.g., ear spool covers) and regalia (e.g., celts). The manner in which native copper was utilized at Moundville suggests that it was very rare, valuable, and reserved for special uses. This conclusion is supported by the low frequency and small dimensions of native copper artifacts found at Moundville.

Based on the inventory of lithologies used in lithic artifacts from Moundville, the small amount of copper recovered does not necessarily suggest that a prestige goods economy existed (Welch, 1986), nor that there was a sustained flow into Moundville of this material from distant sources. This assessment of the Moundville economy based on the lithic artifact inventory is also supported when the small amount of other goods composed of lithologies from distant sources (e.g., catlinite, galena) and the small number of different types of lithologies obtained through complex transferal are taken into consideration.

It appears that these exotic materials, like native copper, trickled into Moundville over the course of its 500 year existence, and they were probably cherished items that were hoarded and greatly coveted. Based on the small volume of copper artifacts discovered at Moundville, the procurement of a single copper artifact probably represented a major event in the life of a high-status individual and was not an everyday, casual occurrence. The scarcity of copper items and the abundance of items obtained from within or near Moundville suggest that Moundville was not part of a well-organized, regional *exchange network*. Instead, Moundville appears to have been a relatively independent polity whose lithic artifact inventory suggests an economy geared more towards utility than prestige. Most of the lithic artifacts in the Moundville collection were used for utilitarian purposes (e.g., grinding corn, woodworking), and were obtained from local or nearby sources through within-polity procurement, simple transfer, or procurement expeditions. These

utilitarian items are composed of the lithic staples that the Indians of the Moundville polity depended upon for tools and containers. Their dominance in the artifact inventory suggests that they were produced in quantity and owned by many members of Moundville society. The cottage industry within the Moundville polity that produced utilitarian goods (e.g., ceramic containers, greenstone celts) did so out of readily available, abundant raw materials. These locally manufactured goods were produced in sufficient quantities to meet local demands, negating the need to import most utilitarian items.

Greenstone Procurement in Premetallurgical Societies: The Moundville Site

> *It would be wrong to think that any man could have personally filed sharp more than a handful of (greenstone) axes in one year. ... If...200 men made 10 axes each every 5 years...production would have run at 40,000 axes per century.* *(Burton, 1984, p. 244)*

In economic geology, placer deposits are alluvial deposits that contain minerals (e.g., gold, platinum, cassiterite) of economic importance. Typically, the minerals of economic importance in placer deposits are mechanically competent, chemically stable, dense minerals that are concentrated by hydraulic processes within stream channels. These lag deposits are easily exploited and also quickly depleted. When placer deposits are depleted, then the original geologic sources (mother lodes) are exploited with greater expenditures of time and effort. As long as adequate supplies of the mineral can be secured by placer mining, little hard rock mining will

take place. Tough greenstones like those of the Hillabee Metavolcanic Complex are very difficult to mine without the advantage afforded by steel tools and explosives; however, it was possible for pre-metallurgical cultures to mine ax-grade greenstone deposits (Burton, 1984; Jones, 1984; McBryde, 1984).

If a premetallurgical culture exploited locally available greenstones, then greenstone quarries probably began when alluvial deposits failed to provide enough ax blanks to meet their needs. The eroding geologic deposit responsible for generating the greenstone boulders would then be mined with little more than wood wedges, mauls, and hammerstones (Burton, 1984). Superficial mining of cliff faces produces small excavations associated with spoils (Jones, 1984; McBryde, 1984). If mining continues, pits and spoils will coalesce forming a quarry floored with rock debitage (Burton, 1984). This trajectory is apparently the path along which quarry development has proceeded in other premetallurgical cultures exploiting greenstone for axes (Burton, 1984; Jones, 1984; McBryde, 1984).

Evidence of prehistoric mining in stream channels is not readily preserved due to erosion of banks and deposition in floodplains; however, hardrock quarrying is more likely to modify the landscape in a lasting and observable manner. No such modifications of the landscape in the Hatchet Creek valley or the Gale Creek valley were observed. Since ample celt blanks were available in properly-proportioned boulders, it seems likely that the Indians exploiting Hatchet Creek and Gale Creek greenstones simply gathered boulders

out of stream channels. Blanks were probably shaped into finished celts over the course of weeks or months; therefore, it is unlikely that the mining sites were also the celt production centers. Boulders were probably carried from the sources of greenstone in the Hillabee Metavolcanic Complex to residences in the Black Warrior River valley where they were manufactured into finished products. From farmsteads and hamlets dispersed along the Black Warrior River valley, hafted celts were supplied to community leaders who transported them to the Moundville site as finished utilitarian goods where they were used primarily for woodworking purposes and as weapons.

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APPENDIX A

CLASSIFICATION OF GREENSTONE ARTIFACTS FROM MOUNDVILLE

A total of 568 greenstone artifacts from the following Moundville site collections (Alabama Museum of Natural History) were examined: excavation west of Mound R (A930.1), excavation of the Rhodes site (A930.2), excavation southwest of Mound M (A930.3), excavation southeast of Mound H (A930.4), excavation north of Mound G (A930.5), excavation east of Mound E (A931.1), excavation north of Mound R (A931.2), excavation south of Mound D (A932.3), excavation north of Mound E (A932.4), excavation west of Mound P (A936.1), roadway construction excavation (A939.2), excavation of Mound W (A940.2), surface collection (A941.3), miscellaneous collection (A941.4). This constitutes all of the greenstone artifacts from these site collections and the bulk of the greenstone artifacts from the Moundville collection.

The following ten artifacts originally classified as *greenstone* are not composed of metabasite:

diabase
- A940.2.165 - ax fragment

porphyroblastic gneiss
- A930.3.75 - celt bit
- A931.2.115 - celt bit (burial 1127)

granite/diorite
- A939.2.442 - celt poll
- A940.2.296 - celt fragment
- A941.3.120 - celt fragment
- A941.3.147 - celt poll
- A941.3.170 - celt
- A941.3.192 - ax fragment
- A941.3.216 - celt

Of the 568 greenstone artifacts examined, 166 were too deeply weathered or stained to classify using nondestructive observations

on colors and rock textures, and 130 were too small (nc = not classified). The remaining 272 greenstone artifacts were placed into the following 6 categories based on nondestructive observations on colors and rock textures:

Type A - fine-grained, light to dark greenish- to bluish-gray, massive metabasite with dark veins and zones

Type B - medium-grained, greenish-gray to gray mottled, massive to slightly foliated metabasite with distinct to indistinct, equigranular to slightly elongate grains

Type C - fine-grained, massive, speckled, greenish-gray metabasite with dark and light colored veins

Type D - fine- to medium-grained , bluish-gray to grayish-black metabasite with medium gray bands delineating foliation, and dark and light colored veins

Type E - fine-grained, massive grayish-black metabasite

Type F - metabasite with relict phenocrysts that produce a distinctly bimodal grain-size assemblage.

1. Greenstone field specimens from west of Mound R (11 total): A930.1.50, celt, Type B; A930.1.51,celt bit, Type A; A930.1.52, celt, Type D; A930.1.53, chip with polish, Type B; A930.1.54, celt fragment, Type D; A930.1.55, celt fragment, Type D; A930.1.56, celt, Type D; A930.1.57, celt bit (burial 1045), Type A; A930.1.58, celt fragment, Type A; A930.1.59, celt bit, nc; A930.1.61, celt bit, Type D.

2. Greenstone field specimens from Rhodes site (25 total): A930.2.139, celt, Type B; A930.2.140, celt, Type A; A930.2.141, miniature monolithic ax pendant, Type D; A930.2.142, chip with polish, Type A; A930.2.143, celt bit, Type A; A930.2.144, celt fragment, nc; A930.2.145, celt poll, Type B; A930.2.146, chip

with polish (burial 2017), Type B; A930.2.147, celt fragment, nc; A930.2.148, celt bit, Type B; A930.2.149, celt poll, Type C; A930.2.150, celt poll, Type A; A930.2.151, celt, Type A; A930.2.152, celt fragment, nc; A930.2.153, celt, Type A; A930.2.155, celt poll, Type B; A930.2.156, celt poll, nc; A930.2.157, celt bit, Type D; A930.2.158, celt fragment, Type A; A930.2.159, celt bit, Type A; A930.2.160, celt bit, Type A; A930.2.161, celt bit, nc; A930.2.162, celt fragment, nc; A930.2.163, celt fragment, nc; A930.2.300, celt fragment, Type A.

3. Greenstone field specimens from southwest of Mound M (11 total):
A930.3.70, celt, Type E; A930.3.71, celt, Type A; A930.3.72, celt (burial 990), Type B; A930.3.73, celt bit, Type A; A930.3.74, celt bit, Type D; A930.3.75, celt bit, nc; A930.3.76, chip with polish, nc; A930.3.77, celt fragment, nc; A930.3.78, celt bit, nc; A930.3.79, celt bit, Type A; A930.3.80, celt fragment (burial 1147), Type B.

4. Greenstone field specimens from southeast of Mound H(5 total); A930.4.30, celt, Type E; A930.4.32, chip with polish, Type A; A930.4.33, celt fragment, Type D; A930.4.34, celt fragment, nc; A930.4.35, celt poll, Type B.

5. Greenstone field specimens from north of Mound G (4 total): A930.5.17, celt bit, Type A; A930.5.19, celt, Type A; A930.5.20, celt bit, Type D; A930.5.21, celt poll, Type B.

6. Greenstone field specimens from east of Mound E (17 total): A931.1.170, celt (burial 1305), Type D; A931.1.172, celt, Type A; A931.1.173, celt, Type A; A 931.1.176, celt (burial 1181), Type B; A931.1.178, celt poll, Type B; A931.1.179, celt poll, nc;

A931.1.180, celt (burial 1305), Type A; A931.1.181, celt bit (burial 1328), Type A; A931.1.183, celt bit, Type C; A931.1.184, celt poll, Type D; A931.1.185, celt bit, Type D; A931.1.186, sawed slab, Type D; A931.1.187, celt bit, Type A; A931.1.193, discoidal, Type B; A931.1.194, discoidal (burial 1276B), Type A; A931.1.200, discoidal, Type A; A931.1.240, celt, Type D.

7. Greenstone field specimens from north of Mound R (36 total): A931.2.87, celt fragment, nc; A931.2.88, celt, Type A; A931.2.89, celt fragment (burial 1096), Type D; A931.2.90, celt poll (burial 1083), Type A; A931.2.91, celt fragment (burial 1083), Type E; A931.2.93, celt poll, Type B; A931.2.94, celt fragment (burial 1101), nc; A931.2.95, celt fragment (burial 1101), nc; A931.2.96, sawed slab, Type A; A931.2.97, celt poll, nc; A931.2.98, celt fragment, nc; A931.2.99, sawed celt fragment, Type A; A931.2.100, celt bit, Type E; A931.2.101, celt bit, Type D; A931.2.102, celt bit, nc; A931.2.103, celt bit, nc; A931.2.104, celt fragment, nc; A931.2.105, celt bit, nc; A931.2.106, celt poll, Type A; A931.2.107, celt fragment, Type A; A931.2.108, celt bit, nc; A931.2.109, celt bit, nc; A931.2.110, celt bit, nc; A931.2.111, celt, Type D; A931.2.112, celt fragment, nc; A931.2.113, celt poll, nc; A931.2.114, celt poll, nc; A931.2.115, celt bit (burial 1127), nc; A931.2.116, celt bit (burial 1127), nc; A931.2.117, celt poll (burial 1127), nc; A931.2.118, celt bit (burial 1127), nc; A931.2.119, celt bit (burial 1127), Type D; A931.2.120, celt fragment (burial 1127), nc; A931.2.121, celt fragment, nc; A931.2.122, celt poll, nc; A931.2.123, celt bit, Type C.

8. Greenstone field specimens from south of Mound D (21 total): A932.3.53, chip with polish, nc; A932.3.257, celt fragment, Type B; A932.3.259, chip with polish, Type E; A932.3.260, celt poll, Type A; A932.3.261, celt poll, Type A; A932.3.263, celt, Type B; A932.3.264, celt fragment, nc; A932.3.179, reworked celt, nc;

A932.3.266, discoidal, Type A; A932.3.288, celt bit, Type B; A932.3.268, celt fragment, nc; A932.3.269, celt fragment, nc; A932.3.270, celt, nc; A932.3.271, celt, Type E; A932.3.272, celt (burial 1520), Type D; A932.3.273, celt, Type B; A932.3.274, celt, Type A; A932.3.275, celt bit, nc; A932.3.276, polished rock slab fragment, nc; A932.3.277, celt, Type D; A932.3.278, celt bit, nc.

9. Greenstone field specimens from north of Mound E (11 total):
A932.4.138, celt (burial 73), Type A; A932.4.139, rock fragment with saw marks, nc; A932.4.140, celt, Type B; A932.4.141, celt bit, Type C; A932.4.142, chip with polish, nc; A932.4.143, celt fragment, nc; A932.4.146, chip with polish, nc; A932.4.147, polished rock slab fragment, Type A; A932.4.154, discoidal, nc; A932.4.409, chip with polish, nc; A932.4.410, reworked celt fragment, nc.

10. Greenstone field specimens from west of Mound P (3 total):
A936.1.5, celt bit, nc; A936.1.111, celt fragment (burial 2421), nc; A936.1.112, celt fragment, Type A.

11. Greenstone field specimens from roadway construction excavation (225 total):
A939.2.437, celt bit (burial 2662), Type A; A939.2.440, ax fragment, Type B; A939.2.441, celt poll, Type A; A939.2.442, celt poll, nc; A939.2.443, celt fragment, Type B; A939.2.444, ax fragment, nc; A939.2.445, celt bit, Type A; A939.2.446, celt fragment, Type E; A939.2.447, chip with polish, nc; A939.2.448, chip celt fragment, nc; A939.2.449, celt bit, Type A; A939.2.450, chip with polish, nc; A939.2.451, celt fragment, nc; A939.2.452, chip with polish, nc; A 939.2.453, chip with polish, nc; A939.2.454, chip with polish, nc; A939.2.455, chip with polish, nc; A939.2.456, celt fragment, nc; A939.2.457, celt poll, nc; A939.2.459, chip with polish, nc; A939.2.460, celt fragment, nc;

A939.2.461, chip with polish, nc; A939.2.462, chip with polish, nc; A939.2.463, celt fragment, nc; A939.2.464, celt fragment, nc; A939.2.465, chip with polish, nc; A939.2.466,celt fragment,nc; A939.2.467, chip with polish, nc; A939.2.468, chip with polish, nc; A939.2.469, celt bit, Type A; A939.2.470, celt fragment, Type A; A939.2.471, celt fragment, nc; A939.2.472, celt fragment, nc; A939.2.473, celt fragment, nc; A939.2.474, celt fragment, nc; A939.2.475, chip with polish, nc; A939.2.476, chip with polish, nc; A939.2.477, celt bit, Type B; A939.2.478, chip with polish, nc; A939.2.479, celt fragment, Type B; A939.2.480, chip with polish, nc; A939.2.481, celt bit, nc; A939.2.482, chip with polish, nc; A939.2.483, celt poll, Type A; A939.2.484, celt fragment, nc; A939.2.485, celt fragment, Type A; A939.2.487, celt poll, Type F; A939.2.488, chip with polish, nc; A939.2.489, chip with polish, nc; A939.2.490, chip with polish, nc; A939.2.491, chip with polish, nc; A939.2.493, celt fragment, nc; A939.2.494, chip with polish, nc; A939.2.495, chip with polish, nc; A939.2.496, celt poll, Type A; A939.2.497, chip with polish, nc; A939.2.498, chip with polish, nc; A939.2.499, chip with polish, nc; A939.2.500, celt fragment, nc; A939.2.501, chip with polish, nc; A939.2.502, celt bit, Type A; A939.2.503, celt fragment, nc; A939.2.504, celt fragment, Type D; A939.2.505, celt poll, Type D; A939.2.506, celt bit, Type B; A939.2.507, discoidal, Type A; A939.2.508, chip with polish, nc; A939.2.509, celt fragment, nc; A939.2.510, chip with polish, nc; A939.2.511, chip with polish, nc; A939.2.512, celt bit, nc; A939.2.513, celt bit, Type B; A939.2.514, chip with polish, nc; A939.2.515, celt poll, nc; A939.2.516, chip with polish, nc; A939.2.517, celt fragment, Type E; A939.2.519, celt poll, Type B; A939.2.520, chip with polish, nc; A939.2.521, chip with polish, nc; A939.2.522, chip with polish, nc; A939.2.523, chip with polish, nc; A939.2.524, chip with polish, nc; A939.2.525, chip with polish, nc; A939.2.526, chip with polish, nc; A939.2.528, celt fragment, nc; A939.2.529, celt bit, Type B; A939.2.530, celt fragment, Type C; A939.2.531, celt poll, Type A; A939.2.532, celt fragment, Type E; A939.2.533, celt fragment, Type F;

A939.2.534, celt preform, nc; A939.2.536, celt fragment, Type C; A939.2.537, chip with polish, nc; A939.2.538, chip with polish, nc; A939.2.539, chip with polish, nc; A939.2.540, chip with polish, nc; A939.2.541, chip with polish, nc; A939.2.542, chip with polish, nc; A939.2.543, chip with polish, nc; A939.2.544, celt fragment, nc; A939.2.546, celt fragment, Type E; A939.2.549, celt fragment, nc; A939.2.550, celt fragment, nc; A939.2.551, chip with polish, nc; A939.2.552, chip with polish, nc; A939.2.553, chip with polish, nc; A939.2.554, celt fragment, nc; A939.2.556, celt fragment, Type D; A939.2.557, celt fragment, nc; A939.2.558, celt fragment, nc; A939.2.559, celt fragment, Type E; A939.2.560, celt fragment, Type D; A939.2.561, celt fragment, Type B; A939.2.562, celt fragment, nc; A939.2.563, chip with polish, nc; A939.2.564, chip with polish, nc; A939.2.565, celt bit, nc; A939.2.566, chip with polish, nc; A939.2.567, celt fragment, nc; A939.2.568, celt bit, nc; A939.2.569, chip with polish, nc; A939.2.570, chip with polish, nc; A 939.2.571, celt poll, Type B; A939.2.572, chip with polish, nc; A939.2.573, chip with polish, nc; A939.2.574, celt fragment, Type D; A939.2.575, celt fragment, Type A; A939.2.576, celt fragment, nc; A939.2.577, ax fragment, Type A; A939.2.578, celt fragment, nc; A939.2.579, celt bit, nc; A939.2.580, chip with polish, nc; A939.2.581, celt fragment, nc; A939.2.582, chip with polish, nc; A939.2.583, celt fragment, nc; A939.2.584, chip with polish, nc; A939.2.585, celt poll, Type E; A939.2.586, chip with polish, nc; A939.2.587, chip with polish, nc; A939.2.588, celt poll, Type A; A939.2.589, chip with polish, nc; A939.2.590, chip with polish, nc; A939.2.593, celt fragment, Type A; A939.2.595, chip with polish, nc; A939.2.596, chip with polish, nc; A939.2.597, celt fragment, nc; A939.2.598, chip with polish, nc; A939.2.599, celt poll, nc; A 939.2.600, spatulate fragment, Type D; A939.2.601, celt fragment, nc; A 939.2.602, chip with polish, nc; A939.2.603, chip with polish, nc; A939.2.604, celt fragment, nc; A939.2.605, celt, nc; A939.2.606, celt, Type B; A939.2.607, celt, Type B; A939.2.608, celt fragment, Type A; A939.2.609, celt fragment, Type D; A939.2.610, chip with polish,

nc; A939.2.611, celt fragment, nc; A939.2.612, celt fragment, nc; A939.2.613, chip with polish, nc; A939.2.614, chip with polish, nc; A939.2.615, chip with polish, nc; A939.2.616, celt poll, Type E; A939.2.617, chip with polish, nc; A939.2.618, chip with polish, nc; A939.2.619, chip with polish, nc; A939.2.620, celt bit, Type C; A939.2.621, celt fragment, Type A; A939.2.622, celt bit, Type C; A939.2.623, celt fragment, Type A; A939.2.624, chip with polish, nc; A939.2.626, celt fragment, nc; A939.2.627, celt bit, nc; A939.2.628, chip with polish, nc; A939.2.630, chip with polish, nc; A939.2.631, celt fragment, nc; A939.2.632, celt bit, nc; A939.2.633, chip with polish, nc; A939.2.634, chip with polish, nc; A939.2.635, chip with polish, nc; A939.2.636, chip with polish, nc; A939.2.637, chip with polish, nc; A939.2.638, chip with polish, nc; A939.2.639, chip with polish, Type E; A939.2.640, celt bit, Type A; A939.2.641, chip with polish, nc; A939.2.644, chip with polish, Type A; A939.2.645, chip with polish, nc; A939.2.646, chip with polish, nc; A939.2.647, celt bit, nc; A939.2.648, celt poll, Type A; A939.2.649, celt bit, Type C; A939.2.650, chip with polish, nc; A939.2.651, celt fragment, Type B; A939.2.652, celt bit, Type B; A939.2.653, celt fragment, nc; A939.2.654, celt fragment, Type B; A939.2.655, chip with polish, Type B; A939.2.656, celt fragment, Type A; A939.2.657, celt poll, Type A; A939.2.658, celt fragment, nc; A939.2.703, celt bit, nc; A939.2.750, pin, nc; A939.2.753, celt, Type A; A939.2.755, celt fragment, Type D; A939.2.756, celt, Type A; A939.2.757, spatulate, Type B; A939.2.758, celt, Type A; A939.2.759, celt, Type A; A939.2.760, celt fragment, Type E; A939.2.761, ax, Type B; A939.2.762, celt fragment, Type A; A939.2.763, celt, Type C; A939.2.764, celt fragment, nc; A939.2.765, celt, Type B; A939.2.766, celt, Type D; A939.2.767, celt, Type D; A939.2.769, celt fragment, nc; A939.2.877, chip with polish, Type B; A939.2.909, chip with polish, nc; A939.2.912, celt fragment, Type C.

12. Greenstone field specimens from Mound W (19 total):
A940.2.164, celt poll, nc; A940.2.165, ax fragment, nc; A940.2.166, celt bit, Type B; A940.2.167, spatulate, Type F; A940.2.169, celt poll, nc; A940.2.171, celt bit, Type E; A940.2.172, celt bit, Type B; A940.2.173, celt fragment, Type B; A940.2.175, celt fragment, Type A; A940.2.179, discoidal, Type A; A940.2.289, celt fragment, Type A; A940.2.290, celt fragment, Type D; A940.2.291, celt fragment, Type D; A940.2.292, celt, Type A; A940.2.293, celt fragment, nc; A940.2.294, celt bit, Type D; A940.2.295, celt, Type B; A940.2.296, celt fragment, nc; A940.2.297, celt fragment, Type C.

13. Greenstone field specimens from the surface collection (134 total):
A941.3.70, celt, Type C; A941.3.72, celt fragment, nc; A941.3.73, celt poll, Type B; A941.3.74, celt poll, Type C; A941.3.75, celt poll, Type A; A941.3.76, celt poll, nc; A941.3.77, celt fragment, nc; A941.3.79, chip with polish, nc; A941.3.80, chip with polish, nc; A941.3.81, chip with polish, nc; A941.3.82, celt fragment, Type E; A941.3.83, celt bit, nc; A941.3.84, celt fragment, nc; A941.3.85, celt fragment, nc; A941.3.86, celt bit, nc; A941.3.87, celt fragment, nc; A941.3.88, chip with polish, nc; A941.3.89, chip with polish, nc; A941.3.91, celt fragment, Type D; A941.3.92, celt bit, nc; A941.3.93, chip with polish, nc; A941.3.94, chip with polish, nc; A941.3.95, chip with polish, nc; A941.3.96, chip with polish, nc; A941.3.97, chip with polish, nc; A941.3.98, chip with polish, nc; A941.3.99, chip with polish, nc; A941.3.100, chip with polish, nc; A941.3.101, celt bit, nc; A941.3.102, celt fragment, nc; A941.3.103, celt poll, nc; A941.3.104, celt fragment, Type A; A 941.3.105, celt fragment, nc; A941.3.106, chip with polish, nc; A941.3.107, celt fragment, nc; A941.3.108, celt bit, nc; A941.3.109, celt bit, nc; A941.3.110, celt fragment, Type E; A941.3.111, celt fragment, nc; A941.3.112-A, celt bit, nc; A941.3.112-B, celt fragment, nc;

A941.3.113, celt fragment, Type A; A941.3.114, celt poll, nc; A941.3.115, chip with polish, Type C; A941.3.116, chip with polish, nc; A941.3.117, celt poll, Type C; A941.3.118, celt fragment, nc; A941.3.119, celt poll, nc; A941.3.120, celt fragment, nc; A941.3.121, celt fragment, nc; A941.3.122-A, celt fragment, Type A; A941.3.122-B, celt poll, nc; A941.3.123, celt poll, nc; A941.3.125, celt fragment, nc; A941.3.126, celt fragment, Type D; A941.3.128, celt poll, Type B; A941.3.129, celt fragment, Type D; A941.3.130, chip with polish, nc; A941.3.131, chip with polish, nc; A941.3.132, celt fragment, nc; A941.3.133, celt fragment, nc; A941.3.134-A, celt bit, Type E; A941.3.134-B, chip with polish, nc; A941.3.135, celt fragment, Type B; A941.3.136, celt fragment, nc; A941.3.137, chip with polish, nc; A941.3.138, chip with polish, nc; A941.3.139, celt poll, Type A; A941.3.142, celt fragment, Type A; A941.3.144, chip with polish, nc; A941.3.145, chip with polish, nc; A941.3.146, chip with polish, nc; A941.3.147, celt poll, nc; A941.3.148, chip with polish, nc; A941.3.150, celt poll, nc; A941.3.151, celt fragment, Type E; A941.3.152-A, chip with polish, nc; A941.3.152-B, celt fragment, nc; A941.3.154, celt fragment, Type C; A941.3.155, celt fragment, Type C; A941.3.156, chip with polish, nc; A941.3.157-A, chip with polish, nc; A941.3.157-B, chip with polish, nc; A941.3.158, chip with polish, nc; A941.3.159, chip with polish, nc; A941.3.160, celt fragment, nc; A941.3.161, celt fragment, Type B; A941.3.162, celt poll, nc; A941.3.163, chip with polish, nc; A941.3.164, chip with polish, nc; A941.3.165, chip with polish, nc; A941.3.166, chip with polish, nc; A941.3.167, celt poll, Type B; A941.3.168, celt bit, Type C; A941.3.169, celt fragment, nc; A941.3.170, celt, nc; A941.3.171, celt fragment, nc; A941.3.172, ax fragment, Type B; A941.3.173, celt fragment, nc; A941.3.175, celt fragment, Type A; A941.3.177, celt bit, Type C; A941.3.179, celt fragment, nc; A941.3.180, celt fragment, nc; A941.3.182, celt poll, nc; A941.3.183, celt poll, nc; A941.3.184, celt poll, nc; A941.3.185, chip with polish, nc; A941.3.186, celt bit, Type A; A941.3.187, celt poll, nc; A941.3.188, chip with polish, nc;

A941.3.189, celt fragment, nc; A941.3.190-A, celt fragment, nc; A941.3.190-B, slab fragment, nc; A941.3.191, chip with polish, nc; A941.3.192, ax fragment, nc; A941.3.193, chip with polish, nc; A941.3.194, celt fragment, nc; A941.3.195, chip with polish, nc; A941.3.196, chip with polish, nc; A941.3.197, celt poll, nc; A941.3.198, celt poll, nc; A941.3.199, celt fragment, Type C; A941.3.200, celt fragment, Type C; A941.3.201, celt fragment, Type D; A941.3.202, chip with polish, nc; A941.3.203, chip with polish, nc; A941.3.204, chip with polish, nc; A941.3.205, chip with polish, nc; A941.3.206, celt fragment, nc; A941.3.207, celt fragment, nc; A941.3.211, chip with polish, nc; A941.3.212, chip with polish, nc; A941.3.213, chip with polish, nc.

14. Greenstone field specimens from miscellaneous collection (56 total):
A941.4.218, celt, Type A; A941.4.219, celt, nc; A941.4.220, celt, Type A; A941.4.221, celt, Type A; A941.4.222, celt, nc; A941.4.223, celt, Type A; A941.4.225, celt, Type A; A941.4.226, celt, Type A; A941.4.227, celt, Type A; A941.4.228, celt, Type E; A941.4.229, celt bit, Type C; A941.4.230, celt, Type A; A941.4.231, celt, nc; A941.4.232, celt bit, Type B; A941.4.233, celt poll, nc; A941.4.234, celt bit, Type A; A941.4.235, celt fragment, Type B; A941.4.236, celt bit, Type A; A941.4.237, celt fragment, Type A; A941.4.238, celt bit, nc; A941.4.239, celt fragment, Type A; A941.4.240, celt bit, Type E; A941.4.241, celt, Type B; A941.4.242, celt bit, Type A; A941.4.243, celt, Type A; A941.4.244, celt poll, Type B; A941.4.245, celt, nc; A941.4.246, celt bit, nc; A941.4.247, celt poll, Type A; A941.4.248, celt, Type B; A941.4.249, celt bit, nc; A941.4.250, celt fragment, Type D; A941.4.251, celt poll, Type A; A941.4.252, celt bit, Type B; A941.4.253, celt fragment, nc; A941.4.254, celt fragment, Type A; A941.4.255, celt bit, Type A; A941.4.256, celt, Type B; A941.4.257, celt, Type A; A941.4.258, celt fragment, Type A; A941.4.259, celt poll, Type C; A941.4.260, celt bit, Type A; A941.4.261, celt

poll, nc; A941.4.262, spatulate fragment, nc; A941.4.265, celt bit, Type A; A941.4.266, celt, Type B; A941.4.267, spatulate, Type A; A941.4.268, celt, Type A; A941.4.269, celt poll, Type B; A941.4.271, celt, Type B; A941.4.272, celt bit, Type B; A941.4.273, celt, Type A; A941.4.274, celt, Type B; A941.4.275, celt poll, Type D; A941.4.341, discoidal with central depression, Type A.

Artifact frequencies by greenstone types are as follows:

Type A	108 artifacts	39.7%
Type B	68 artifacts	25.0%
Type C	28 artifacts	10.3%
Type D	41 artifacts	15.1%
Type E	23 artifacts	8.5%
Type F	4 artifacts	1.5%
Total	272 artifacts	100.1%

A total of 556 artifacts (96%) are celts (or similar ax forms), celt fragments, and celt chips. The remaining 22 artifacts are discoidals, polished slabs, spatulates, rough stone (celt preforms?), a monolithic ax pendant, and a pin (Table A-1).

Table A-1. Greenstone artifacts from Moundville in the Alabama Museum of Natural History Collections organized according to function.

Catalog Number	Artifact Type									
	Celt Fragment	Celt Chip	Whole Celt	Disk	Slab	Spud	Celt Preform (?)	Pendant	Pin	Total
A 930.1	7	1	3							11
A 930.2	18	2	4					1		25
A 930.3	7	1	3							11
A 930.4	3	1	1							5
A 930.5	3		1							4
A 931.1	7		6	3	1					17
A 931.2	32		2		2					36
A 932.3	9	2	8	1	1					21
A 932.4	3	3	2	1	1		1			11
A 936.1	3									3
A 939.2	110	94	15	2		2	1		1	225
A 940.2	15	1	1	1		1				19
A 941.3	86	45	2		1					134
A 941.4	28		25	1		2				56
	331	150	73	9	6	5	2	1	1	578

Sample size of greenstone types that underwent destructive analysis are as follows:

Type A	9 artifacts	8.3% of type
Type B	8 artifacts	11.8% of type
Type C	3 artifacts	10.7% of type
Type D	5 artifacts	12.2% of type
Type E	2 artifacts	8.7% of type
Type F	1 artifact	25% of type
Total	28 artifacts	

The 28 greenstone artifacts (Figs. A-1 to A-28) that comprise the sample that underwent destructive analysis are as follows:

Type A: A 930.3.51, A 931.2.90, A 931.2.106, A 936.1.112, A 939.2.441, A 940.2.289, A 941.3.75, A 941.3.86, A 941.3.122

Type B: A 930.2.145, A 930.2.148, A 930.5.21, A 939.2.651, A 941.3.107, A 941.3.108, A 941.3.167, A 941.4.244

Type C: A 930.2.149, A 939.2.626, A941.3.74

Type D: A 930.1.52, A 931.1.184, A 939.2.556, A 941.3.126, A 941.4.250

Type E: A 931.2.91, A 939.2.546

Type F: A 939.2.487

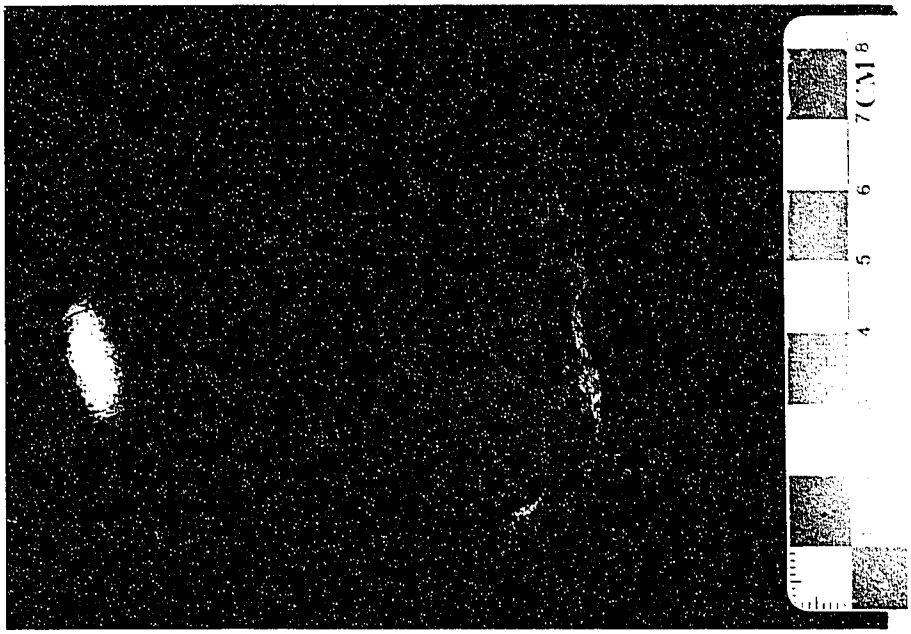


Figure A-1. Celt fragment A930.3.51, Type A greenstone. Scale units are in centimeters

Figure A-2. Celt fragment A931.2.90, Type A greenstone. Scale units are in centimeters.

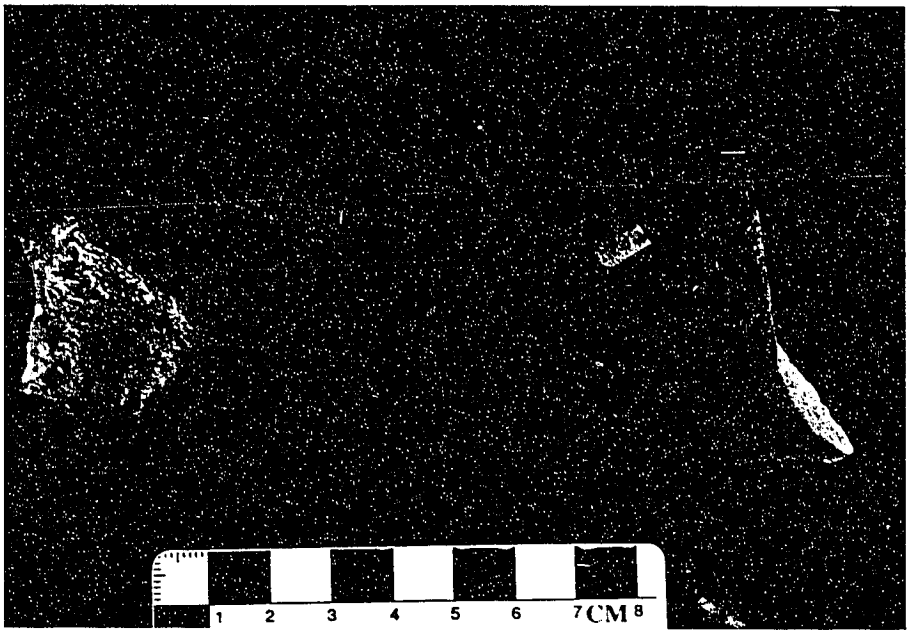


Figure A-3. Celt fragment A931.2.106, Type A greenstone. Scale units are in centimeters.

Figure A-4. Celt fragment A936.1.112, Type A greenstone. Scale units are in centimeters.

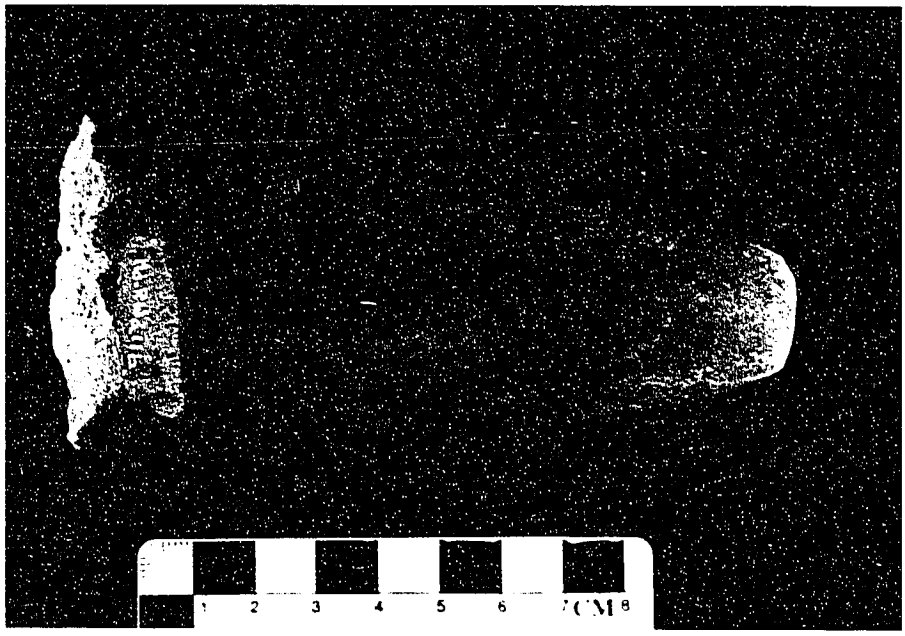


Figure A-5. Celt fragment A939.2.441, Type A greenstone. Scale units are in centimeters.

Figure A-6. Celt fragment A940.2.289, Type A greenstone. Scale units are in centimeters.

Figure A-7. Celt fragment A941.3.75, Type A greenstone. Scale units are in centimeters.

Figure A-8. Celt fragment A941.3.86, Type A greenstone. Scale units are in centimeters.

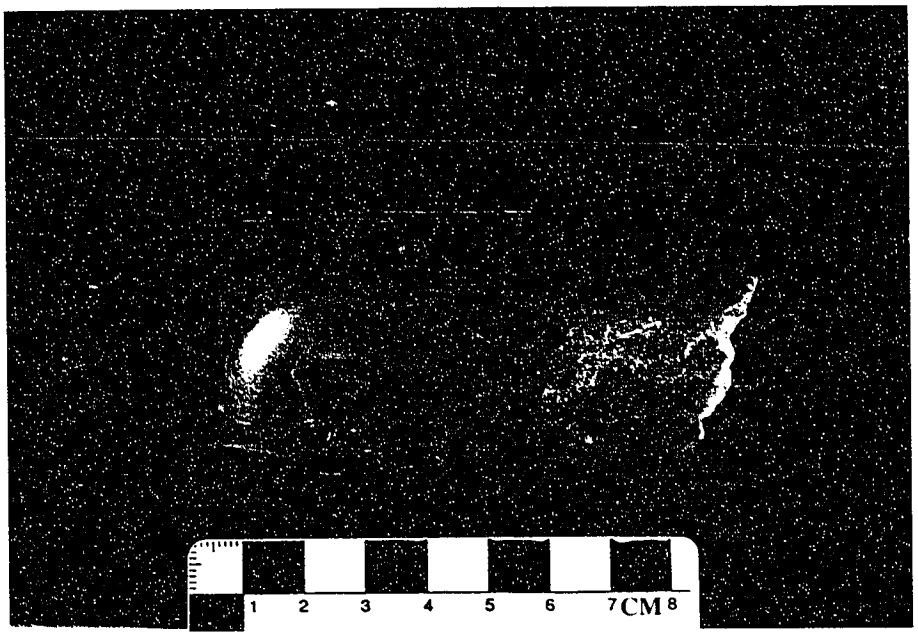


Figure A-9. Celt fragment A941.3.122, Type A greenstone. Scale units are in centimeters.

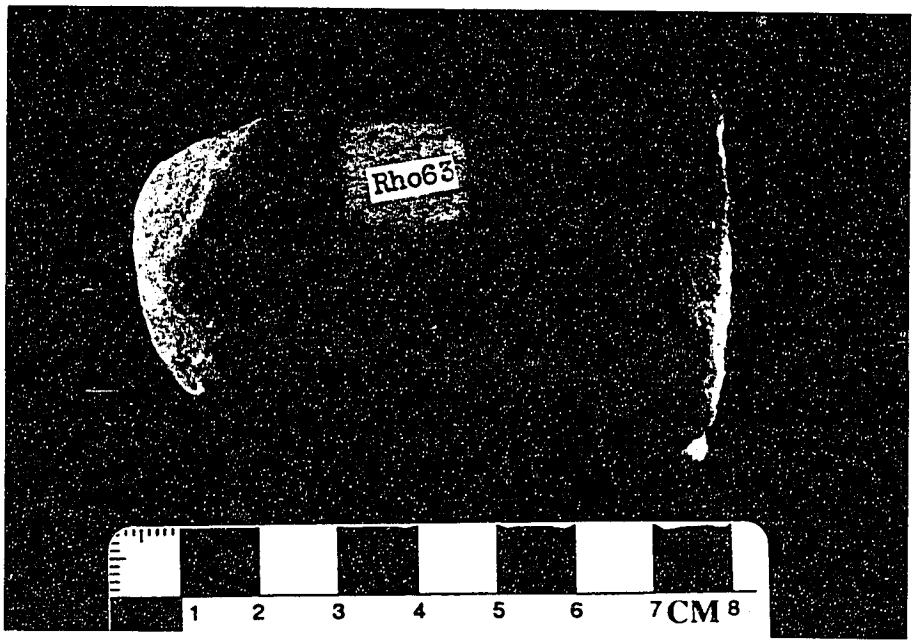


Figure A-10. Celt fragment A930.2.145, Type B greenstone. Scale units are in centimeters.

Figure A-11. Celt fragment A930.2.148, Type B greenstone. Scale units are in centimeters.

Figure A-12. Celt fragment A930.5.21, Type B greenstone. Scale units are in centimeters.

Figure A-13. Celt fragment A939.2.651, Type B greenstone. Scale units are in centimeters.

Figure A-14. Celt fragment A941.3.107, Type B greenstone. Scale units are in centimeters.

Figure A-15. Celt fragment A941.3.108, Type B greenstone. Scale units are in centimeters.

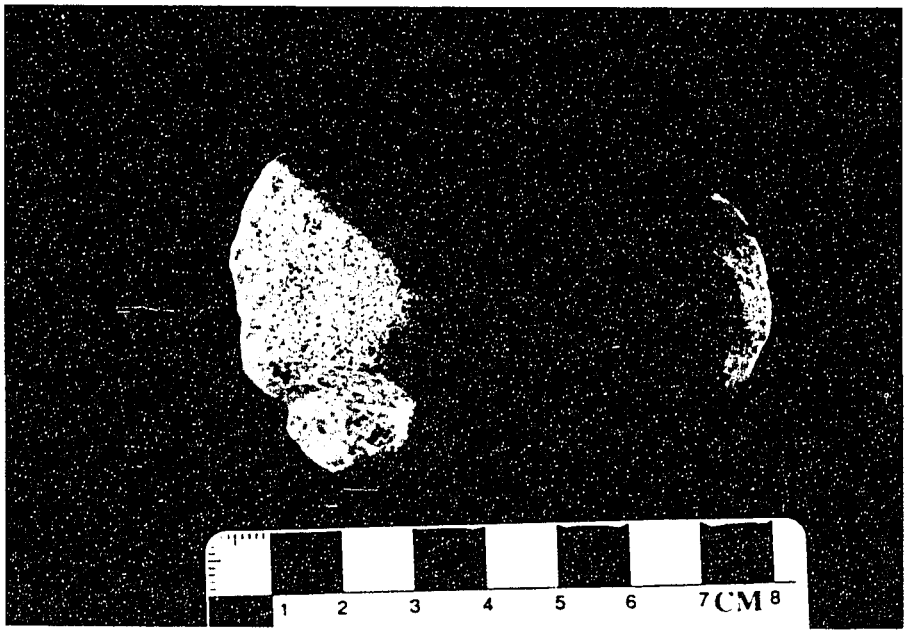


Figure A-16. Celt fragment A941.3.167, Type B greenstone. Scale units are in centimeters.

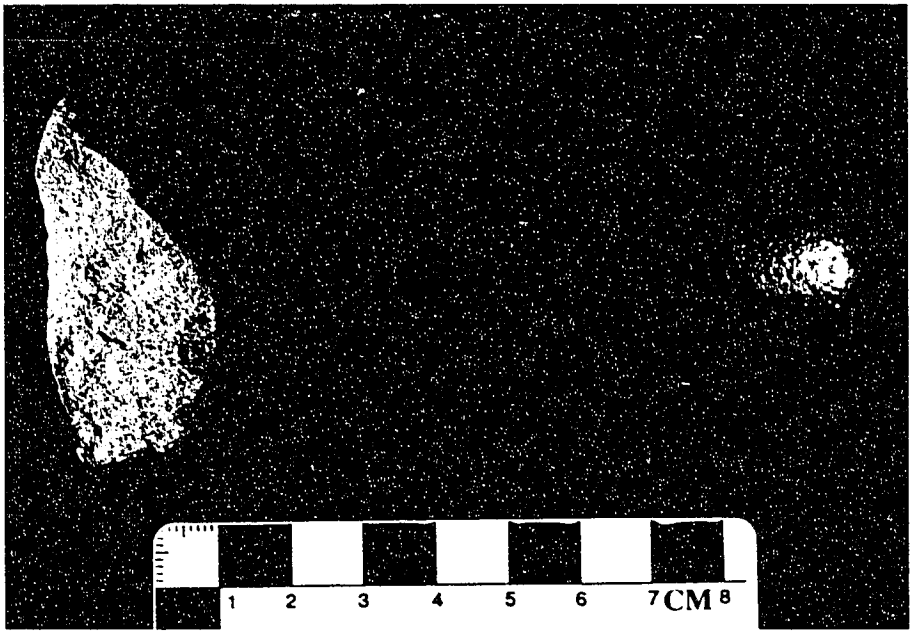


Figure A-17. Celt fragment A941.4.244, Type B greenstone. Scale units are in centimeters.

Figure A-18. Celt fragment A930.2.149, Type C greenstone. Scale units are in centimeters.

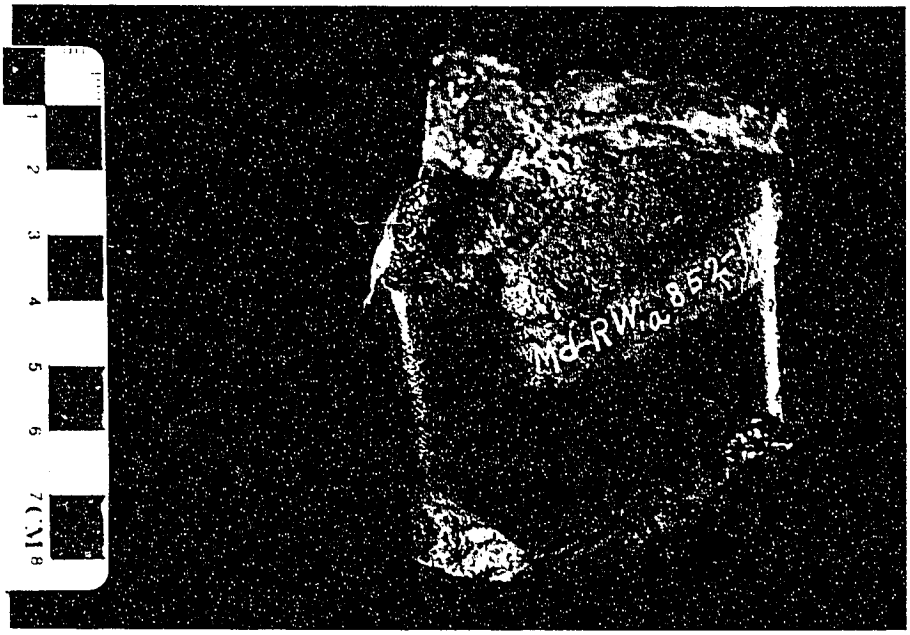


Figure A-19. Celt fragment A939.2.626, Type C greenstone. Scale units are in centimeters.

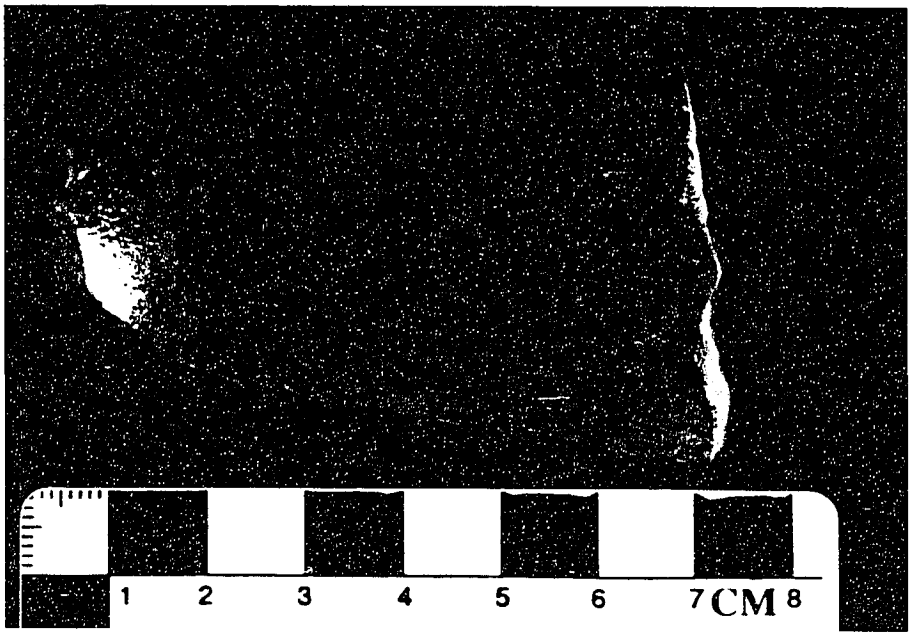


Figure A-20. Celt fragment A941.3.74, Type C greenstone. Scale units are in centimeters.

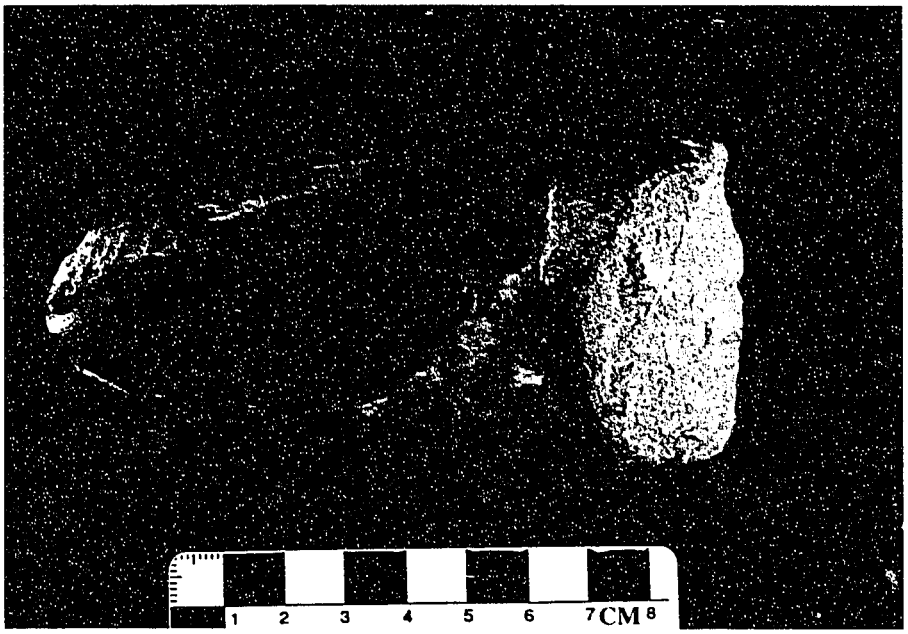


Figure A-21. Celt fragment A930.1.52, Type D greenstone. Scale units are in centimeters.

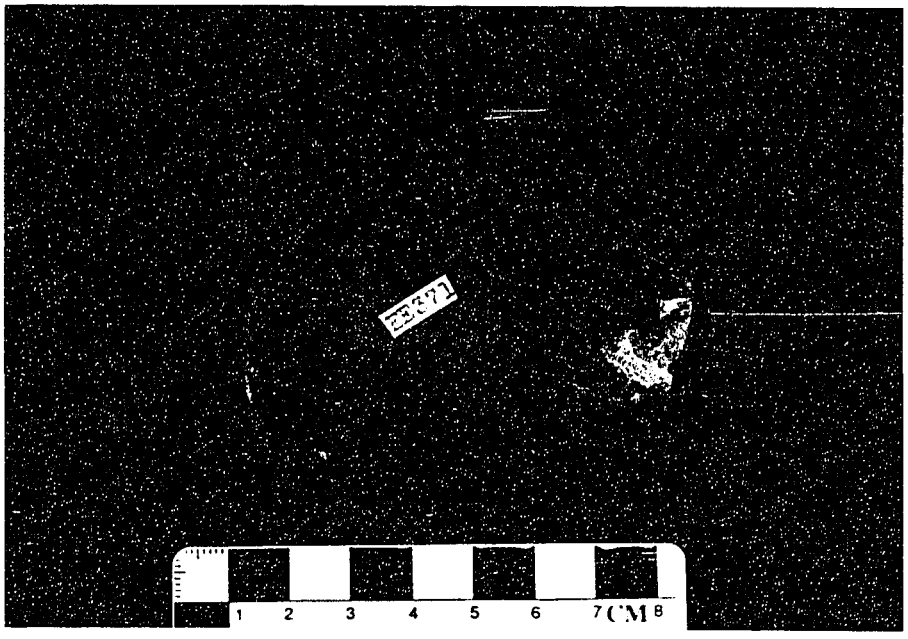


Figure A-22. Celt fragment A931.1.184, Type D greenstone. Scale units are in centimeters.

Figure A-23. Celt fragment A939.2.556, Type D greenstone. Scale units are in centimeters.

Figure A-24. Celt fragment A941.3.126, Type D greenstone. Scale units are in centimeters.

Figure A-25. Celt fragment A941.4.250, Type D greenstone. Scale units are in centimeters.

Figure A-26. Celt fragment A931.2.91, Type E greenstone. Scale units are in centimeters.

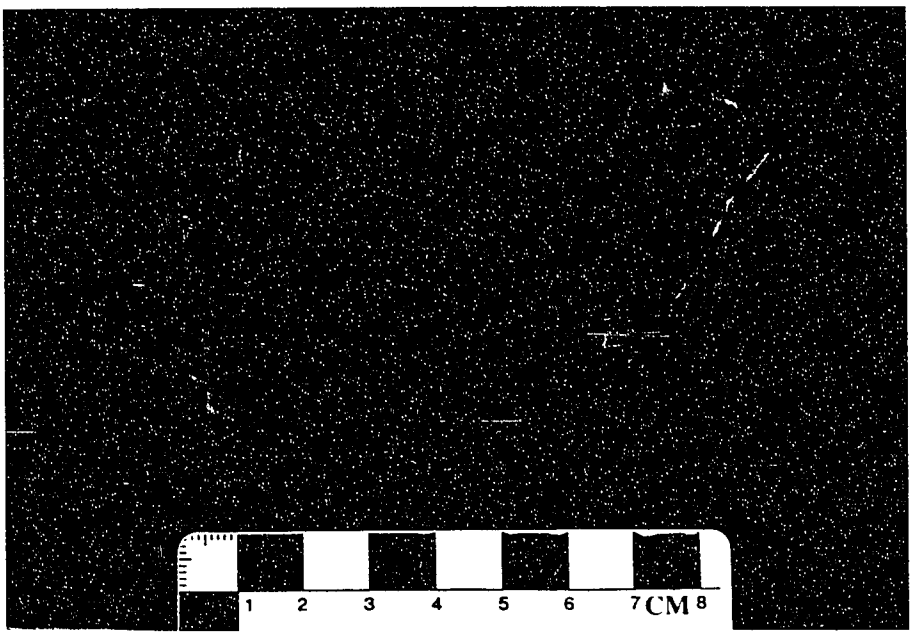


Figure A-27. Celt fragment A939.2.546, Type E greenstone. Scale units are in centimeters.

Figure A-28. Celt fragment A939.2.487, Type F greenstone. Scale units are in centimeters.

APPENDIX B

MINERALOGICAL AND CHEMICAL DATA: GREENSTONE ARTIFACTS, MOUNDVILLE SITE, ALABAMA

Whole rock densities of the 28 greenstone artifacts selected for destructive analysis were determined using the immersion technique and a hydrologic balance constructed out of a Harvard Trip Balance. The samples' weight in air and water were measured and densities were calculated using the following formula (Mason and Berry, 1968):

$$\text{Density} = \left(\text{Weight}_{air}/[\text{Weight}_{air} - \text{Weight}_{water}]\right) \text{ X Density}_{water}$$

Weights, volumes, and whole rock densities for the 28 artifacts are as follows:

Type A

A930.3.51	255.38 g / 82.44 cm^3	= 3.10 g/cm^3
A931.2.90	256.68 g / 82.96 cm^3	= 3.09 g/cm^3
A931.2.106	438.09 g / 142.93 cm^3	= 3.07 g/cm^3
A936.1.112	432.23 g / 141.90 cm^3	= 3.05 g/cm^3
A939.2.441	396.30 g / 135.72 cm^3	= 2.92 g/cm^3
A940.2.289	427.94 g / 139.14 cm^3	= 3.08 g/cm^3
A941.3.75	235.84 g / 77.78 cm^3	= 3.03 g/cm^3
A941.3.86	135.40 g / 44.81 cm^3	= 3.02 g/cm^3
A941.3.122	139.02 g / 45.74 cm^3	= 3.04 g/cm^3

Type B

A930.2.148	1015.62 g / 341.62 cm^3	= 2.97 g/cm^3
A930.5.21	167.15 g / 53.95 cm^3	= 3.10 g/cm^3
A939.2.651	330.06 g / 110.67 cm^3	= 2.98 g/cm^3
A941.3.107	337.47 g / 123.47 cm^3	= 3.05 g/cm^3
A941.3.108	207.37 g / 67.01 cm^3	= 3.09 g/cm^3
A941.3.167	185.07 g / 61.16 cm^3	= 3.03 g/cm^3
A941.4.244	381.52 g / 123.49 cm^3	= 3.09 g/cm^3

Type C

A930.2.149	544.39 g / 180.80 cm^3	= 3.01 g/cm^3
A939.2.626	364.12 g / 119.90 cm^3	= 3.04 g/cm^3
A941.3.74	166.31 g / 55.40 cm^3	= 3.00 g/cm^3

Type D

A930.1.52	359.36 g / 116.56 cm^3	= 3.08 g/cm^3
A931.1.184	176.06 g / 57.05 cm^3	= 3.09 g/cm^3
A939.2.556	314.23 g / 102.79 cm^3	= 3.06 g/cm^3
A941.3.126	456.93 g / 150.10 cm^3	= 3.04 g/cm^3
A941.4.250	367.83 g / 123.32 cm^3	= 2.98 g/cm^3

Type E

A931.2.91	441.28 g / 135.12 cm^3	= 3.07 g/cm^3
A939.2.546	404.43 g / 132.73 cm^3	= 3.05 g/cm^3

Type F

A939.2.487	292.33 g / 95.24 cm^3	= 3.07 g/cm^3

The 28 greenstone artifacts listed above underwent destructive analysis. They were sectioned using diamond rock saws, and cut surfaces were ground using corundum grits to remove saw marks and metal contamination. Standard petrographic thin sections were prepared by Idaho Petrographics of Grangeville, Idaho. Rock powders were prepared using a tungsten carbide percussion ball mill. Rock powders were used for X-ray diffraction analysis and instrumental neutron activation analysis.

The petrographic microscope was used primarily to determine rock textures, identify minerals, and take photomicrographs. Rock textures vary as follows:

Type 1: Relict diabasic texture (Fig. 6) - 14 total (50% of sample)

A930.3.51	Type A greenstone
A931.2.106	Type A greenstone
A941.3.75	Type A greenstone
A941.3.86	Type A greenstone

A930.5.21	Type B greenstone
A941.3.107	Type B greenstone
A941.4.244	Type B greenstone
A939.2.626	Type C Greenstone
A941.3.74	Type C greenstone
A930.1.52	Type D greenstone
A931.1.184	Type D greenstone
A939.2.556	Type D greenstone
A931.2.91	Type E greenstone
A939.2.546	Type E greenstone

Type 2: Very fine-grained to fine-grained granoblastic texture (Fig. 8) - 10 total (35.7% of sample)

A931.2.90	Type A greenstone
A936.1.112	Type A greenstone
A939.2.441	Type A greenstone
A940.2.289	Type A greenstone
A941.3.122	Type A greenstone
A930.2.145	Type B greenstone
A939.2.651	Type B greenstone
A941.3.108	Type B greenstone
A941.3.167	Type B greenstone
A941.4.250	Type D greenstone

Type 3: Fine- to medium-grained granular to crudely-foliated texture (Fig. 10) - 3 total (10.7 % of sample)

A930.2.148	Type B greenstone
A930.2.149	Type C greenstone
A941.3.126	Type D greenstone

Type 4: Relict porphyritic texture (Fig. 11) - 1 total (3.6% of sample)

A939.2.487	Type F greenstone

The X-ray diffractometer (copper filament) was used to identify the major mineral components of the celt greenstones. Mineral Powder Diffraction File Cards and results from mineral standards were used to interpret XRD data. The celt greenstones are remarkably similar in mineralogy; all of them are composed primarily of actinolite, epidote, and albite with minor amounts of chlorite. Minor amounts of quartz occurs in the following artifacts: A930.5.21, A941.3.167, A941.3.107, A939.2.651, A939.2.487, A941.4.244, A939.2.546. The absence or presence of quartz in detectable amounts is the only difference between the samples: 75% of the samples (21 out of 28 samples) do not contain quartz in detectable amounts, 25% (7 out of 28 samples) do contain enough quartz for it be detected. The amount of quartz present, however, is very minor because the strongest diffraction line (d-spacing = 3.343 angstroms, *hkl* = 101) is just discernible above background and no other quartz diffraction lines are readable. The similarity of artifact greenstone mineralogy accounts for their similarities in whole rock densities of 3.0 to 3.1 g/cm^3.

Rock powders were analyzed by XRAL Laboratories of Ann Arbor, Michigan. The 33-element quantitative chemical analysis (Table B-1) was determined using Instrumental Neutron Activation Analysis (INAA). The 33 elements of the INAA analysis and their lower detection limits are as follows (Fe_2O_3 = Total iron as Fe_2O_3 wt.%):

Element	Lower Detection Limit	Element	Lower Detection Limit
Ag	5.0 ppm	As	2.0 ppm
Au	5.0 ppb	Ba	100 ppm
Br	1.0 ppm	CaO	1.399 wt.%
Ce	3.0 ppm	Co	5.0 ppm
Cr	10.0 ppm	Cs	3.0 ppm
Eu	0.2 ppm	Fe_2O_3	0.143 wt.%
Hf	1.0 ppm	Ir	20.0 ppb
La	1.0 ppm	Lu	0.05 ppm
Mo	5.0 ppm	Na_2O	0.0674 wt.%
Nd	10.0 ppm	Ni	100.0 ppm
Rb	30.0 ppm	Sb	0.2 ppm
Sc	0.1 ppm	Se	5.0 ppm
Sm	0.5 ppm	Sr	500.0 ppm
Ta	1.0 ppm	Tb	0.5 ppm
Th	0.5 ppm	U	0.5 ppm
W	4.0 ppm	Yb	0.2 ppm
Zn	50.0 ppm		

Hillabee greenstone samples B-GS-100 and GS-18 were also analyzed with the 10 celt samples that underwent INAA (Appendix C). They were included to check on data reproducibility, and the results obtained with the 50-element multi-instrumental analysis compares well with the results obtained from the 33-element INAA data in this appendix (Table B-1).

Table B-1 a. Thirty-three element INAA chemical analyses of Moundville greenstone celts (catalog number): A930.1.52, A930.2.145, A930.2.148, A930.2.149, A930.3.51, A930.5.21, and A930.1.184.

	Greenstone Celt Samples						
Element	A930.1. 52	A930.2. 145	A930.2. 148	A930.2. 149	A930.3. 51	A930.5. 21	A930.1. 184
CaO wt%	10.63	10.21	8.53	11.19	11.19	11.89	12.59
Na2Owt%	2.02	2.56	3.78	1.89	1.75	2.02	2.16
Fe wt%	11.30	11.15	11.87	10.87	10.3	13.01	11.3
Ag ppm	<5	<5	<5	<5	<5	<5	<5
As ppm	<2	19	<2	<2	<2	<2	<2
Au ppb	<5	<5	<5	<5	<5	<5	8
Ba ppm	200	100	100	100	<100	<100	<100
Br ppm	<1	<1	1	1	1	1	1
Ce ppm	11	13	10	8	10	13	10
Co ppm	56	24	53	56	45	59	52
Cr ppm	260	260	120	310	300	90	260
Cs ppm	<3	<3	<3	<3	<3	<3	<3
Eu ppm	0.8	0.8	0.7	0.6	0.8	1.2	0.8
Hf ppm	2	1	2	1	2	2	1
Ir ppb	<20	<20	<20	<20	<20	<20	<20
La ppm	4	5	4	3	4	5	4
Lu ppm	0.33	0.37	0.34	0.27	0.30	0.42	0.33
Mo ppm	<5	<5	<5	<5	<5	<5	<5
Nd ppm	<10	<10	<10	<10	<10	10	<10
Ni ppm	<100	100	<100	<100	<100	<100	<100
Rb ppm	<30	<30	<30	<30	<30	<30	<30
Sb ppm	<0.2	1.2	<0.2	<0.2	<0.2	0.2	<0.2
Sc ppm	46.6	47.5	46.8	38.3	43.3	48.4	45.7
Se ppm	<5	<5	<5	<5	<5	<5	<5
Sm ppm	2.4	2.5	2.0	1.8	2.2	2.9	2.4
Sr ppm	<500	<500	<500	<500	<500	<500	<500
Ta ppm	<1	<1	<1	<1	<1	<1	<1
Tb ppm	<0.5	0.6	<0.5	<0.5	0.6	0.7	0.5
Th ppm	<0.5	0.5	0.7	<0.5	<0.5	0.8	0.8
U ppm	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
W ppm	<4	<4	<4	<4	<4	<4	<4
Yb ppm	2.3	2.5	2.2	1.8	2.1	2.8	2.3
Zn ppm	60	80	110	120	170	130	210

Table B-1 b. Thirty-three element INAA chemical analyses of Moundville greenstone celts (catalog number): A931.2.106, A931.2.90, A931.2.91, A936.1.112, A939.2.441, A939.2.487, and A939.2.546.

	Greenstone Celt Samples						
Element	A931.2. 106	A931.2. 90	A931.2. 91	A936.1. 112	A939.2. 441	A939.2. 487	A939.2. 546
CaO wt%	10.77	12.59	12.59	10.63	10.21	11.19	12.31
Na2Owt%	1.89	1.89	2.16	2.16	2.97	1.75	1.89
Fe wt%	10.15	11.15	10.87	10.58	11.01	8.01	11.01
Ag ppm	<5	<5	<5	<5	<5	<5	<5
As ppm	<2	<2	<2	<2	<2	<2	<2
Au ppb	<5	<5	7	<5	<5	<5	<5
Ba ppm	200	<100	<100	200	<100	<100	100
Br ppm	1	<1	1	1	1	<1	1
Ce ppm	11	11	10	9	15	8	9
Co ppm	50	46	49	47	42	44	58
Cr ppm	320	250	300	330	330	260	340
Cs ppm	<3	<3	<3	<3	<3	<3	<3
Eu ppm	0.9	1.1	1.0	0.7	0.8	0.7	1.2
Hf ppm	1	2	2	2	2	1	1
Ir ppb	<20	<20	<20	<20	<20	<20	<20
La ppm	4	4	4	4	6	3	3
Lu ppm	0.30	0.37	0.28	0.29	0.36	0.20	0.33
Mo ppm	<5	<5	<5	<5	<5	<5	<5
Nd ppm	<10	<10	<10	<10	10	<10	<10
Ni ppm	100	<100	<100	100	<100	<100	<100
Rb ppm	<30	<30	<30	<30	<30	<30	<30
Sb ppm	<0.2	<0.2	<0.2	0.2	<0.2	0.2	0.5
Sc ppm	40.5	45.3	44.6	43.2	46.6	30.7	44.6
Se ppm	<5	<5	<5	<5	<5	<5	<5
Sm ppm	2.0	2.3	2.2	2.1	2.6	1.8	2.1
Sr ppm	<500	<500	<500	<500	<500	<500	<500
Ta ppm	<1	<1	<1	<1	<1	<1	<1
Tb ppm	0.5	0.6	0.5	0.5	0.6	<0.5	0.5
Th ppm	<0.5	0.5	<0.5	<0.5	0.5	<0.5	<0.5
U ppm	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
W ppm	<4	<4	<4	<4	<4	<4	<4
Yb ppm	2.0	2.3	2.0	2.4	2.5	1.5	2.2
Zn ppm	90	70	240	100	100	100	90

Table B-1 c. Thirty-three element INAA chemical analyses of Moundville greenstone celts (catalog number): A939.2.556, A939.2.626, A939.2.651, A940.2.289, A941.3.107, A941.3.108, and A941.3.122.

	Greenstone Celt Samples						
Element	A939.2. 556	A939.2. 626	A939.2. 651	A940.2. 289	A941.3. 107	A941.3. 108	A941.3. 122
CaO wt%	12.03	11.19	10.21	11.89	11.19	11.89	11.75
Na2Owt%	2.29	2.02	2.70	1.89	1.35	2.02	2.43
Fe wt%	11.15	10.3	10.58	9.30	10.3	11.01	10.73
Ag ppm	<5	<5	<5	<5	<5	<5	<5
As ppm	<2	<2	<2	<2	<2	<2	10
Au ppb	<5	<5	9	<5	<5	<5	<5
Ba ppm	100	100	100	100	<100	<100	100
Br ppm	1	<1	1	1	<1	1	1
Ce ppm	11	9	12	8	10	10	14
Co ppm	48	47	40	52	39	51	46
Cr ppm	340	310	20	310	290	260	280
Cs ppm	<3	<3	<3	<3	<3	<3	<3
Eu ppm	1.0	1.0	0.6	0.7	1.3	0.7	0.9
Hf ppm	2	1	1	1	2	2	2
Ir ppb	<20	<20	<20	<20	<20	<20	<20
La ppm	4	3	5	3	4	4	5
Lu ppm	0.36	0.30	0.31	0.28	0.31	0.31	0.37
Mo ppm	<5	<5	<5	<5	<5	<5	<5
Nd ppm	<10	<10	<10	<10	<10	<10	<10
Ni ppm	<100	<100	<100	100	<100	100	<100
Rb ppm	<30	<30	<30	<30	<30	<30	<30
Sb ppm	<0.2	<0.2	<0.2	<0.2	<0.2	0.2	2.1
Sc ppm	46.3	40.5	40.2	36.4	40.7	44.2	46.1
Se ppm	<5	<5	<5	<5	<5	<5	<5
Sm ppm	2.3	1.9	1.9	1.7	2.1	2.2	2.6
Sr ppm	<500	<500	<500	<500	<500	<500	<500
Ta ppm	<1	<1	<1	<1	<1	<1	<1
Tb ppm	0.5	0.5	<0.5	<0.5	0.5	0.5	0.6
Th ppm	<0.5	<0.5	1.1	<0.5	<0.5	<0.5	0.5
U ppm	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
W ppm	<4	<4	<4	<4	<4	<4	<4
Yb ppm	2.2	1.8	2.2	1.9	1.8	2.2	2.5
Zn ppm	80	60	<50	110	130	70	90

Table B-1 d. Thirty-three element INAA chemical analyses of Moundville greenstone celts (catalog number): A941.3.126, A941.3.167, A941.3.74, A941.3.75, A941.3.86, A941.4.244, and A941.4.250.

	Greenstone Celt Samples						
Element	A941.3. 126	A941.3. 167	A941.3. 74	A941.3. 75	A941.3. 86	A941.4. 244	A941.4. 250
CaO wt%	11.19	11.19	7.97	9.93	11.61	12.17	10.77
Na2Owt%	2.43	3.10	2.02	2.70	2.29	1.89	3.10
Fe wt%	10.30	14.16	10.15	11.58	9.72	11.44	10.44
Ag ppm	<5	<5	<5	<5	<5	<5	<5
As ppm	<2	3	<2	<2	<2	<2	<2
Au ppb	<5	<5	6	<5	5	14	<5
Ba ppm	100	100	200	100	200	100	200
Br ppm	1	1	1	1	1	1	1
Ce ppm	9	21	9	10	9	13	11
Co ppm	49	42	48	50	45	50	49
Cr ppm	290	350	340	330	340	300	320
Cs ppm	<3	<3	<3	<3	<3	<3	<3
Eu ppm	1.0	1.8	0.7	0.8	0.9	0.7	0.6
Hf ppm	2	3	1	2	1	2	1
Ir ppb	<20	<20	<20	<20	<20	<20	<20
La ppm	4	8	3	4	3	5	4
Lu ppm	0.32	0.56	0.26	0.33	0.30	0.32	0.34
Mo ppm	<5	<5	<5	<5	<5	<5	<5
Nd ppm	<10	10	<10	<10	<10	10	<10
Ni ppm	<100	100	200	<100	100	<100	<100
Rb ppm	<30	<30	<30	<30	<30	<30	<30
Sb ppm	0.2	1.8	<0.2	<0.2	0.4	0.4	0.2
Sc ppm	41.5	42.7	38.2	46.2	41.1	47.5	45.4
Se ppm	<5	<5	<5	<5	<5	<5	<5
Sm ppm	2.1	3.8	1.8	2.3	2.0	2.5	2.3
Sr ppm	<500	<500	<500	<500	<500	<500	<500
Ta ppm	<1	<1	<1	<1	<1	<1	<1
Tb ppm	0.5	0.8	0.5	0.6	<0.5	0.6	0.5
Th ppm	0.6	1.5	<0.5	<0.5	<0.5	<0.5	<0.5
U ppm	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
W ppm	<4	<4	<4	<4	<4	<4	<4
Yb ppm	2.1	3.7	1.8	2.2	2.1	2.5	2.2
Zn ppm	150	100	90	80	<50	80	120

The following fifteen elements are present in large enough quantities in most of the celt samples to be detected by INAA (Table B-1): calcium, cerium, cobalt, chromium, europium, iron, hafnium, lanthanum, lutetium, samarium, scandium, sodium, terbium, ytterbium, and zinc. The number of celt samples that contained detectable quantities of these elements, value averages, median values, and the range of values are listed in Table B-2. Zinc values fall below detection limits (< 50 ppm) for 2 of the 28 celt samples (Table B-1); therefore, for statistical calculations (Table B-2), a value of 40 ppm was assigned to those two samples. Terbium values fall below detection limits (< 0.5 ppm) for 7 of the 28 samples (Table B-1); therefore, a value of 0.4 ppm was assigned to those 7 samples for statistical calculations (Table B-2). Histograms are used in this appendix to depict chemical trends for calcium, sodium, total iron as Fe_2O_3, chromium, cerium, samarium, ytterbium, and lutetium (Figs. B-1 - B-8).

Scatter plots comparing the celt values of sodium to calcium (Fig. 18), iron to chromium (Fig. 19), ytterbium to lutetium (Fig. 20), and samarium to cerium (Fig. 21) are used to illustrate similarities and difference between these elements. Clusters and outliers are identified using the scatter plots. The average values and medians for the clusters are given in Table B-2.

Table B-2. Table listing the average chemical values for selected elements of the celt greenstones. The number of samples indicates the number of celt samples (out of 28 total) that contained the element in detectable amounts. The sample data used to calculate the statistical averages and determine the medians are contatined in Table B-1. Clusters for selected elements are identified by their outliers in Figures 18 - 21.

Chemical Averages and Median Values for Greenstone Celts

Element	Number of Samples	Sample Average	Median Value	Range of Values	Cluster Average	Cluster Median
CaO wt.%	28	11.13	11.19	7.97-12.59	11.35	11.19
Na2O wt.%	28	2.25	2.09	1.35 - 3.78	2.20	2.02
Fe2O3wt.%	28	10.85	10.87	8.01-14.16	10.74	10.87
Cr ppm	28	279	300	20 - 350	303	310
Co ppm	28	48	48.5	24 - 59	49	48
Sc ppm	28	43.2	44.4	30.7 - 48.4	43.6	44.6
Zn ppm	26	104	95	< 50 - 240	95	90
Hf ppm	28	1.6	2	1 - 3	1.6	2
La ppm	28	4	4	3 - 8	4	4
Ce ppm	28	10.9	10	8 - 21	10.5	10
Sm ppm	28	2.2	2.2	1.7 - 3.8	2.2	2.2
Eu ppm	28	0.9	0.8	0.6 - 1.8	0.9	0.8
Tb ppm	21	0.5	0.5	< 0.5 - 0.8	0.5	0.5
Yb ppm	28	2.2	2.2	1.5 - 3.7	2.2	2.2
Lu ppm	28	0.33	0.32	0.20 - 0.56	0.31	0.315

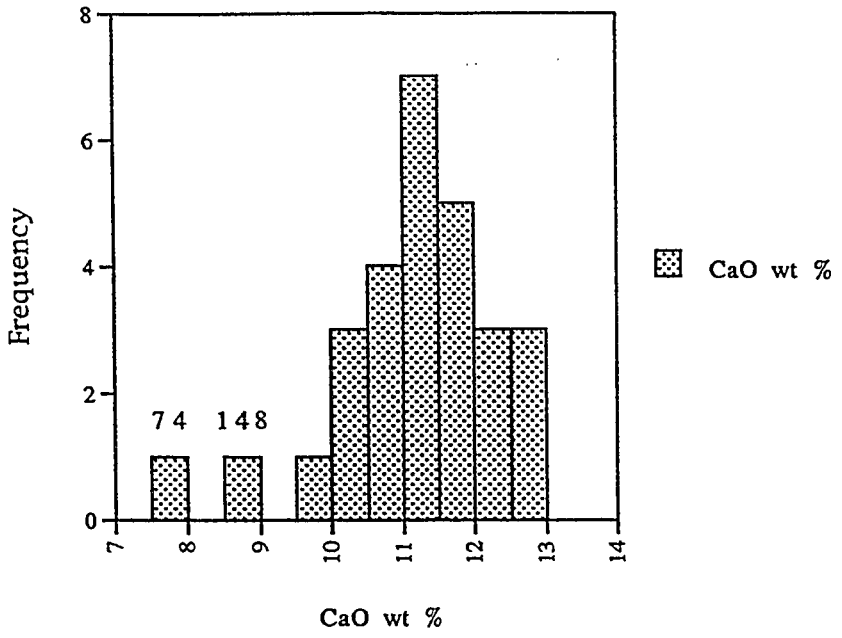


Figure B-1. Histogram showing the distribution of the calcium (CaO wt.%) values for the 28 celt samples. The group outliers are A930.2.148 (148) and A941.3.74 (74).

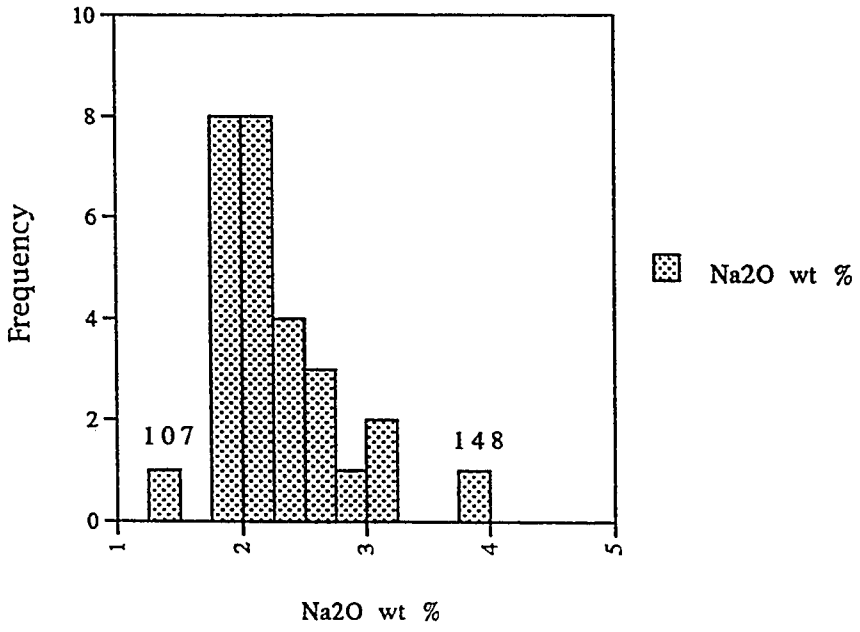


Figure B-2. Histogram showing the distribution of the sodium (Na_2O wt.%) values for the 28 celt samples. The group outliers are A930.2.148 (148) and A941.3.107 (107).

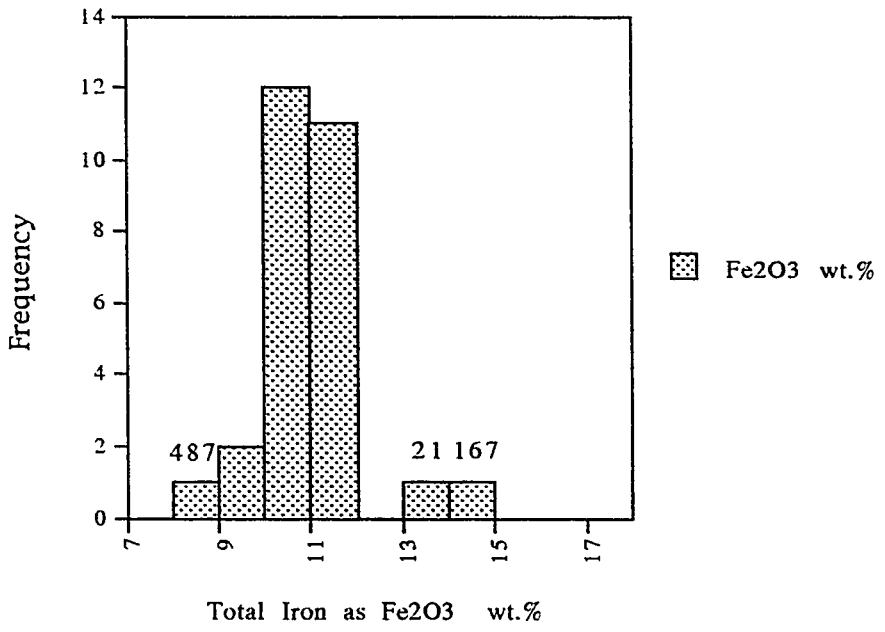


Figure B-3. Histogram showing the distribution of the total iron (as Fe_2O_3 wt.%) values for the 28 celt samples. The group outliers are A930.5.21 (21), A939.2.487 (487), and A941.3.167 (167).

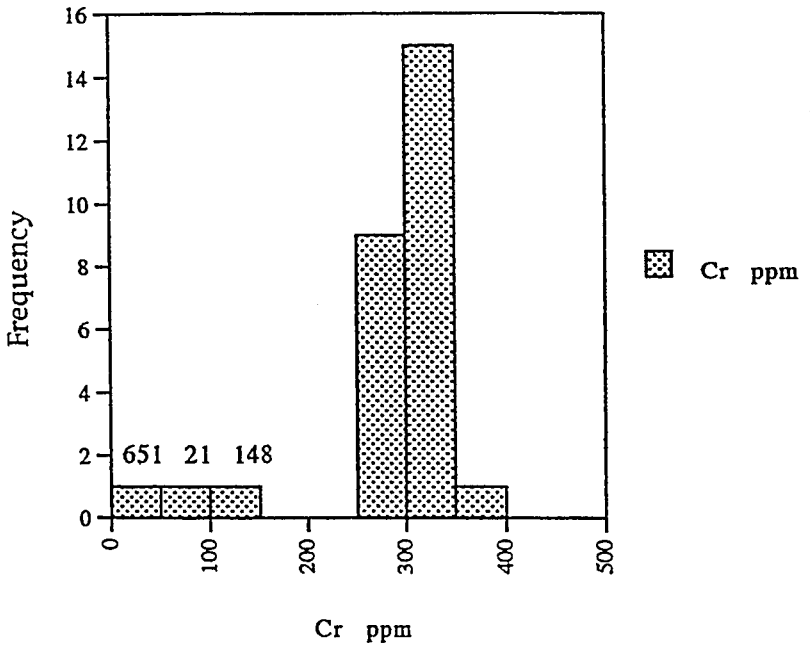


Figure B-4. Histogram showing the distribution of the chromium (Cr ppm) values for the 28 celt samples. The group outliers are A930.2.148 (148), A930.5.21 (21), and A939.2.651 (651).

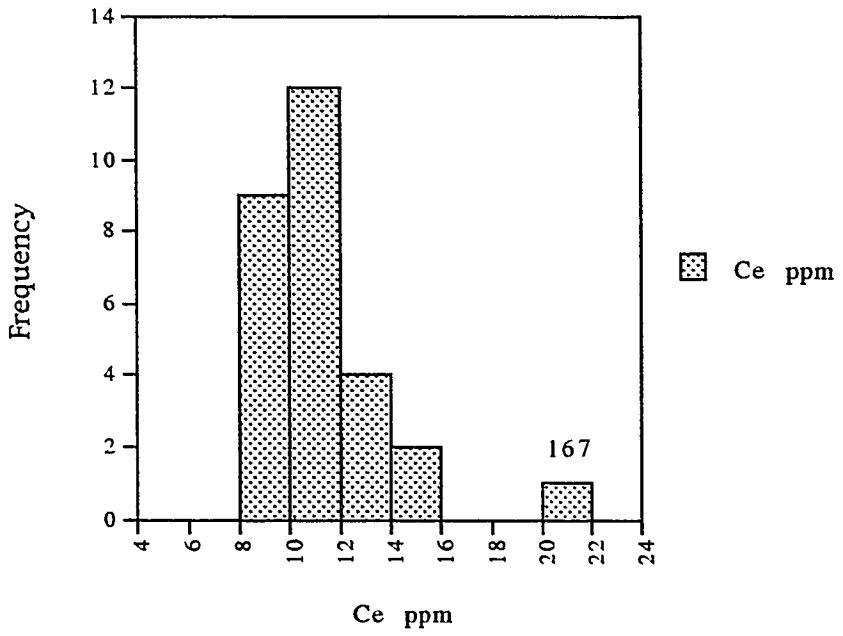


Figure B-5. Histogram showing the distribution of the cerium (Ce ppm) values for the 28 celt samples. The group outlier is A941.3.167 (167).

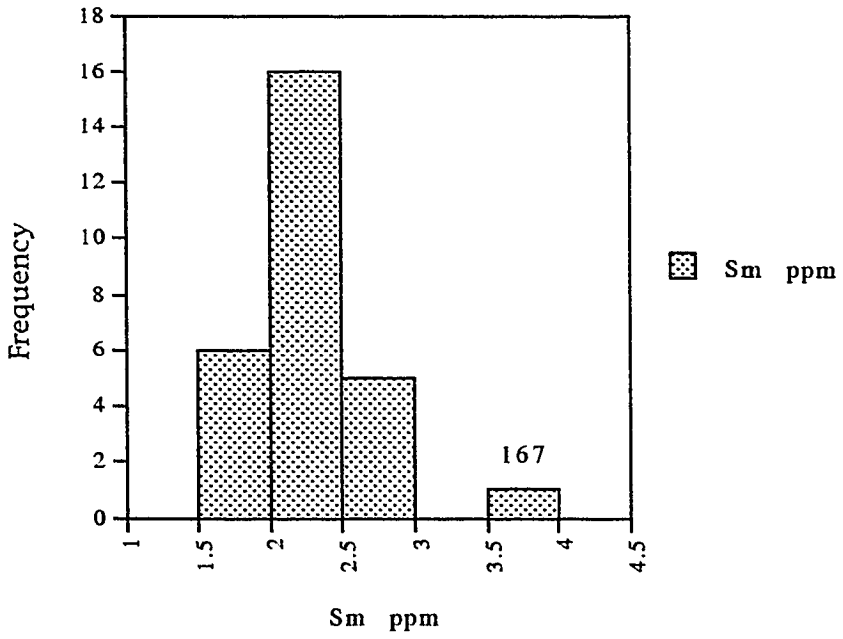


Figure B-6. Histogram showing the distribution of the samarium (Sm ppm) values for the 28 celt samples. The group outlier is A941.3.167 (167).

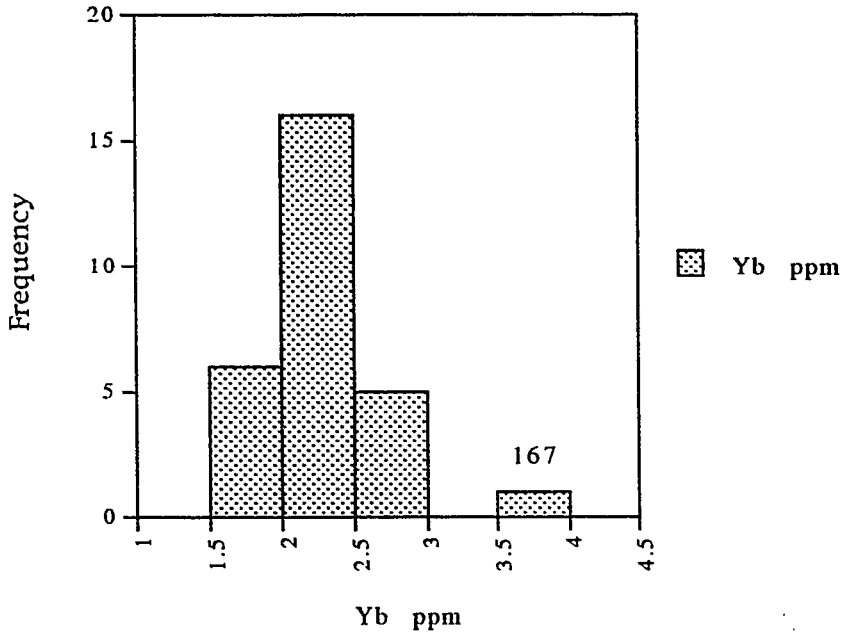


Figure B-7. Histogram showing the distribution of the ytterbium (Yb ppm) values for the 28 celt samples. The group outlier is A941.3.167 (167).

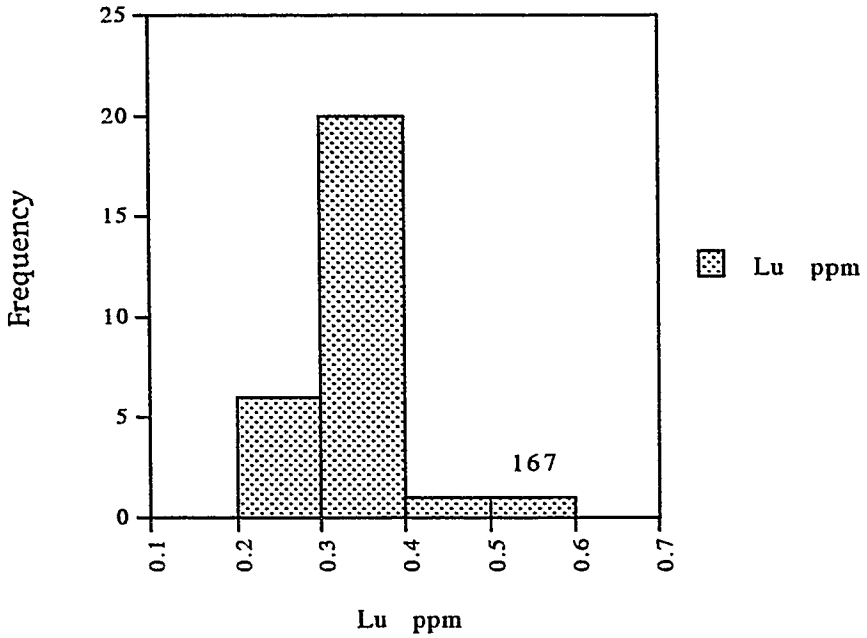


Figure B-8. Histogram showing the distribution of the lutetium (Lu ppm) values for the 28 celt samples. The group outlier is A941.3.167 (167).

APPENDIX C

MINERALOGICAL AND CHEMCIAL DATA: GREENSTONES FROM THE HILLABEE METAVOLCANIC COMPLEX

The Hillabee Metavolcanic Complex was examined in the field, and 62 metabasite samples were collected along its strike (Fig. C-1). Twenty-seven standard petrographic thin sections were prepared by Idaho Petrographics of Grangeville, Idaho. As with the artifact greenstones (Appendix B), the petrographic microscope was used primarily to determine rock textures, identify minerals, and take photomicrographs. Microscopic examination of petrographic thin-sections and handspecimen analysis was used to place the mafic rocks into the following 5 categories:

1. Massive Greenstone - fine-grained (< 0.1 mm) , massive , granoblastic texture (Fig. 25), 16 of 62 samples (25.8%), 12 thin-sections;
2. Granular to Crudely-Foliated Greenstone - fine- to medium-grained (≤ 1.0 mm), granular to crudely-foliated texture (Figs. 26 and C-2), 14 of 62 samples (22.6%), 6 thin-sections;
3. Mylonite - fine-grained (< 1.0 mm), flinty, banded, granulated texture (Figs. C-3 and C-4), 8 of 62 samples (12.9%), 6 thin sections;
5. Relict Diabasic Texture- fine-grained (< 1.0 mm), lath-shaped areas in a fine-grained matrix (Figs. 27 and C-5), 5 of 62 samples (8.1%), 2 thin sections;
2. Phyllite - very fine - grained, foliated texture with sheen on foliation surface (Fig. C-6), 19 of 62 samples (30.6%), 1 thin-sections.

Whole rock densities of the 26 greenstone samples selected for petrographic analysis were determined using the immersion technique and a hydrologic balance constructed out of a Harvard Trip

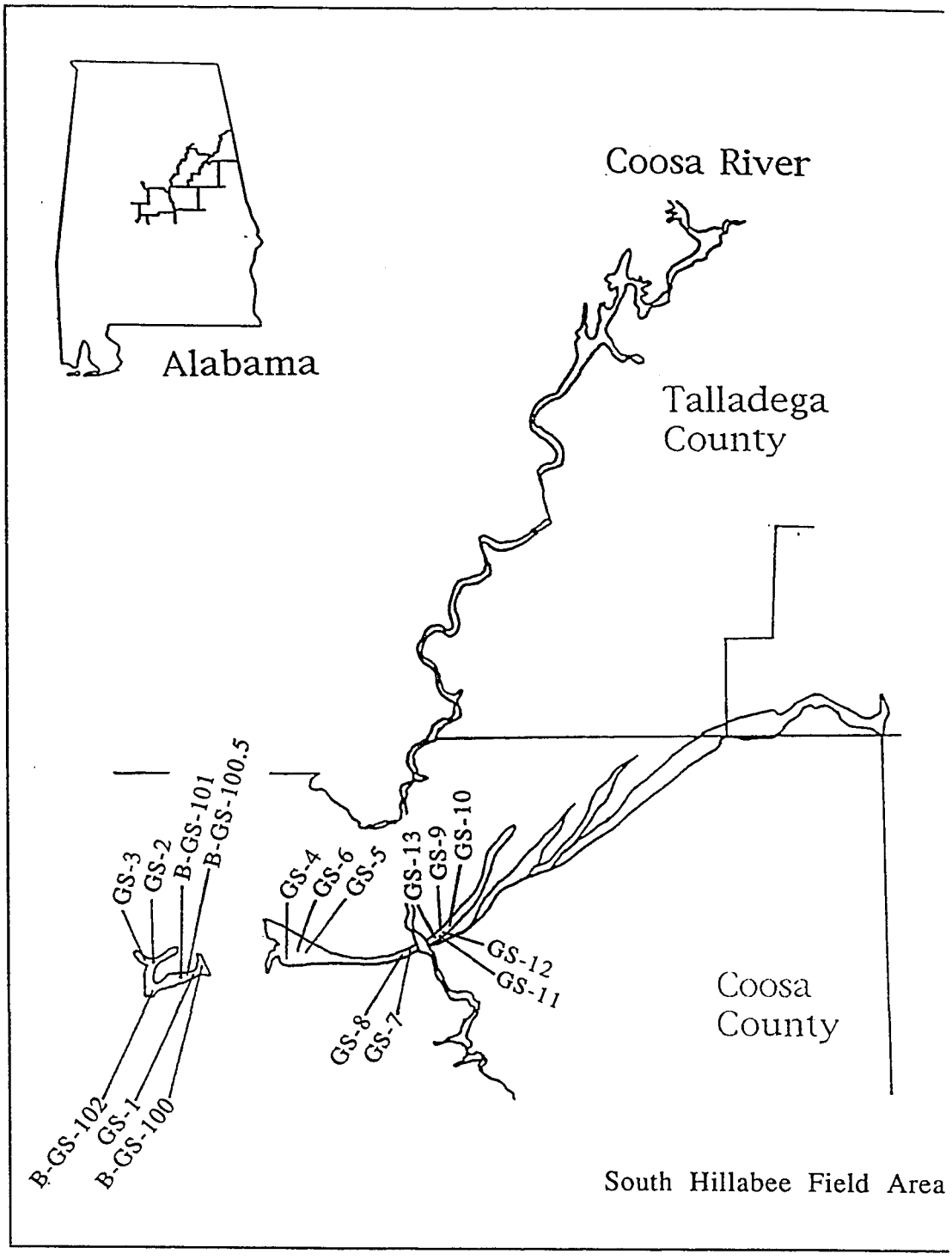
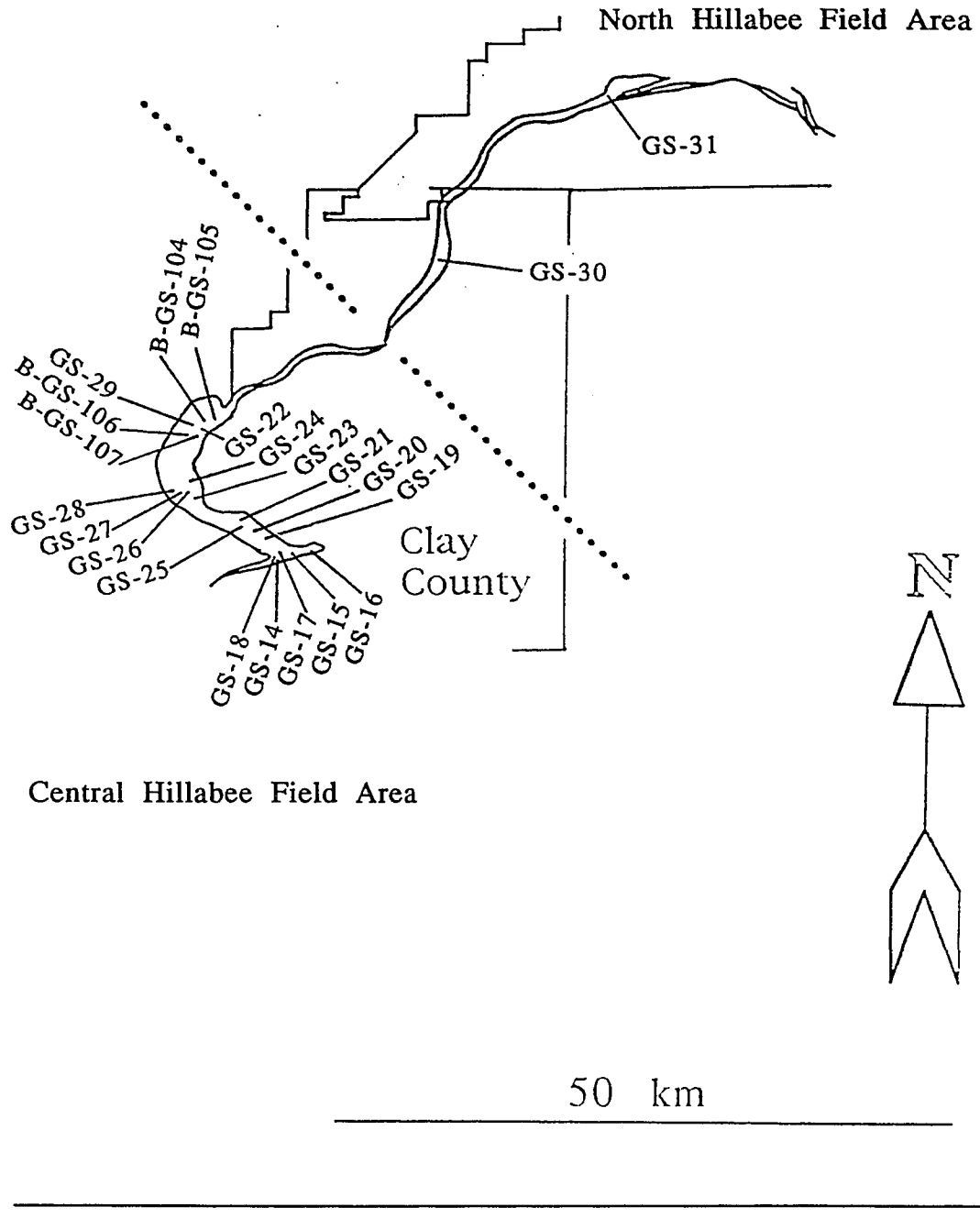


Figure C-1. Map showing the outcrop trace of the Hillabee that underwent petrographic analysis (Tull, 1979, p. 5).



Metavolcanic Complex and the locations of the 62 greenstone samples

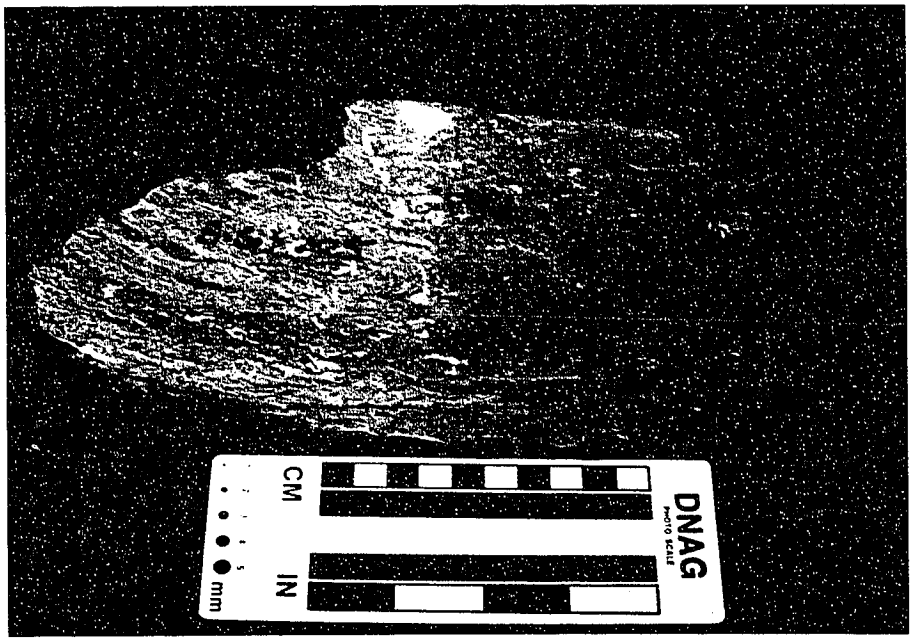


Figure C-2. Photograph of Hillabee greenstone sample B-GS-105.

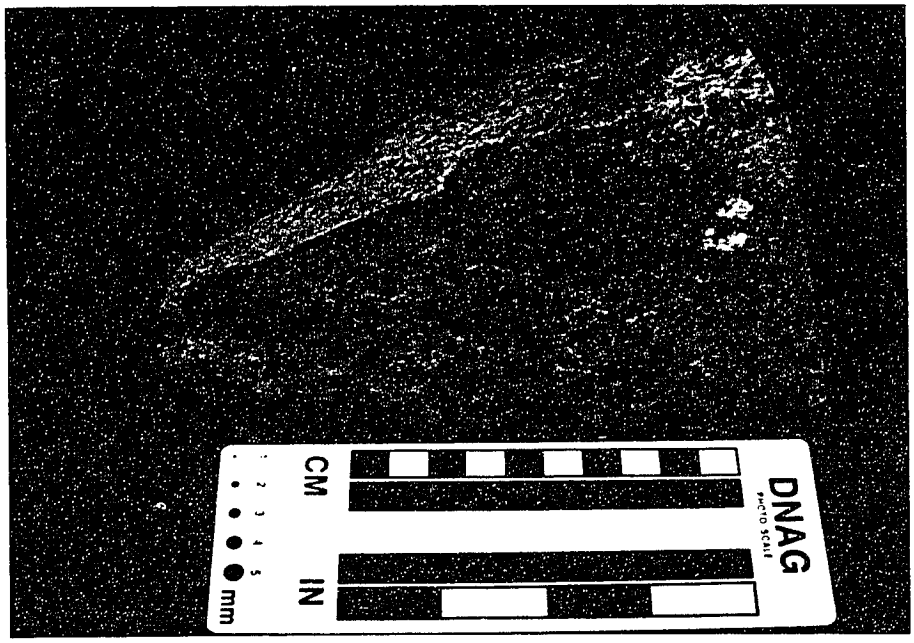


Figure C-3. Photograph of Hillabee greenstone sample GS-1-A.

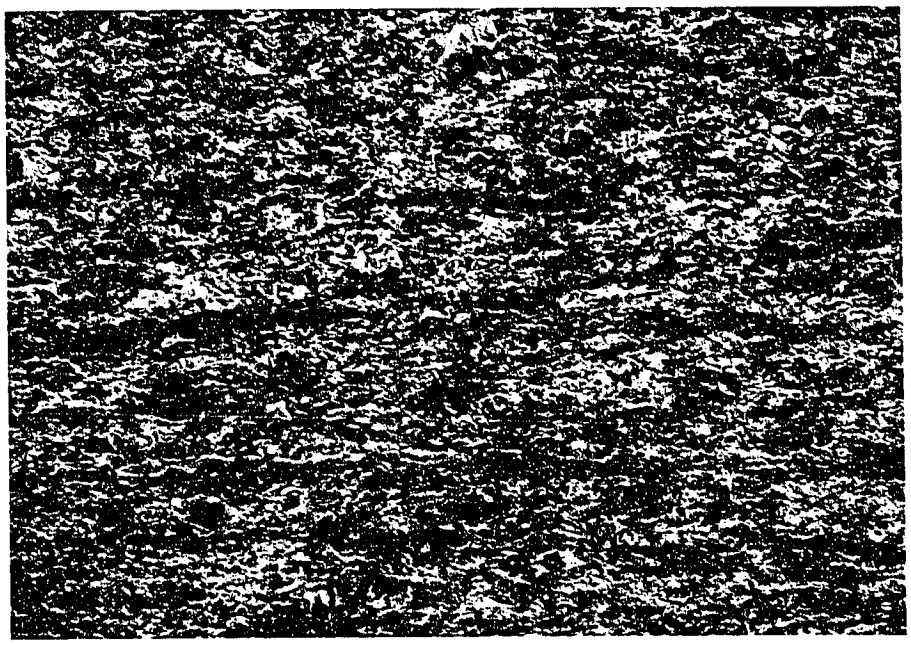


Figure C-4. Photomicrograph of Hillabee mylonite sample GS-15 showing fine-grained, banded, granular texture. The length of the photomicrograph corresponds to 5 mm, and it was taken using plane-polarized light.

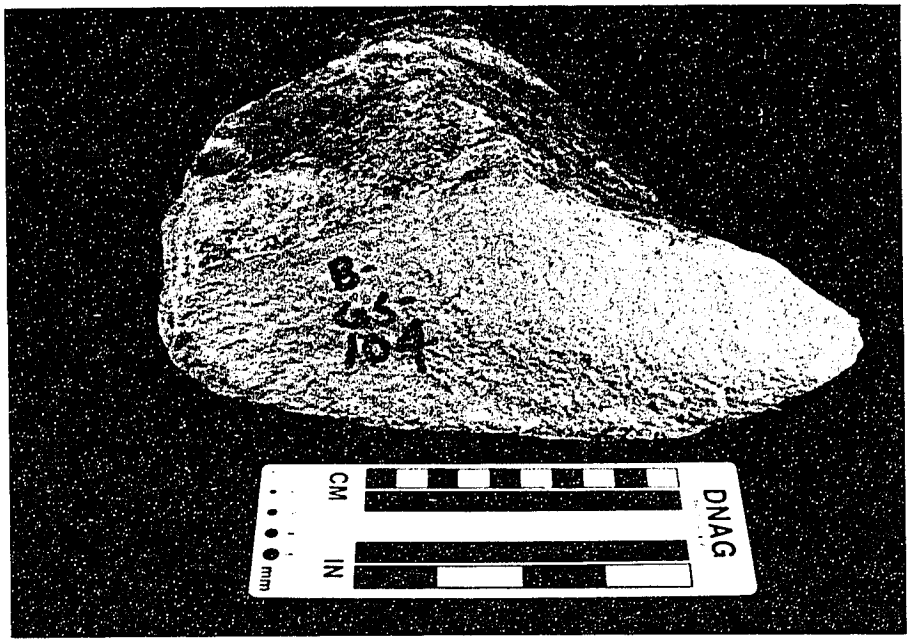


Figure C-5. Photograph of Hillabee greenstone sample B-GS-104.

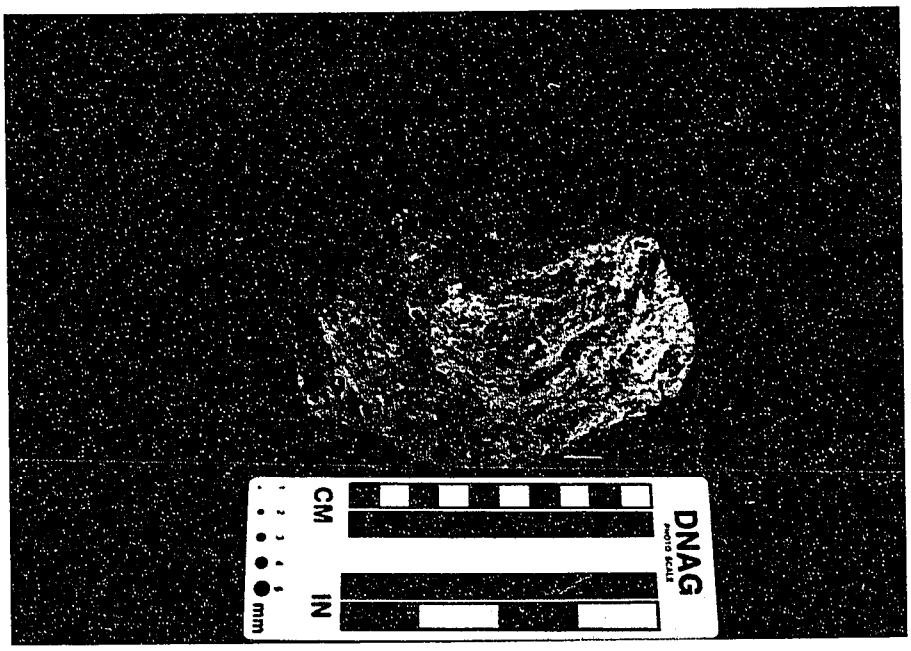


Figure C-6. Photograph of Hillabee mafic phyllite sample GS-2.

Balance. The samples' weight in air and water were measured, and densities were calculated using the following formula (Mason and Berry, 1968):

$$\text{Density} = \left(\text{Weight}_{air}/[\text{Weight}_{air} - \text{Weight}_{water}]\right) \text{ X Density}_{water}.$$

Weights, volumes, and whole rock densities for the 26 greenstone samples that were thin-sectioned are as follows:

Massive Greenstone

GS-14-A	173.60 g / 56.20 cm^3	=	3.09 g/cm^3
GS-22-B	47.88 g / 16.28 cm^3	=	2.94 g/cm^3
GS-22-C	71.53 g / 23.72 cm^3	=	3.02 g/cm^3
GS-22-D	1011.91 g / 351.5 cm^3	=	2.88 g/cm^3
GS-23	44.39 g / 14.97 cm^3	=	2.97 g/cm^3
GS-26	104.78 g / 35.10 cm^3	=	2.99 g/cm^3

GS-27	764.71 g / 257.37 cm^3	=	2.97 g/cm^3
GS-29	837.73 g / 273.85 cm^3	=	3.06 g/cm^3
GS-31-A	163.53 g / 50.58 cm^3	=	3.23 g/cm^3
B-GS-104	26.45 g / 8.58 cm^3	=	3.08 g/cm^3
B-GS-106	229.34 g / 76.44 cm^3	=	3.00 g/cm^3
B-GS-107	158.54 g / 53.65 cm^3	=	2.96 g/cm^3
	Total - 12 samples	=	3.02 g/cm^3

Granular to Crudely-Foliated Greenstone

GS-1-A	386.75 g / 129.78 cm^3	=	2.98 g/cm^3
GS-1-D	144.89 g / 49.45 cm^3	=	2.93 g/cm^3
GS-20	176.48 g / 62.29 cm^3	=	2.83 g/cm^3
B-GS-100	44.45 g / 14.88 cm^3	=	2.99 g/cm^3
B-GS-102-A	101.88 g / 34.20 cm^3	=	2.98 g/cm^3
B-GS-100.5	55.80 g / 19.52 cm^3	=	2.86 g/cm^3
	Total - 6 samples	=	2.93 g/cm^3

Mylonite

GS-6	102.42 g / 35.79 cm^3	=	2.86 g/cm^3
GS-7-B	63.67 g / 22.39 cm^3	=	2.84 g/cm^3
GS-15	669.37 g / 222.76 cm^3	=	3.00 g/cm^3
GS-24	230.92 g / 77.35 cm^3	=	2.99 g/cm^3
GS-25	386.56 g / 132.37 cm^3	=	2.92 g/cm^3
GS-28-B	131.45 g / 44.66 cm^3	=	2.94 g/cm^3
	Total - 6 samples	=	2.93 g/cm^3

Relict Diabasic Texture

GS-18	100.10 g / 33.00 cm^3	=	3.03 g/cm^3
GS-30-A	35.50 g / 11.81 cm^3	=	3.01 g/cm^3
	Total - 2 samples	=	3.02 g/cm^3

Greenstone Total - 26 samples = 2.98 g/cm^3

Rock powders were prepared by crushing slabs in a tungsten carbide puck mill (shatter box). Rock powders of the samples selected for thin-sectioning were used for X-ray diffraction analysis and multi-instrumental quantitative chemical analysis (Appendix 3). The X-ray diffractometer (copper filament) was used to identify the major mineral components of the greenstones. Mineral Powder Diffraction File Cards and results from mineral standards were used to interpret XRD data. As with the celt greenstones, the Hillabee greenstones are also remarkably similar in mineralogy; all of them are composed primarily of actinolite, epidote, and albite with minor amounts of chlorite. Minor amounts of quartz occur in the following greenstones: GS-23, B-GS-106, GS-20, GS-24, GS-25, GS-30-A. The absence or presence of quartz in detectable amounts is the only difference between the samples: 77.9% of the samples (20 out of 26 samples) do not contain quartz in detectable amounts, 23.1% (6 out of 26 samples) do contain enough quartz for it be detected. The amount of quartz present, however, is very minor because the strongest diffraction line (d-spacing = 3.343 angstroms, *hkl* = 101) is just discernible above background and no other quartz diffraction lines are readable. Variations in the relative abundance of albite to actinolite plus epidote accounts for the range in greenstone densities form 2.8 to 3.2 g/cm^3.

The following 11 greenstone samples were selected for chemical analysis: B-GS-100, B-GS-102-A, GS-1-A, GS-6, GS-7-B, GS-14-A, GS-18, GS-27, GS-29, GS-30-A, and GS-31-A. These samples of Hillabee greenstone were selected because they meet the

requirements of Moundville celt stone; that is, they are tough, they are composed of actinolite-albite-epidote metabasite, and they have similar colors and textures. These rocks were collected from the outcrops of the Hillabee Formation which are releasing boulders (alluvium and colluvium); therefore, these sources are likely candidates based on accessibility and abundance as well.

The 11 greenstone samples selected for chemical analysis came from the northern, central, and southern parts of the Hillabee Metavolcanic Complex (Fig. 30); however, large segments of the Hillabee Formation are composed of only mafic phyllite, not massive greenstone. These sections contain no celt-stone grade Hillabee lithologies for analysis (or for ax making).

Rock powders were analyzed by XRAL Laboratories of Ann Arbor, Michigan (Table C-1). The 50-element quantitative analyses used multi-instrumental techniques (X-Ray Fluorescence [XRF], Instrumental Neutron Activation Analysis [INAA], Inductively Coupled Plasma Emission Spectrometry [ICP], and Direct Current Plasma Emission Spectrometry [DCP]) to provide the best possible data for each element. The elements, lower detection limits, and analysis instruments are as follows:

Element	Lower Detection Limit	Instrument
SiO_2	0.01 wt.%	XRF
Al_2O_3	0.01 wt.%	XRF
CaO	0.01 wt.%	XRF

Element	Lower Detection Limit	Instrument
MgO	0.01 wt.%	XRF
Na_2O	0.01 wt.%	XRF
K_2O	0.01 wt.%	XRF
Fe_2O_3	0.01 wt.%	XRF
MnO	0.01 wt.%	XRF
Cr_2O_3	0.01 wt.%	XRF
TiO_2	0.01 wt.%	XRF
P_2O_5	0.01 wt.%	XRF
LOI	0.01 wt.%	XRF
Ag	0.1 ppm	ICP
As	1.0 ppm	INAA
Au	2.0 ppb	INAA
Ag	0.1 ppm	ICP
B	10.0 ppm	DCP
Ba	10.0 ppm	XRF
Be	1.0 ppm	DCP
Br	0.5 ppm	INAA
Cd	1.0 ppm	ICP
Ce	1.0 ppm	INAA
Co	0.5 ppm	INAA
Cr	0.5 ppm	INAA
Cs	0.5 ppm	INAA
Cu	0.5 ppm	ICP
Eu	0.05 ppm	INAA
Ge	10.0 ppm	DCP
Hf	0.2 ppm	INAA

Element	Lower Detection Limit	Instrument
Ir	5.0 ppb	INAA
La	0.1 ppm	INAA
Lu	0.01 ppm	INAA
Mn	2.0 ppm	DCP
Mo	2.0 ppm	INAA
Nb	10.0 ppm	XRF
Nd	3.0 ppm	INAA
Ni	1.0 ppm	ICP
Pb	2.0 ppm	ICP
Rb	10.0 ppm	XRF
Sb	0.1 ppm	INAA
Sc	0.05 ppm	INAA
Se	1.0 ppm	INAA
Sm	0.01 ppm	INAA
Sr	10.0 ppm	XRF
Ta	0.5 ppm	INAA
Tb	0.1 ppm	INAA
Th	0.2 ppm	INAA
U	0.1 ppm	INAA
V	2.0 ppm	DCP
W	1.0 ppm	INAA
Y	10.0 ppm	XRF
Yb	0.05 ppm	INAA
Zn	0.5 ppm	ICP
Zr	10.0 ppm	XRF

A comparison of the average chemical values of Tull et al. (1978) and the average chemical values for the greenstone of this study (Table C-1) are listed in Table C-2. A determination on data reproducibility between sample batches is possible because Hillabee greenstone samples GS-18 (from the central part) and B-GS-100 (from the southern part) were included with each batch of celt and Hillabee samples. The results of the analyses of GS-18 and B-GS-100 are listed in Table C-3.

Table C-1 a. Results of the 50-element, multi- instrumental chemical analyses of the Hillabee greenstone samples from the southern study area.

	Hillabee Greenstone Samples				
Element	B-GS-102A	GS-1A	B-GS-100	GS-6	GS-7B
SiO2 wt%	48.8	49.2	52.7	47.8	45.6
Al2O3wt%	14.7	14.6	13.7	15.0	14.7
CaO wt%	10.5	10.6	9.97	8.16	15.5
MgO wt%	6.71	7.75	5.27	5.94	4.25
Na20 wt%	3.28	3.35	4.08	4.3	4.05
K2O wt%	0.1	0.07	0.06	0.06	0.08
Fe2O3wt%	10.7	10.4	10.7	12.2	7.27
MnO wt%	0.18	0.18	0.25	0.53	0.14
TiO2 wt%	0.96	0.78	1.12	0.97	0.53
P2O5 wt%	0.13	0.08	0.1	0.11	0.1
LOI	2.4	2.4	1.15	4.0	7.05
Sum	98.5	99.43	99.13	99.1	99.3
Ag ppm	0.4	0.2	0.4	0.5	0.2
As ppm	<1	<1	1	<1	<1
Au ppb	6	6	6	17	<2
B ppm	<10	10	<10	10	<10
Ba ppm	50	60	50	60	40
Be ppm	1	<1	1	1	<1
Br ppm	2.1	3	2.7	3	2.7
Cd ppm	1	<1	1	<1	<1
Co ppm	52	52	58	45	36
Cr ppm	61	240	180	200	110
Cs ppm	<0.5	<0.5	<5	<0.5	<0.5
Cu ppm	10.4	93.8	55.5	62.9	84.4
Ge ppm	10	<10	<10	<10	<10
Hf ppm	<0.2	<0.2	2.9	2	<0.2

Fe_2O_3 = total iron as Fe_2O_3.

Table C-1 a. Continued.

	Hillabee Greenstone Samples				
Element	B-GS-102A	GS-1A	B-GS-100	GS-6	GS-7B
Mo ppm	<2	<2	<2	<2	<2
Nb ppm	10	10	<10	20	20
Ni ppm	34	68	62	65	50
Pb ppm	<2	<2	<2	<2	<2
Rb ppm	<10	<10	<10	<10	<10
Sb ppm	<0.1	<0.1	0.1	0.4	0.1
Sc ppm	38.5	39.5	40.2	40.1	31.9
Se ppm	<3	<3	<3	<3	<3
Sr ppm	140	90	100	90	120
Ta ppm	<0.5	<0.5	<0.5	<0.5	<0.5
Th ppm	<0.2	<0.2	<0.2	<0.2	0.5
U ppm	<0.1	<0.1	<0.1	<0.1	1.2
V ppm	250	250	280	280	330
W ppm	110	67	99	24	31
Y ppm	30	<10	20	10	10
Zn ppm	70	68	110	77	50
Zr ppm	50	20	60	50	20
La ppm	2.9	1.3	2.4	3.5	4.7
Ce ppm	9	5	8	10	11
Nd ppm	7	4	6	6	6
Sm ppm	2.7	1.62	2.34	2.27	1.55
Eu ppm	1.1	0.68	0.68	1.19	0.74
Tb ppm	0.7	0.4	0.5	0.7	0.3
Yb ppm	2.95	1.81	2.51	2.64	1.28
Lu ppm	0.48	0.3	0.4	0.38	0.21
Ir ppb	<5	<5	<5	<5	<5

Table C-1 b. Results of the 50-element, multi-instrumental chemical analyses of the Hillabee greenstone samples from the central and northern study areas.

	Hillabee Greenstone Samples					
Element	GS-18	GS-14A	GS-27	GS-29	GS-30A	GS-31A
SiO2 wt%	47.2	48.4	49.6	47.9	43.0	43.6
Al2O3wt%	13.7	13.6	13.2	14.7	15.8	14.5
CaO wt%	10.9	12.4	9.87	13.1	13.1	18.2
MgO wt%	7.08	7.15	7.81	7.41	8.43	5.08
Na2O wt%	2.06	2.26	2.54	1.84	1.02	0.38
K2O wt%	0.56	0.06	0.7	0.1	0.1	0.05
Fe2O3wt%	13.4	12.6	12.0	11.4	12.5	14.7
MnO wt%	0.22	0.21	0.21	0.18	0.21	0.17
TiO2 wt%	1.38	1.23	1.2	1.02	1.24	1.16
P2O5 wt%	0.13	0.12	0.11	0.1	0.07	0.12
LOI	2.25	1.7	2.25	1.9	2.9	1.35
Sum	98.92	99.76	99.54	99.69	98.41	99.45
Ag ppm	0.4	0.3	0.4	0.5	0.4	0.4
As ppm	19	<1	15	<1	<1	2
Au ppb	<2	5	13	8	8	66
B ppm	<10	<10	<10	<10	<10	10
Ba ppm	100	40	140	100	30	<10
Be ppm	1	1	1	1	1	2
Br ppm	2.3	2.5	2	3.1	3.4	3.7
Cd ppm	<1	<1	<1	<1	<1	2
Co ppm	58	61	54	70	69	43
Cr ppm	120	210	290	330	490	250
Cs ppm	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Cu ppm	120	83.9	211	144	<0.5	13
Ge ppm	<10	<10	<10	<10	<10	<10
Hf ppm	2.7	2.5	2.1	2.3	1.8	2.6

Fe_2O_3 = total iron as Fe_2O_3.

Table C-1 b. Continued.

	Hillabee Greenstone Samples					
Element	GS-18	GS-14A	GS-27	GS-29	GS-30A	GS-31A
Mo ppm	<2	<2	<2	<2	<2	<2
Nb ppm	10	<10	10	20	20	<10
Ni ppm	47	56	54	97	210	34
Pb ppm	<2	<2	<2	<2	<2	<2
Rb ppm	20	<10	30	<10	<10	<10
Sb ppm	2.1	0.3	3.1	0.5	<0.1	1.7
Sc ppm	48.7	49.8	46.5	44.7	47.6	45.9
Se ppm	<3	<3	<3	<3	<3	<3
Sr ppm	110	110	100	110	170	1160
Ta ppm	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Th ppm	1	<0.2	0.7	0.3	<0.2	0.3
U ppm	0.4	<0.1	0.3	<0.1	0.2	0.4
V ppm	320	300	280	260	270	280
W ppm	31	51	94	60	46	65
Y ppm	20	10	20	10	20	<10
Zn ppm	98	94	92	75	72	33
Zr ppm	80	70	80	50	60	30
La ppm	6	5.4	5	4.5	3.3	4.3
Ce ppm	15	16	13	12	9	13
Nd ppm	10	10	9	8	8	10
Sm ppm	3.2	2.97	2.65	2.43	2.79	3.32
Eu ppm	1.51	1.27	1.18	1.06	1.17	1.86
Tb ppm	0.6	0.7	0.6	0.6	0.9	0.7
Yb ppm	2.7	2.53	2.2	2.05	2.45	2.77
Lu ppm	0.42	0.38	0.33	0.31	0.37	0.42
Ir ppb	<5	<5	<5	<5	<5	<5

Table C-2 a. Average chemical values for greenstones of Tull et al. (1978) for the southern study area (South), central study area (Central), northern study area (North), and for all of the greenstones (Average).

	Hillabee Greenstones			
Element	South	Central	North	Average
SiO2 wt%	48.8	49.9	48.8	49.4
Al2O3 wt%	15.5	15.0	15.0	15.1
CaO wt%	9.8	11.1	10.9	10.8
MgO wt%	5.64	6.37	6.57	6.26
Na2O wt%	4.28	2.64	2.37	2.92
K2O wt%	0.31	0.31	0.28	0.30
Fe2O3 wt%	11.2	12.4	13.0	12.3
MnO wt%	0.184	0.169	0.191	0.177
TiO2 wt%	1.00	1.28	1.36	1.24
P2O5 wt%	nd	0.17	nd	0.17
LOI	3.76	1.62	2.38	2.25
Sum	98.85	100.1	99.99	100.15
Ag ppm	0.06	0.05	0.04	0.05
Ba ppm	118	58	61	71
Cd ppm	0.08	0.08	0.09	0.08
Co ppm	35	37	41	38
Cr ppm	167	183	84	158
Cu ppm	60	338	158	234
Ni ppm	38	50	51	48
Pb ppm	nd	21	19	20
Rb ppm	5	31	2	13
Sr ppm	188	195	211	198
V ppm	304	292	55	294
Y ppm	28	25	24	25
Zn ppm	133	72	82	81
Zr ppm	60	75	78	72
Number of samples	10	26	11	47

Fe_2O_3 = total iron as Fe_2O_3.
nd = not determined.

Table C-2 b. Average chemical values for greenstones of this study (Table C-1) for the southern study area (South), central study area (Central), northern study area (North), and for all of the greenstones (Average).

	Hillabee Greenstones			
Element	South	Central	North	Average
SiO2 wt%	48.82	48.28	43.30	47.62
Al2O3 wt%	14.54	13.8	15.15	14.38
CaO wt%	10.95	11.57	15.65	12.03
MgO wt%	5.98	7.36	6.76	6.63
Na2O wt%	3.81	2.18	0.70	2.65
K2O wt%	0.07	0.36	0.08	0.18
Fe2O3 wt%	10.25	12.35	13.6	11.62
MnO wt%	0.26	0.21	0.19	0.23
TiO2 wt%	0.87	1.21	1.2	1.05
P2O5 wt%	0.10	0.12	0.10	0.11
LOI	3.40	2.03	2.13	2.67
Sum	99.06	99.44	98.84	99.16
Ag ppm	0.34	0.40	0.40	0.37
Ba ppm	52	95	19	62
Cd ppm	<1	<1	1.4	nd
Co ppm	49	61	56	54
Cr ppm	158	238	370	226
Cu ppm	61	140	6.6	88
Ni ppm	56	64	122	71
Pb ppm	<2	<2	<2	<2
Rb ppm	<10	17	<10	nd
Sr ppm	108	108	665	209
V ppm	278	290	275	282
Y ppm	16	15	14	15
Zn ppm	75	90	53	76
Zr ppm	40	70	45	52
Number of samples	5	4	2	11

Fe_2O_3 = total iron as Fe_2O_3.
nd = not determined.

Table C-3. Chemical values for selected elements for Hillabee samples GS-18 and B-GS-100 are given for two 33-element INAA analyses (INAA#1 and INAA#2) and for the 50-element multi-intstrumental analyses (50-Elem).

	GS-18			B-GS-100		
Element	50-Elem	INAA#1	INAA#2	50-Elem	INAA#1	INAA#2
CaO wt%	10.9	11.2	10.5	9.97	9.79	7.97
Na2O wt%	2.06	2.16	2.16	4.08	4.31	4.45
Fe2O3wt%	13.4	12.7	12.3	10.7	9.58	10.15
Co ppm	58	54	55	58	60	59
Cr ppm	120	110	110	180	170	190
Hf ppm	2.7	<1	2	2.9	<1	<1
Sc ppm	49.0	47.8	47.7	40.2	40.6	40.6
Zn ppm	98	280	100	110	190	130
La ppm	6	5	6	2.4	2	2
Ce ppm	15	14	15	8	7	8
Sm ppm	3.2	2.9	2.9	2.34	2.2	2.2
Eu ppm	1.51	1.1	1.0	0.68	1.3	0.9
Tb ppm	0.6	0.7	0.7	0.5	0.6	0.8
Yb ppm	2.7	2.8	2.8	2.51	2.2	2.7
Lu ppm	0.42	0.42	0.41	0.4	0.42	0.42

Fe_2O_3 = total iron as Fe_2O_3.