ELEMENTAL ANALYSIS OF NINETEENTH CENTURY LEAD ARTIFACTS FROM LEWIS AND CLARK AND HUDSON'S BAY SITES OF THE PACIFIC NORTHWEST

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B.S. The University of Montana, 1998
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presented in partial fulfillment of the requirements

for the degree of

Master of Arts

May 2006

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Date

Lockman, Jamie Ryan, M.A., May 2006 Anthropology

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This thesis investigates the potential to use bulk element, trace element, and lead isotope characterizations to differentiate historic lead artifacts based on type and recovery location and to explore the potential to determine the source of the parent ore used to manufacture these artifacts. The sample set of artifacts, believed to date to the early to late nineteenth century, includes eight chemically characterized artifacts recovered from Travelers' Rest, Lolo, Montana and thirty chemically characterized artifacts recovered from various locales at Fort Vancouver National Historic Site, Vancouver, Washington. The analysis was completed using an Inductively Coupled Plasma Mass Spectrometer (ICP-MS) at Missouri University Research Reactor (MURR). An additional thirty-eight artifacts and modern manufactured bullets, characterized using lead isotope analysis alone, are included from outside studies for comparison.

This investigation employs a framework of six steps that examine the historical, use-life, deposition, and recovery contexts, elemental analysis, and data interpretation to facilitate a successful elemental analysis. This six step framework also includes a decision matrix to assist with interpretation of the results based on artifact form and chemical characterization. The potential to determine the parent ore source of the artifacts is investigated using an additional five step framework. By applying the first six step framework, it is determined that bulk element, trace element, and lead isotope analysis are powerful tools to differentiate artifact form and recovery location. An especially relevant finding is that ball and shot artifacts are chemically distinct, possibly due to manufacturing differences. The investigation also finds that it is problematic to attempt to determine the parent ore sources of the artifacts, likely due to the common practice of alloying lead products, recycling old lead into new products, and using mixed ore sources.

ACKNOWLEDGEMENTS

At long last, it is time to acknowledge everyone who has helped, supported, endured, believed, forgiven, and cheered as this project has come together. It would be an empty accomplishment if I couldn't share the joy of completing this project with all who have encouraged me.

I must first thank my professors and teachers. Teaching is a noble and generous profession. Your time, dedication, and commitment to passing on your knowledge to students is infinitely appreciated. I am grateful to Dr. John E. Douglas for being patient, kind, encouraging, and supportive, to Dr. Thomas A. Foor for giving me opportunities to think and to develop professionally, and to Dr. Nancy W. Hinman for pushing me further than I thought I could go. Additionally, I am grateful to Linda McLean and the entire Department of Anthropology at The University of Montana. The School of Business at The University of Montana has also been an integral part of my educational experience. I value the support and interest of Dr. Michael Brown, Dr. Joe Weber, Dr. Theresa Beed, and Sue Malek. I must also acknowledge my gratitude to those teachers who shared their talents throughout my education including (but not limited to) Sister Mary Hourigan, Father Bob Fox, Thomas Shepard, Nancy Marmont, Jim Cusker, Hal Stearns, and Greg Hirst. I have thought of you and your lessons during this process.

I am grateful to my professional colleagues. This thesis would never have been conceived and completed without the support and sponsorship of Bob Cromwell at Fort Vancouver and Daniel S. Hall of Western Cultural Inc. Thank you for believing me capable of this undertaking! My coworkers at HRA, Inc.; T. Weber Greiser, Janene Caywood, Derek Beery, Brian Herbel, Bjorn Iverson, Jesse Adams, and Todd Ahlman, must also be credited for their encouragement and tolerance. Thank you too, Steve Platt of the Montana Department of Transportation, and Damon Murdo of the Montana State Historic Preservation Office, for their understanding and words of cheer!

I am grateful for the financial support provided by the National Parks Service through the assistance of Bob Cromwell, Kathy Tonnessen, Darryll Johnson, Stephanie Toothman, David Louter, Douglas Wilson, Elaine Huff, Tracy Fortmann, and Jim Thomson, and for financial assistance provided by the Missouri University Research Reactor through the assistance of Dr. David Robertson, Barry J. Higgins, James McKamey Guthrie, and Pam Altman. I am obliged to James McKamey Guthrie and Barry J. Higgins at the Missouri University Research Reactor for their assistance and commitment to excellence. A word of thanks to Sharon Thomson, Database/Collections Specialist, Western Canada Service Centre, Parks Canada in Calgary for assistance with the Rocky Mountain House artifacts. I had the serendipitous and great pleasure of meeting Sara Workman Hall and am grateful to her for generously granting permission to use her data.

I must thank my family. You have been incredibly patient with me. I have missed dinners, birthdays, vacations, weddings, and funerals to squeeze in a little extra time with my thesis. I look forward to spending time with you. I am indebted to my parents for their absolute belief in me. Thank you. I love you both.

Thank you to my friends Hal, Carolyn, Kathleen, Toni, and Carmen. You are always in my thoughts and prayers. Knowing that I share in your unconditional friendship has made this project less lonely. Please know that your faith in me is as necessary as

breathing. Another big thank you to the Mother/Daughter book group; you keep me centered!

Thank you, thank you, thank you, to my daughter Gwen. I can’t thank you enough for your assistance, your words of encouragement, your backrubs, your forgiveness, your love, and your understanding. You helped get this done. I hope that your educational path will be smoother now that you have first hand experience with graduate school!

To all my children, reach as far as you can! I love you and believe in you all!

And lastly, I am deeply indebted to my husband Clem. What a ride we’re having! I am so happy to be sharing it with you! I love you!

Dedicated to Mom and Dad,
Kristen, Andria, Tyler, Elliot, Camden, and Gwendolyn,
Meghen and Chase,
Willie P. and Grandma Inez,
Nana Mary, Nana Ruth, and Papa Tom,
And to my
Ever loving, supportive, and patient husband, Clem

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Chapter 1
INTRODUCTION

In 1805, Lewis and Clark became the first Americans to trek across the North American continent from the eastern United States to the western Pacific Coast. The Captains, more than forty men, the singular woman, Sacagawea, and her infant son Jean Baptiste Charbonneau, followed the Missouri River, crossing the Bitterroot Mountains, ultimately following the Columbia River to reach the Pacific Coast.[1] While Lewis and Clark were the first Americans to reach the Pacific Ocean by crossing the Rocky Mountains, many Euro-Americans preceded Lewis and Clark on the North American West Coast, arriving in the region from west, south, and east routes. While personal, corporate, and political motives were many, the search for a Northwest Passage that might link the Atlantic and Pacific Oceans and subsequent trade it could produce propelled many explorers.

More than sixty years before the Lewis and Clark Expedition, Russians, under the command of Vitus Johassen Bering, a Dane, pushed east across what became known as Bering Sea in the 1740s. The Russians established fur trade in present day Alaska beginning in 1742 (Newman 1998: 201-203). From the south, Spanish navigators extended their knowledge of the West Coast by mapping and exploring north from California all the way to the Queen Charlotte Islands by 1774 (Newman 1998: 220).

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[1] The exact number of men accompanying Lewis and Clark is unknown as a no formal roster was ever completed.

West coast inquiries by the British, initiated in 1778 by Captain James Cook, continued the quest for the Northwest Passage. Cook optimistically and incorrectly identified the Northwest Passage as Cook's River in 1792 (Ronda 1998: 6). He was followed by several exploratory expeditions, including those of American trader Robert Gray, Captain of the *Columbia,* who reported in 1792 the longitude and latitude of the Columbia River, named for his ship.

Captain George Vancouver was also on the Pacific Coast in 1792, the year he claimed the Columbia River for Britain (Thomas et al. 1984: 29). Vancouver and his men charted the Columbia as far inland as Sandy River on the south bank approximately 32 km (20 miles) east of present day Portland, Oregon (Ambrose 1996: 308). In 1794, under orders of the British government, Vancouver located Cook's River to explore it as the much expected Northwest Passage. Vancouver found Cook's River was a false hope rather than the desired passage and renamed the location Cook Inlet (Ronda 1998: 6).

North West Company[2] explorer Alexander MacKenzie traversed the North American Continent in 1793, going as far south and west as the mouth of the Fraser River. While the quest for the Northwest Passage was for naught, the fur trade continued to develop. Americans, from Boston, and British traders were already exploiting the fur trade on the Pacific Northwest Coast when Lewis, under the direction of United States President Thomas Jefferson, developed the plans for the expedition using in part MacKenzie's account of his explorations west. The plans included the possibility of

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[2] The North West Company name occurs as both two words "North" and "West" and as the singular "Northwest." The author chose to employ the spelling commonly used by the National Park Service.

meeting trade ships already working the Pacific Coast and possibly providing back-up supplies if needed (Ambrose 1996: 315).

Shortly postdating the Lewis and Clark Expedition, in 1807, David Thompson, also of the North West Company, established Kootenai House on the upper Columbia River, north of present day Montana in British Columbia (Josephy 1959: 37). By 1812, American John Jacob Astor established Fort Astoria at the mouth of the Columbia River (Thomas et al. 1984: 29).

The Lewis and Clark Expedition represents a pioneering, systematic movement of a culture into a new frontier. Lewis planned the expedition relying on documents and experiences of Euro-Americans attempting travel into the area before him. The success of the venture relied not only on the informed preparation, but also on building relationships with Native American people living in the areas in which they traveled. Important to establishing friendly relations with Native Americans were gifts and the promise of future trade. The trek was epic and successful in producing documents, observations, and collections that provided invaluable knowledge to those following them who hoped to find success in the land newly acquired by the fledgling United States.

Mined and manufactured goods accompanied the Euro-Americans. They assumed value not only as supplies for successful journeys, but as trade items and gifts to the Native Americans who occupied the land. Native American trade routes facilitated the flow of Euro-American trade goods throughout the Pacific Northwest, preceding the actual presence of Euro-Americans. The trade routes were well established and in long existence prior to the Euro-American efforts to establish their own trade with Native

Americans (Ewers 1988: 34). Lewis and Clark recognized the native trade and recorded in their journals the presence of Euro-American trade goods along the Missouri and the Columbia Rivers. They found some Native Americans that they encountered anxious to develop a relationship with the Americans to obtain trade goods, specifically, the guns and ammunition that their enemies already possessed.

Such supply and trade items brought first by the Euro-Americans, then traded and passed amongst and between Native Americans, remain as physical evidence of the tentative exploratory and commercial movements into the landscape that ultimately lead to the settling of the West. Lead ammunition, bale seals, bar, and assorted other fabrications served as necessary supplies, desirable trade goods, and incidental debris, first appearing in the Pacific Northwest as Euro-Americans made their exploratory incursions into the region. Archaeological excavations combined with historical inquiry and scientific analysis provides meaningful interpretation of these historical artifacts and their movement among the traders, both Euro-American and Native American.

Lead artifacts, because of lead metal's usual non-corrosive characteristics, are commonly recovered from historical archaeological contexts. Bulk element, trace element, and lead isotope analysis provide an avenue for investigating and interpreting artifacts, potentially linking them within and between assemblages and providing the potential to determine the mine source of the lead used to fabricate the objects.

Travelers' Rest[3] served an important role in the transcontinental exploration occurring from 1803 to 1807, by the Corps of Discovery, lead by Captains Meriwether

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[3] Several spellings exist and have been used historically for Travelers' Rest. The author chose the spelling used by the Travelers' Rest State Park. Any variations throughout the text represent other authors' spelling choice.

Lewis and William Clark. The Corps twice stopped and camped at the site at Lolo Creek, Montana; the first stay occurred September 9-11, 1805 with the return to the site about six months later June 30 – July 3, 1806. The name "Travelers' Rest" occurs as the site name in the journals of Lewis and Clark during the first stopover in 1805. The camp served as a point of preparation for crossing the Bitterroot Mountains, as the point of separation on the return, and as an important crossroads of western geography as understood by Lewis and Clark through earlier Euro-American explorations of the West and as conveyed by Native Americans the Corps that encountered on the journey.

An investigation attempting to precisely locate Travelers' Rest took place in August and September of 2003 in preparation for the Bicentennial of the expedition. The investigation sought to formally recognize and better document the suspected location of the camp as a National Historic Landmark.[4] The interdisciplinary investigation, under the direction of archaeologist Daniel S. Hall, Western Cultural, Inc., consisted of historical and ethnographic research, remote sensing techniques (magnetometer, electromagnetic conductivity, metal detectors, and mercury vaporizer analysis), historical archaeological excavations, and laboratory analysis (radiocarbon dating, lead isotope, and artifact analysis). Archaeological and historical evidence from the investigation assembled to establish the site's connection with the Lewis and Clark Expedition included fire hearths

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[4] The existing National Historic Landmark nomination is broad and imprecise, encompassing a large enough area to include both sides of Lolo Creek from the Bitterroot River south of US Highway 93 and to areas north of the highway as well. Daniel S. Hall's work strives to more precisely locate Travelers' Rest on the south side of Lolo Creek, approximately a mile and a half from its confluence with the Bitterroot River (Hall et al. 2003).

and a latrine trench; a tombac button;[5] a blue trade bead; a melted portion of metal, artifact number WC-TR-324, originally identified as lead; and expedition journal descriptions of the locale.

The research presented in this thesis began with the investigations into artifact WC-TR-324. As part of the initial investigation, Geochron Laboratories of Cambridge, Massachusetts, was contracted to submit a sample of the melted metal to lead isotope analysis. The analysis was done in hopes of determining the provenance or source of the parent material. The closest ore sample match to the artifact was a sample retrieved from Olive Hill, Kentucky. Several expedition members, including William Clark, were residents of Kentucky; therefore, because the location was within the realm of being reasonably linked to the Expedition, this match was used as one of the “multiple lines of evidence” to determine a more definitive location of Travelers’ Rest (Hall et al. 2003).

Upon further examination of the lead isotope data of the single artifact, it became apparent that determining the provenance of the metal ore used to manufacture the artifact would be difficult. For example, in addition to the Kentucky ore sample, there were other ore sources with similar lead isotope signatures from Maine, England, and France (Figure 1-1). Moreover, historical research did not provide any indication that Kentucky ever had a significant lead mining industry. Documentation of what lead mining occurred in Kentucky was mostly anecdotal in nature and took place later than the early 1800s, postdating the Lewis and Clark Expedition. Given that the artifact sample was similar to diverse ore samples with a lack of historical documentation supporting

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[5] Tombac, also known as German or Dutch brass, is an alloy of mostly copper and zinc used to make ornaments and jewelry. 1994 *Webster's New World Dictionary Of American English*. Third College ed. Prentice Hall, New York..

lead mining in the region where the artifact data most closely matched, the likelihood of sourcing the artifact to a particular ore source diminished. The lack of clear evidence linking the lead isotope data to a specific source resulted in further research on the applications and limitations of the lead isotope analysis as method of artifact analysis.

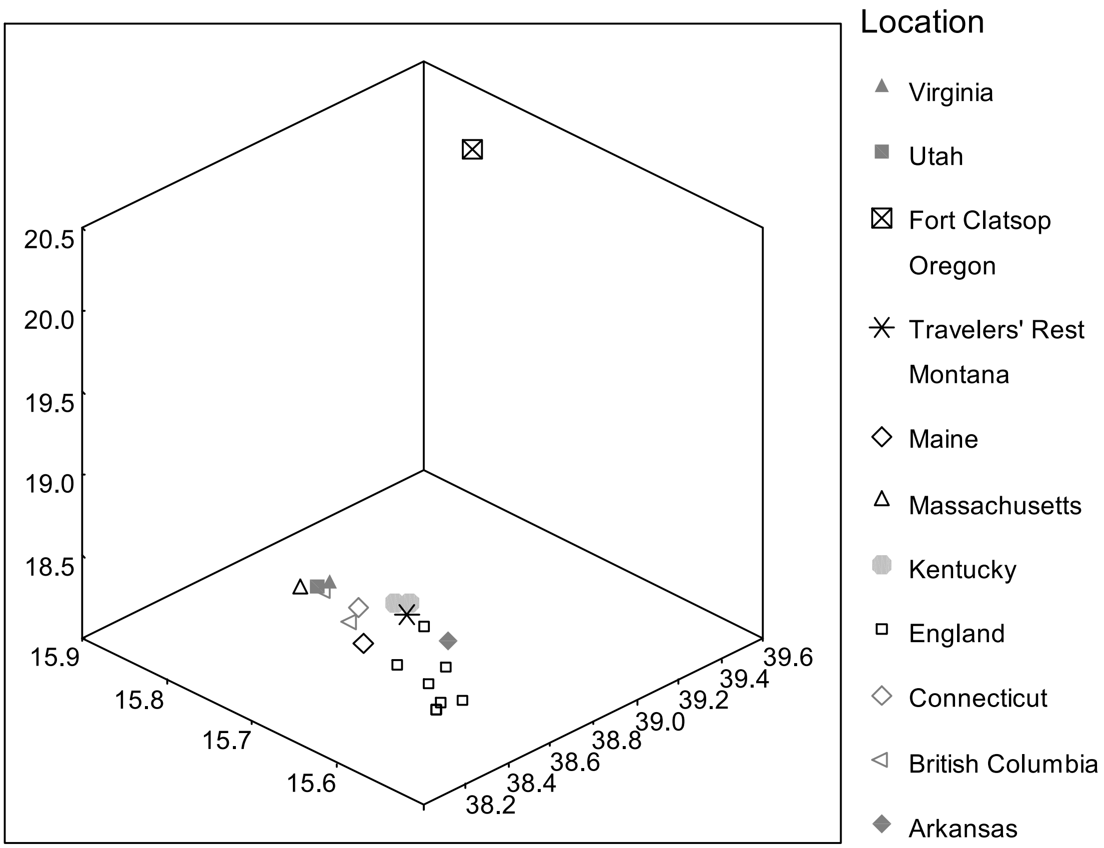

Figure 1-1 Artifact WC-TR-324 and Fort Clatsop artifact placed within an array of possible lead ore sources (Appendix A).

Researching lead isotope analysis resulted in identifying other small-scale studies that employed the technique as a method of analysis applied to historic artifacts. This research provided the basis for developing a project that would place the lead isotope data from artifact WC-TR-324 within a broader context of characterized historic artifacts, perhaps providing a more relevant interpretation. In order to understand better the chemical character of the artifacts, both bulk element and trace element analysis were also conducted. Bulk element analysis identifies the bulk or primary metal elements of the lead artifacts. Trace element analysis identifies chemical elements present in the artifacts to parts per million (ppm).

Research also produced a method of organizing the chemical analysis problem within two multi-step frameworks. The first framework (Table 2-1) provides a method formulating the research and analysis based on six steps evaluating the historic, use-life, deposition, recovery contexts and elemental analysis provided by an artifact or given set of artifacts (Hancock 2000: 11-20). The six step framework also includes an associated decision matrix (Table 2.3) that assists with interpreting the data collected from the previous five steps using quantitative or statistical methods (Hancock 2000: 12). The second framework provides five additional steps for evaluating the appropriateness of determining the ore source of a given artifact (Table 2-4).

The goals of this thesis are twofold. The first goal is to determine whether the approach of combining bulk element, trace element, and lead isotope analysis is a valid method of inquiry in order to place characterized artifacts within a broader context of characterized artifacts. If the approach is valid, then what can be learned from placing the artifacts within a broader context? The second goal is to determine whether lead isotope analysis can be used to associate a particular historical artifact with its parent ore source.

Chapter 2
METHODS

Project Initiation

In addition to attempting to match artifact number WC-TR-324 to an ore sample, the initial comparative analysis focused on an artifact recovered from the Lewis and Clark archaeological site at Fort Clatsop. Located on the south bank near the mouth of the Columbia River, and south of present day Astoria, Oregon, Fort Clatsop served as the wintering camp for the Lewis and Clark Expedition from December 7, 1805 to March 23, 1806 (Moulton 1990: 2). This line of inquiry resulted in obtaining lead isotope data from a single lead ball retrieved during 1996 excavations at Fort Clatsop (Farquhar 1997). It provided a single comparison of lead isotope data of artifacts recovered in the Pacific Northwest. The comparison of the two lead isotope characterizations revealed little about the artifacts other than the two appeared to be composed of material with very different lead isotope signatures.

In the course of searching for comparable artifacts recovered from Fort Clatsop, Robert Cromwell, National Park Service Archaeologist at Fort Vancouver National Historic Site, became an instrumental contact for this project. Cromwell suggested analyzing a sample set of lead artifacts collected from the vast collection recovered from the Fort Vancouver and Kanaka Village properties to establish a database for comparing the characterized lead artifacts. The National Park Service (NPS) within the United States Department of Interior (USDI) provided funding for the analysis of thirty artifacts from

Fort Vancouver, seven artifacts from Travelers' Rest, and a reanalysis of the original Travelers' Rest "lead puddle." Missouri University Research Reactor (MURR) further underwrote the project.

The planned analysis included obtaining bulk element, trace element, and lead isotope data for the artifacts. These analyses methods are collectively known as elemental analysis. Bulk element analysis was employed to identify the primary metal components, including alloys, of the artifacts. Trace element analysis was included to strengthen the data comparisons of the artifacts by employing additional variables for the statistical analysis and to understand the elemental composition of the artifacts. Lead isotope analysis was included to provide more precise chemical characterizations based on three lead isotope ratios.

Fort Vancouver serves as a suitable source for obtaining artifacts comparable with the Travelers' Rest artifacts, not only because of its vast collections, but also because it was the center for the distribution of goods used in the Pacific Northwest fur trade from 1825 – 1849 (Caywood 1947: 2). When the North West Company surrendered to and was absorbed by the British Hudson's Bay Company (HBC) in 1821, the conception of Fort Vancouver represented the company's radical new strategy of trade expansion into the Pacific Ocean and exploitation of western Rocky Mountain fur resources (Newman 1998: 498). The establishment of Fort Vancouver also represented the British attempt to thwart United States expansion and boundary claims. The fort was established as a trading hub by the Hudson's Bay Company in 1825 on the north bank of the Columbia River and a little over a hundred miles from where the Columbia empties into the Pacific Ocean

(Caywood 1947: 6; Newman 1998: 498). During the winter of 1828-1829, the fort was moved closer to the Columbia River for more convenient shipping access and potable water sources (Caywood 1947: 6).

The fort, accessible by British ships via a route around Cape Horn at the tip of South America, was conceived to be self-sustaining. The fort served not only the Hudson's Bay Company traders, but also Russians and American traders, religious missionaries, and early settlers (Caywood 1947: 6). The fort maintained farms, lumber mills, grain mills, a shipyard, and repair shops in order to lessen reliance on transporting building supplies, food, and perishable goods (Caywood 1947: 6). Inside the Fort's stockade walls, measuring approximately 200 by 120 m (700 by 400 ft.), were at least twenty-two structures including a bastion, trade store, bakery, kitchen, churches, store houses, powder magazine, the Chief Factor's house and well structures (Caywood 1947: plate 30). Outside the stockade wall was the Kanaka Village consisting at various times from thirty to seventy-five buildings. Kanaka Village, established by at least 1832, was a scattered collection of homes where the various laborers employed Hudson's Bay Company and their families lived (Carley 1982: 1; Hussey 1957: 216-221). The village dwellers were of Hawaiian, Native American, French, English, and American cultural heritage (Hussey 1957: 218). The United States Army took possession of the location in 1849 and by the 1850s began clearing out the village structures (Hussey 1957: 220).

Thirty artifacts were randomly selected for the analysis. The chosen artifacts varying in form and recovery location provide representative Hudson's Bay Company and United States Army artifacts.

Laboratory Identification of Lead

Although lead may seem a simple metal to identify, as will be demonstrated in this investigation, lab identification by archaeologists can be difficult.

In general, lead is identified by its softness, gray color, metallic luster, high specific gravity, and malleability (Light 2000: 12). Although not a recommended approach for all artifacts, pure or nearly pure lead artifacts scratch easily. Galena or lead sulfide (PbS), the most common lead ore, registers 2.5 on the Mohs hardness scale, is easily scratched with a penny (Nesse 2000: 99, 385-386). Bullets and shot commonly contain pure lead with trace elements present, however lead frequently occurs with alloys such as arsenic, antimony, tin, and bismuth (Light 2000: 12). Lead does not conduct electricity well, nor is it magnetically susceptible. Lead generally resists corrosion very well although upon exposure lead rapidly oxidizes and changes color from bluish gray to dull gray.

Framework for artifact analysis

The first question addressed in this thesis concerns what information can be learned about the artifacts from their chemical characterizations. The chemical characterizations are accomplished by subjecting artifact samples to analyses measuring attributes unavailable to ordinary human observation capabilities. Advanced scientific methods of observation include using technologically sophisticated and sensitive instruments to investigate and consider attributes that would otherwise be unnoticed (Ciliberto 2000: 4). Once the analyses are complete, then the researcher organizes and interprets the resulting data using quantitative or statistical methods.

Because numerous scientific techniques are available for artifact elemental characterization, it is necessary to evaluate a given approach for appropriate use. Choosing a technique requires balancing what type of problem exists with laboratory accuracy and sensitivity, with the precision required. Additionally, financial considerations and equipment availability are considerations when determining a technique for advanced scientific analysis (Ciliberto 2000: 6). In some cases, elemental analysis stands alone as a method of investigation. In other cases, elemental analysis should be combined with physical analysis for effective evaluation of artifacts (Hancock 2000: 11).

Ronald Hancock suggests a "chain of events" or six steps evaluating the historic, use-life, deposition, and recovery contexts relevant to a given set of artifacts, the chemical analysis those artifacts undergo, and the interpretation of the results (Table 2-1). The six steps provide a framework for raising questions about the possible chemical deletions and additions that objects undergo before being submitted to elemental analysis in order to complete an appropriate interpretation of the resulting data. This framework allows the investigator to incorporate an evaluation of the archaeological data not only relevant to the elemental analysis, but also to consider critically the archaeological data. Once the five steps have been completed, the resulting data are then interpreted using quantitative or statistical techniques.

Hancock's steps, as tailored for the investigation of the lead artifacts, build on one another, providing a logical investigative sequence. The goal of the first step is to identify possible chemical alterations of raw materials as they are processed and formed into artifacts through individual small scale production or large scale mass manufacture. The second step conceptualizes the artifacts' use-life and possible chemical alterations that may occur during expected use. The third step in the continuum considers the chemical affects of long-term storage or deposition. The fourth step pursues documenting the recovery processes the artifact undergoes and examines the possibility of chemical alteration due to artifact cleaning and handling. For this thesis, the fourth step also evaluates the archaeological data, specifically evaluating the stratigraphic integrity of the excavations producing the recovered artifacts. The fifth step is the elemental analysis itself (Hancock 2000: 11-20). The sixth step draws on the data collected during the previous five steps and applies appropriate quantitative or statistical methods for interpretation.

Hancock's Six Steps	Suggested Questions
Historical contexts	How was object constructed? What raw materials were historically available for its fabrication?
Use-life	How was the object altered during its use-life? Was the object moved from its origin?
Deposition	How has the object changed since it was discarded?
Recovery	How has the object been treated since its archaeological recovery? What information is available from the recovery?
Elemental Analysis	What methods are used to chemically characterize the object?
Data Interpretation	What do similarities and differences in the data mean? How are historical, use-life, deposition, and recovery contexts interpreted in light of the chemical data?

Table 2-1 Hancock's six steps for successful analysis (Hancock 2000: 11-20).

Historical Context

The first step Hancock advocates for a successful analysis is to attempt to understand the production or manufacture of the artifacts undergoing analysis.

Understanding the process by which a given object was made allows the researcher to consider the possible raw materials used to create an artifact and how the processes used to make the artifact may alter the elemental concentration of those raw materials (Hancock 2000: 15-16). This step can be broadened to consider whether a given artifact was produced as the result of a single production episode, and therefore a unique object, or whether the artifact was the result of mass production, possibly similar to numerous other artifacts. The researcher may also consider for sourcing purposes whether raw materials may have been collected far from the manufacture location or traded for the production or manufacture of the artifact.

Historical research provides a context for understanding artifact fabrication and importantly for the elemental analysis, the introduction, or deletion of chemical elements.

Use-life Alterations

The second step considers how the artifact's elemental composition may be altered during its use-life. Alteration may occur by absorbing or leaching out certain elements by exposure to heat, water, chemicals, and/or weather depending on how the artifact was used (Hancock 2000: 16). Questions to consider during the second step include defining the normal use of the artifact and whether the artifact shows use wear evidence. Use wear may indicate not only how it was used, but if it was ever used or was rather lost or discarded before use. The researcher at this step may also consider whether the artifact was traded during its use-life and if so, likely trade routes and raw material sources. While trade is not likely to affect an artifact's elemental composition, the researcher may gain insight in order to address problems determining the source of raw materials used for fabrication and artifact comparison.

Normal use of lead artifacts would not subject them to lead isotope alteration, except in the case where lead objects of varying sources were remelted and recycled into new objects. It is impossible to discern from the appearance of an object whether an object underwent such conversion.

Deposition

Steps 3 and 4 consider how the artifact is affected after being discarded and no longer in use. Step 3 considers how and where the artifact was discarded and what environmental forces may affect the elemental composition of the artifact. Similar to the issues raised in the second step, questions such as the absorption or leaching and potential alteration of chemical elements are considered.

Recovery

Step 4 considers the archaeological methods used to recover artifacts, the resulting data, and how the artifacts are treated after recovery. This strategy considers questions such as artifact cleaning and subsequent storage that may affect the artifact. Depending on the goals of the analysis, chemical agents as innocuous as water can affect the elemental analysis. Additionally, simply handling the artifact with bare hands can have a detrimental effect on certain future analyses. The data provided by the controlled excavations at Travelers' Rest and Fort Vancouver provide the underlying context of the artifact recovery histories.

Elemental Artifact Analysis

Step 5 addresses the elemental analysis itself. Elemental analysis determining the bulk chemical, trace element, and lead isotope signatures serves to characterize the chemical composition of artifacts through a variety of techniques depending on the needs of the investigation.

Bulk Element Analysis

Bulk element analysis is used to identify the primary metal components of a given artifact and answers the general question “What is this made of?” This question is important serving often as the initial categorization of an artifact such as silver, tin, iron, or lead. This initial categorization leads to formatting further research. Techniques and instrumentation vary for obtaining bulk chemical compositions.

Bulk elemental techniques generally require that an analytical sample be obtained from an object and that the sample be dissolved in solution. Inductively coupled plasma – mass spectrometry (ICP-MS), as well as atomic absorption spectroscopy (AAS), optical emission spectroscopy (OES), and inductively coupled plasma-atomic emission spectrometry (ICP-AES) can be used to analyze the dissolved samples.

Sample dissolution preparation often requires experimentation to obtain the best results. For example, as a rule, nitric acid (HNO_3) is the preferred dissolving agent for all materials and is especially appropriate for materials composed of iron, copper, and their alloys (Young and Pollard 2000: 24-25). The exceptions include employing hydrochloric acid (HCL) as the preferred dissolving agent for bone or metal and paint materials (those materials primarily composed of gold, silver, tin or lead; or tin and lead alloys; and using hydrofluoric acid (HF), the best choice for mineral, ceramic, or glass samples (Young and

Pollard 2000: 24-25). Materials with intermediate composition require experimentation with both HNO_3 and HCL to determine the optimum mixture for dissolution (Young and Pollard 2000: 25).

Trace Element Analysis

Trace element analysis serves to further understand and refine the chemical composition characterizations. Chemical analysis, using a number of techniques, serves to identify elements present at parts per million (ppm) levels. By identifying the composition of a given artifact, the data can then be used to solve a variety of archaeological problems addressing questions such as trade routes and the movement of articles between varying groups of people within a geographical area (Hancock 2000: 12).

Trace elements in metal objects occur via natural inclusions within an ore source or through introduction of alloying metals (Hancock 2000: 14). It is a common practice to add various minerals in the alloying process to produce a more desirable product. For example, antimony is often added to molten lead fabricated for shot and bullets to achieve harder projectiles that maintain shape better when fired (Minchinton 1990: 54).[6]

Conversely, trace elements can also be eliminated during the smelting or fabrication processes through evaporation or selective removal. For example, silver often found in sufficient quantities with lead ore, make it, despite additional processing steps and costs, economically feasible to collect. During the smelting process, silver is

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[6] "Hard" or "chilled" shot, as it is known, came into formal production in the 1860s after the Civil War.

“cupelled” or collected from the molten metal, with lead essentially being the by-product rather than the primary product of production (Gowland 1912: 264).

Despite the disadvantages of trace element analysis, it is surmised that artifacts manufactured from the same “batch” of lead would have a similar chemical composition. Thus, trace element analysis is employed to understand more fully the chemical composition of the artifacts. The trace element data adds variables for statistical analysis to more precisely identify similarities and differences.

Additionally, trace element analysis in archaeology is often used for matching artifacts to identified source material. For example, it has been successfully applied to identifying obsidian sources, because obsidian deposits have fairly homogeneous chemical compositions within well known and well defined geographic locations. While variations within obsidian sources do exist, the chemical compositions between source locations are generally distinct (Reeves and Brooks 1978: 365).

Trace element analysis has met with varying degrees of success for archaeological applications of identifying the parent source of materials such as chert, glass, clays used in ceramics, and metals including gold, silver, lead, and tin (Reeves and Brooks 1978: 363).

Because the lead artifacts underwent selective addition and subtraction of trace elements through the smelting and fabrication processes, trace element analysis is only included in this project to investigate whether including the additional data is beneficial for establishing meaningful patterns within the data.

Lead Isotope Analysis

Lead (Pb), has four stable isotopes, ^{204}Pb, ^{206}Pb, ^{207}Pb, and ^{208}Pb. Three of the isotopes, ^{206}Pb, ^{207}Pb, and ^{208}Pb, are generally portrayed as ratios to ^{204}Pb, providing unique identifying signatures of analyzed material. The four lead isotopes vary in relative proportions depending on the geological history of particular ore deposits (Brill and Wampler 1967: 63). Of the four isotopes, ^{204}Pb is primordial, existing at the time of planet formation. ^{206}Pb is the result of the radioactive decay of ^{238}Uranium (U), ^{207}Pb is the result of the radioactive decay of ^{235}U, while ^{208}Pb is the result of radioactive decay of ^{232} Thorium (Th) (Table 2-2.). The ability to utilize lead isotopes for investigation of the origin and age of geological formations, and specifically ore deposits, has been available to scientists since the late 1920s (Doe 1970: 1; Rabinowitz 1995: 649).

Four lead (Pb) isotopes	Present at planet formation: ^{204}Pb ^{238}U → ^{206}Pb ^{235}U → ^{207}Pb ^{232}Th→ ^{208}Pb

Table 2-2 Four lead isotopes including primordial (^{204}Pb) and those resulting from the radioactive decay of parent material (^{206}Pb, ^{207}Pb, and ^{208}Pb).

Most studies until the late 1960s focused on questions regarding geology and determining the age of the earth, but it became apparent that the unique geologic histories of ore deposits made available data signatures that could be used to source ores. The ability to identify ore deposits based on isotopic signatures make lead isotope analysis a useful tool for many applications, including medical investigations, environmental studies, forensics, and archaeology (Brill and Wampler 1967: 63-77; Gale et al. 1984: 389-406; Habicht-Mauche et al. 2000: 709-713; Meharg et al. 2002: 81-86; Stupian et al. 2001: 1342-1351).

Pioneering archaeological applications of lead isotope analysis by European archaeologists included investigations on the ore sources of Bronze Age artifacts (Sayre et al. 2001: 77-115; Trincherini 2001: 393-406). Investigations broadened to address a variety of sourcing questions around the world including studies of Egyptian cosmetics (Shortland et al. 2000: 153-157), Chinese bronzes (Yeung et al. 2000: 487-491), galena artifacts from Archaic/Woodland sites from the Eastern United States (Farquhar and Fletcher 1984: 774-785), and Rio Grande pottery glazes in the American Southwest (Habicht-Mauche et al. 2000: 709-713).

Robert H. Brill and J. M. Wampler were among the first to apply lead isotope analysis to archaeological questions. Their 1967 study attempted to match Aegean Bronze Age artifacts to known Greek, Spanish, and British ores sources. Brill collected 230 lead samples, 70 samples of lead ores and 160 samples from lead artifacts. The initial samples were analyzed at the Chemistry Department of Brookhaven National Laboratory in Upton, New York, using a thermal-emission mass spectrometer under the direction of Dr. J.M. Wampler of the United States Atomic Energy Commission (Brill and Wampler 1967: 63). Ore sources in Greece, Spain, and Britain were sampled to provide provenance data in the study. The work had two goals; the primary goal was to analyze and characterize isotopic signatures of lead ore samples from likely ancient mine works, the secondary goal was to determine whether it was possible to correlate isotopic signatures from artifact samples to those specific ore signatures.

Brill and Wampler were able to categorize the ore sample signatures into three main groups according to geography. Importantly, isotopic signatures of those artifacts known to have come from a particular geographic area matched isotopic signatures of ore samples analyzed from those areas (Brill and Wampler 1967: 64).

However, the project revealed several problems with lead isotope analysis. Among them, samples of lead ores may not be available for sourcing because the mines have been worked to such an extent that little remains or because they never have been identified (Brill and Wampler 1967: 64). Another problem identified by this project is that geographically separated samples may have similar isotopic signatures due to a similar geologic history. Additionally, lead ore samples from geographically close areas may be quite different from one another (Brill and Wampler 1967: 64).

For archaeological applications, one of the primary advantages of using lead isotope analysis for characterizing artifacts is that very small samples are needed to examine the material and is therefore not overly intrusive on the integrity of a given artifact (Brill and Wampler 1967: 63). Additionally, when objects are fabricated from lead recovered from a single ore source, lead isotopes do not vary as the result of mining, smelting, and manufacture of the lead ore into products.

The primary limitation of using lead isotope analysis on artifacts is that when material from various ore sources are mixed, there is an alteration of the signatures. Isotopic signatures of lead from mixed origin will have intermediate values, and it is a challenge to identify if mixing has taken place (Brill and Wampler 1967: 70, 73). One way around this problem is to use the data to draw negative conclusions. It is possible to rule out single sources and to conclude that lead artifacts were not manufactured from ore from a single or particular locale (Brill and Wampler 1967: 72). However, this approach still does not address or help to identify whether a given sample is the result of mixed origin ores.

Attempts to determine the provenance of artifacts to ore sources holds additional disadvantages; while isotopic signatures of ore sources are fairly consistent, it is possible for isotopic composition to vary within a source (Brill and Wampler 1967: 63). While the potential to correspond artifacts to ores deposits exists, the ultimate strength of lead isotope analysis is that unlikely sources can often be eliminated (Brill and Wampler 1967: 71; Yener 1986). An additional use of the technology is the production of a lead isotope database of signatures assigned to artifacts, in order to compare the signatures of artifacts within and between assemblages.

In the early days of lead isotope analysis, in order to compare samples, it was necessary that the samples be prepared in a similar fashion prior to analysis and that analysis was completed on the same mass spectrometry instrument (Brill and Wampler 1967: 73). As equipment and methods evolved, and with the development of standard test blanks or reference materials, inter-laboratory comparisons became feasible. Both precision and accuracy standards are important factors to consider when comparing the analysis from different laboratories (Brill and Wampler 1967: 73). Accuracy of measurements refers to the standard error of the measurement, while precision refers to the reproducibility of the measurements. Brill and Wampler were hopeful that using lead isotopes to determine the source material of artifacts would prove to be a useful tool to the archaeologist with geographically expanded sampling and technological improvements (Brill and Wampler 1967: 71).

Farquhar and Fletcher (1984) provide a straightforward provenance study of native ore galena artifacts recovered from Late Archaic/Early Woodland burial sites to illustrate the potential for lead isotope studies. They concluded that using lead isotope analysis was an effective method to distinguish lead artifacts from one another and to identify possible ore sources within a given region. Artifacts were analyzed, and then their lead isotope signatures compared with an existing lead isotope database of ore sources. They identified a single vein of galena in Rossie, New York as the origin of artifacts found in a widespread area of the Northeastern United States, while dismissing local galena ores as possible sources of the artifacts. By identifying a single source, they assigned ceremonial or cultural significance to the site. Farquhar and Fletcher admitted that it would be possible for ore to be moved by natural hydrologic forces to outlying areas, thus weakening the argument. Because the artifacts were formed of unsmelted ore, mixed ore sources were not a factor(Farquhar and Fletcher 1984: 783).

Missouri University Research Reactor (MURR)

The Missouri University Research Reactor (MURR) was chosen to conduct the chemical analysis because the laboratory has extensive experience testing artifacts, had available time, and provided underwriting costs of the project (Glascock 2006: electronic document). James McKamey Guthrie, research chemist, provided the following information on sample preparation, lead isotope, and trace element analyses (Guthrie 2004).

Initial sample preparation was begun by inspecting each artifact to identify an appropriate inconspicuous location selected for sampling. An attempt was made to control for extraneous surface material by employing a razor blade to scrape the selected area to reveal bare metal. Once surface material was scraped away and the bare metal exposed, the sample was then masked with tape and the tape cut away over the area that had been scraped to reveal the area to be sampled.

To retrieve the actual sample, a small .4 to .9 mm (0.020 to 0.036 in.) drill bit was used to bore a hole into the artifact. The first shavings obtained were discarded, to control for extraneous surface material. Only material removed from deep within the hole was collected for the sample. Each artifact produced 10 to 30 mg (.00004 to .001 oz.) sample material for analysis.

Once the sample materials were recovered and weighed, they were placed into pre-cleaned, trace metal free, virgin polypropylene tubes. In order to break the sample down into its chemical components, 1.5 mL of Fisher Brand Optima Grade Hydrochloric Acid (HCl) was added to each tube. The samples were then allowed to "digest" or break down at room temperature. Samples dissolved in a period ranging from days to weeks depending on the chemical make up of the artifact. Once the samples were dissolved completely, 250 µL Fisher Brand Optima Grade Nitric acid (HNO_3) was added to the tubes. The "digestates" were then diluted to a total volume of 10 mL with ultra-pure water. All tubes were weighed to calculate the precise mass of digestate.

To establish control and provide a basis for evaluating the precision and reliability of the analysis, four reagent blanks were prepared in the same way to monitor tube and reagent backgrounds. Additionally, replicate digestions of samples "WC-TR-320" and "FV-SS-8062" were prepared, with each replicate originating from a different sampling area on the artifact in order to establish homogeneity of the artifacts. All samples were diluted using gravimetric serial dilutions to appropriate concentrations for trace metal analysis, Yttrium (Yb) and Indium (In) were added to the final dilutions in order to control for internal standards and to correct the instrument raw data for sample matrix effects.

A high-resolution GV Platform hexapole ICP-MS was used for the analysis. It was calibrated using two series of linearity standards prepared from dilutions of commercially available High-Purity Standards multi-element solutions. A four-point curve was used for all elements. The Yb/In internal standards were added to these linearity standards as well. Blanks and quality control (QC) standards were analyzed among the samples during the analytical run in order to correct for analyte backgrounds and ensure consistent instrument response.

The measured concentrations were multiplied by total sample dilution factor in order to determine the concentration of each analyte in the lead metal. The sample limit of detection (LOD) was calculated by multiplying the instrumental limit of detection by the total sample dilution factor. The instrumental LOD is calculated as three times the standard deviation of the concentration of each analyte measured in ten runs of a blank solution.

A solution of dissolved Standard Reference Material (SRM) 981, “Common Lead Isotopic Standard” was prepared to 50 parts per billion (ppb). SRM 981 solution was analyzed before and after every pair of samples. Each analysis consisted of ten runs (separate measurements) of all Pb isotopes. In addition, ^{202}Hg was monitored in order to correct for a possible ^{202}Hg interference in the ^{204}Pb data. It was determined that this correction was not necessary.

The small mass bias of the instrument was corrected for each sample using the two bracketing analyses of SRM 981 solution. The ratios ^{206}Pb/^{204}Pb, ^{207}Pb/^{204}Pb, and ^{208}Pb/^{204}Pb were calculated using this corrected data. For the ten runs of each sample, the ratio means and standard deviations were calculated and reported.

Data Interpretation and Conclusion Matrix

With Step 6, Hancock provides the researcher a starting point for data interpretation by suggesting possible combinations of appearance and chemical composition with likely conclusions drawn from the combinations. Table 2.3 derived from the combinations provides a clear and logical framework for organizing data. Once the chemical element data are generated, interpreting and presenting the data in a meaningful way is necessary to proceed with comparisons. Bigger questions such as sourcing, trade and the movement of goods can then be considered (Hancock 2000: 11-20).

Physical form	Chemical composition	Conclusion
Artifacts look alike.	Same chemical composition.	Artifacts made from same source.
Artifacts look alike.	Similar chemical composition.	Artifacts probably made from same source.
Artifacts look alike.	Different chemical composition.	Artifacts probably made from different source.
Artifacts look different.	Same chemical composition.	Artifacts made from same source.
Artifacts look different.	Similar chemical composition.	Artifacts probably made from same source.

Artifacts look different.	Different chemical composition.	Artifacts probably made from different source.

Table 2-3 Organizing physical and chemical attributes of artifacts and drawing probable conclusions based on those attributes (Hancock 2000:12).

Steps for Determining the Parent Ore Source

The second question posed with this thesis is whether lead isotope analysis can be employed to associate a particular artifact with its parent ore source. A framework originally developed for using trace elements to identify source material is adapted for lead isotopes (Reeves and Brooks 1978: 364). The outline for matching artifacts with identified raw material sources through lead isotope analysis is presented in Table 2-4.

Steps for Successful Source Identification Using Chemical Analysis
1. Identify raw source material from discrete locations within given geographical region.
2. Collect and analyze samples from each location.
3. Data from samples should show that variability is greater between source locations than within source locations.
4. Use sample data to establish parameters that can be applied with a high degree of confidence to distinguish between source locations.
5. Analyze archaeological material and assign to the source locations using step 4 (discriminant analysis).

Table 2-4 Steps for successful source identification using chemical analysis (Reeves and Brooks 1978: 364).

Steps 1-4 have been developed in previous studies. The lead isotope data are available as discrete lead ore sources characterized by lead isotope in the Doe Database (Doe and Rohrbough 1977) as well as in journal articles and geological reports on specific locales (See for example Gale et al. 1984: 389-406; Heyl et al. 1966: 933-956; Moorbath 1962: 295-360). Therefore, it is only necessary to consider whether it is reasonable to compare the analyzed artifacts with characterized locales.

Chapter 3
RESULTS: LEAD ARTIFACT CONTEXTS AND ANALYSIS

Historical Context

Historical research of the artifacts focuses on the history of lead mining and production in Europe and in the United States, ammunition manufacture through time, the function of bale seals, bar and pig lead production, and lead recycling. Additional research focuses on understanding the historical context of the Travelers' Rest and Fort Vancouver artifacts.

Lead Mining, Smelting, Refining, and Alloying

The use of metals serves as a milestone in the development of human societies. Importantly, metal provides material for the manufacture of tools and implements. Gold, silver, and copper, known as native metals, are aesthetically pleasing. In their most pure state, they are useful as elements to create objects of adornment, prestige, and exchange, rather than serving as elements useful for tool manufacture. The native metals are too precious, soft, and malleable to create effective tools. And except for copper, they are also rarely found in a naturally recognizable state (Gowland 1912: 237).

Gowland imagines that the recognition of the value of metals began at a hot campfire that unexpectedly became a crude furnace when a certain rock heated by the embers, melted, and glowed. Experimentation with the resulting metallic globule provided the chance to recognize the attractive, malleable, and hard or soft qualities (Gowland 1912: 237). Archaeologically, the earliest evidence of metal use is often seen in manufactured ornaments (Rabbitt 1979: 7). Gold, copper, and some silver artifacts occur throughout the world at early dates. However, lead is not recognized as serving as an important mineral in prehistoric times (Rabbitt 1979: 7).

Lead production is a straightforward process beginning with mining and concentration, proceeding to smelting, refining, and alloying. Lead processed direct from ore to final product is a primary production. Post production recycling of lead is known as secondary production (Thornton et al. 2001: 47-48).

Lead ores occur throughout world and are the often found in the form of galena ore, described chemically as PbS. A sulfide mineral, it is often pure, however, silver can substitute for sulphur within the crystal structure of the mineral. Galena has a lead-gray color, metallic luster, and produces a lead-gray streak. It is soft, with a measurement of 2.5 on Moths scale of hardness and dense, with a specific gravity of 7.58 grams per cubic centimeter (g/cm^3) (Nesse 2000: 385-386). One of the desirable qualities of lead is its low melting point of 327.5° C. Galena is found in both igneous and sedimentary rocks (Nesse 2000: 385). Other lead ore minerals include the carbonate, cerussite ($PbCO_3$); the sulfate, anglesite ($PbSO_4$); and the lead phosphate chloride, pyromorphite ($Pb_5 [PO_4]_3Cl$). Often lead occurs with other minerals such as silver, zinc, copper and gold, and can be considered a by-product of ore processing (Thornton et al. 2001: 50).

Once lead ore has been mined, extraneous rock material known as gangue must be removed in an operation known as ore concentration. This is accomplished in a variety of ways including washing the mined ore with water to leave the desired heavier lead ore, using sifting or shaking methods, or grinding the ore until to a pulp then adding water and/or chemicals (Thornton et al. 2001: 50). The goal of these processes is to prepare the ore for smelting.

The following simplified descriptions of smelting and refining provide a basis for understanding the processes required for producing metallic lead. The goal of smelting is twofold; first, sulphur is removed from the lead ore to produce lead oxide; second, the lead oxide is reduced to metallic lead. Metallic lead has such a low melting point that lead smelting can be accomplished using simple hearths and available fuel. In the first stage, air is required to reduce the sulphur content of the lead. The chemical equation for the release of the sulphur to produce lead oxide is:

$$2PbS + 3O_2 => 2PbO + 2SO_2$$

Before the advent of modern pollution controls, the sulphur dioxide ($2SO_2$) was simply released into the air. The remaining lead oxide (2PbO), now in chunks, is then reduced by adding a carbon (coke)[7], other fluxing agents such as silica, and heat. The chemical equation for the reduction of lead oxide to metallic lead is:

$$2PbO + C => 2Pb + CO_2$$

The molten slag produced from the fluxing agents contains a large amount of incidental elements such as zinc. This slag floats to the top of the molten lead. The molten lead, however, still contains trace amounts of minerals such as gold, silver, copper, tin, arsenic, antimony, and bismuth. The lead is now ready for refining to recover or remove remaining impurities (Thornton et al. 2001: 52)

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[7] Coke is the nearly pure carbon residue produced by roasting coal in the absence of oxygen.

Lead refining requires separate processes to remove specific minerals. Silver was commonly collected from lead by cupellation, an inefficient but effective means of recovery. Gold can also be recovered through this method. Cupellation is achieved by heating and stirring lead metal in oxygen to created lead oxide. The silver and gold are then left behind. The lead oxide can then be re-smelted to again produce metallic lead.

European Lead Use, Production and Sources

As a building material, lead obtains an aesthetically desirable white patina, resists corrosion under most circumstances, is unaffected by cold temperatures, is easy to form or mold, accepts paint, and can be worked into intricate designs (Weaver 1909). The disadvantage of lead is that it can "creep" and require maintenance to ensure design and structural integrity.

Lead did not become a widely desired or useful commodity until the Roman Iron Age beginning at about 250 BC (Kitman 2000: 14; Tylecote 1976: 53, 169). The Romans found that lead was useful for their large civic building enterprises, and particularly for use as plumbing material. Because it is malleable, non-corrosive, relatively easy to mine, smelt, and process into the desired product, it did not command the high price of other metals. The Romans also found lead useful to manufacture uniform bullets used with slings for its large organized armies (Tylecote 1976: 53). In addition to the extensive public works projects, the Romans used lead for cisterns, statues, coffin sheets, and pewterware with a very high (1:1) lead to tin ratio (Tylecote 1976: 62).

The Romans exploited the lead mineral resources in conquered territories in Britain, Spain, and Central Europe as evidenced by the remains of lead slags (the molten ore waste) and litharge (PbO) at smelting sites. Lead pigs (large ingots) bearing inscriptions that include the date and ruling emperor at the time of manufacture have also been recovered by archaeologists notably near the Roman exploited Mendips lead mines in Britain dating to the first century AD (Tylecote 1976: 61). In ores where the silver content was high, lead became a by-product rather than the primary commodity of production. This was the notable case in Laurion, Greece (Tylecote 1976: 61).

The decline of the Romans caused lead mine production to decline. However, those mines, such as at Beinsdorf, Saxony, containing ore with high silver content continued to be worked to a great extent. Evidence suggests that sufficient lead was available through collection and recycling of the Roman public works, as they fell into disuse with the destruction of their towns (Tylecote 1976: 76). The lull in lead mining production lasted until the demand increased for building material of the medieval period.

The European non-ferrous metal mining experienced a boom in the medieval age partly due to large-scale building projects such as cathedrals and monasteries. Roofing, gutters, leaded windows, pipes, and lead glass increased the demand for lead, copper and tin (Burt 1995: 24). Lead took the position as the desired building material because it is simple to process, inexpensive, malleable, and easily repaired. Central Europe provided most of the lead demanded at this time frequently recovered as a by-product of precious metal mining. (Burt 1995: 24).

After an initial upsurge of production during the period, several factors finally served to create an environment that again depressed European mining economy for all metals towards the end of the medieval period. The reasons included governmental control of mining, large mines with deep shafts, full-time specialized labor, cheaper metals shipped from the New World, increased cost of extracting ore from existing sources, and interestingly, a large influx of recycled lead claimed from disbanded monasteries in England (Burt 1995: 24). Britain did not experience the depression as deeply as continental Europe because it had small scale, part time miners who supplemented their farm production by mining, a lack of governmental intervention, and surface or shallow ore sources that lacked precious metals (Burt 1995: 24-25).

British lead mining methods continued at medieval scale at least until the end of the seventeenth century (Burt 1995: 23). Small scale mining occurred by part time miners with crude ore collecting, smelting, and processing techniques. The industry avoided taxation by the government because of the insignificant production. However, as demand increased for lead products with increasing industrialization and large building projects, independent owner-operated mines were so entrenched in the culture and Common Law that the British Crown met too many obstacles to alter the existing system. The British mining industry was poised to meet increasing demand at home, in the Colonies, and in Europe at the end of the seventeenth century with its small scale, flexible capabilities. Capitalist investment became significant and possible due to the lack of government control over the expanding industry.

In Europe, increased building in cities and by new industries, military use of firearms, and packaging and shipping perishable goods to and from new Colonial markets created new demands for lead beginning in the seventeenth century (Burt 1995: 34)

New World Lead Sources

Historic detection and exploitation of the lead ore sources in North America, centered on the Mississippi and Missouri river valleys, closely followed the French exploration and development of fur trade opportunities. The Spanish, controlling the lower portion of the Mississippi, hoped to find sources of gold and silver, and had little interest in fur, lead, or trade with Native Americans. The French and the British however, found the fur trade lucrative. Trading relationships with Native Americans and small and scattered settlements strengthened their strategic positions and territorial claims (Rabbitt 1979: 10).

The competitive fur trade of the British and the French lead to the incorporation of the great trading companies the Hudson's Bay Company and the North West Company. The Louisiana Purchase and subsequent American free navigation of the Mississippi provided the Americans with opportunities to develop a stronger presence in the international fur trade. The successful explorations of the Lewis and Clark expedition and of Zebulon Montgomery Pike helped the Americans to establish their own trading presence and relationships with tribes, and lead to the exploitation of American controlled resources. Private companies such as John Jacob Astor's American Fur Company and government owned "factories" participated in the fur trade, establishing relationships with the native people.

These commercial and governmental concerns lead to the development and settling of the west as Euro-American traders, manufactured goods, forts, and subsequent agriculturists and military presence pushed the frontier westward. The development of mineral resources of the Missouri and Mississippi proved itself integral to this push westward.

The earliest account of lead ores in North America dates to 1658, likely the result of early French traders and explorers Pierre Esprit Radisson and Medard Chouart, Sieur Des Groseillers excursions, contact, and trade with the Sioux on the Upper Missouri. Nicholas Perrot, at the end of the 17th Century, exploited several sources of lead ore in this area (Rabbitt 1979: 10). The French were instrumental in the early exploration of North America, attempting to further their goal of profitable fur trading. Montreal established itself as an early center of the fur trade with exchange taking place on the network of rivers and lakes extending inland from the St. Lawrence (Chittenden 1986, 1935: 87). The early fur trade, established by French corporate entities represented by traders and trappers, found the most success establishing trade relationships with the Native North Americans (Chittenden 1986, 1935: 88). Ironically, French trader Groseilliers took the initiative to establish the Hudson's Bay Company under British authority, officially chartered as Governor and Company of Adventurers of England in 1670 (Chittenden 1986, 1935: 90).

In 1668, French trader Groseilliers, after suffering imposition of other French interests in what he perceived to be his trading domain, acquired the patronage of Prince Rupert of England for his fur trading enterprise (Chittenden 1986, 1935: 89). The English investment in the French concern included a ship and cargo of trade goods that led to Groseilliers subsequently establishing the first fort on Hudson's Bay. The fort, under

English sponsorship, was called Fort Charles, after the English King (Chittenden 1986, 1935: 89).

In 1687, Reverend Father Louis Hennepin produced a map indicating a lead mine near Galena, Illinois (Thwaites 1903: 301). Robert Cavalier de La Salle (La Salle) and Cadillac explored the Upper Mississippi Valley in the late Seventeenth Century furthering the knowledge of the lead sources. Lead mines noted along the Mississippi River were included on a map produced in 1703 (Walthall 1981: 18). The French loosely controlled the two early supplies of lead in North America by the beginning of the Eighteenth Century in the Upper Mississippi Valley in present day Illinois, Iowa, and Wisconsin and on the Meramec River in Missouri (Walthall 1981: 18).

Julien Dubuque began production at lead mines at the mouth of the Wisconsin River in Iowa in 1788. Dubuque had obtained the rights to exploit the ores from the Fox, reportedly producing “between 20,000 and 40,000 pounds of lead per year” that was then processed into lead pigs (Walthall 1981: 19; Williams 1992, 1953: 231). After Dubuque’s death in 1810, the Fox took control once again of the lead mines. The Sacs, a closely related tribe to the Fox, mined the locations, sending the ore to American traders and settlers across the Mississippi who processed the ore by smelting. Schoolcraft notes that at one time, the Native Americans smelted the lead in crude “log-heaps,” but they abandoned the practice to the Americans. The American traders encouraged the Fox and Sacs to scavenge the former smelting works to collect lead ashes for further processing to retrieve lead.

In 1820, Henry Schoolcraft, hired on as a geologist as part of an expedition to investigate the Upper Mississippi, made a special effort to visit "Dubuque's Lead Mines" (Williams 1992, 1953: 223-224). Schoolcraft convinced the Fox and Sacs tribal members to show him the mines after negotiations and a gift of whiskey and tobacco. He describes the general mineralogy of the lead as "common sulphuret of lead, with a broad foliated structure, and high metallic luster" found in veins or beds near the surface and easily mined or collected (Williams 1992, 1953: 225). Schoolcraft describes crude "drifts" extending underground approximately 40 feet, best described as pits rather than tunnels. Women and older men of the Fox and Sac tribes, used simple tools such as crowbars, shovels, axes, and hoes, sold by the American traders, to retrieve the lead ore in baskets. The Fox and Sacs then canoed the ores across the Mississippi to the Americans for trade and smelting. Schoolcraft notes that there are three additional mines on the Mississippi that are worked exclusively by Native Americans; the Sissinaway Mines and the Mine au Fevre on the east bank of the Mississippi, and Mine of Maquanquitons fifteen miles above the Dubuque Mines on the west bank of the Mississippi (Williams 1992, 1953: 226-227).

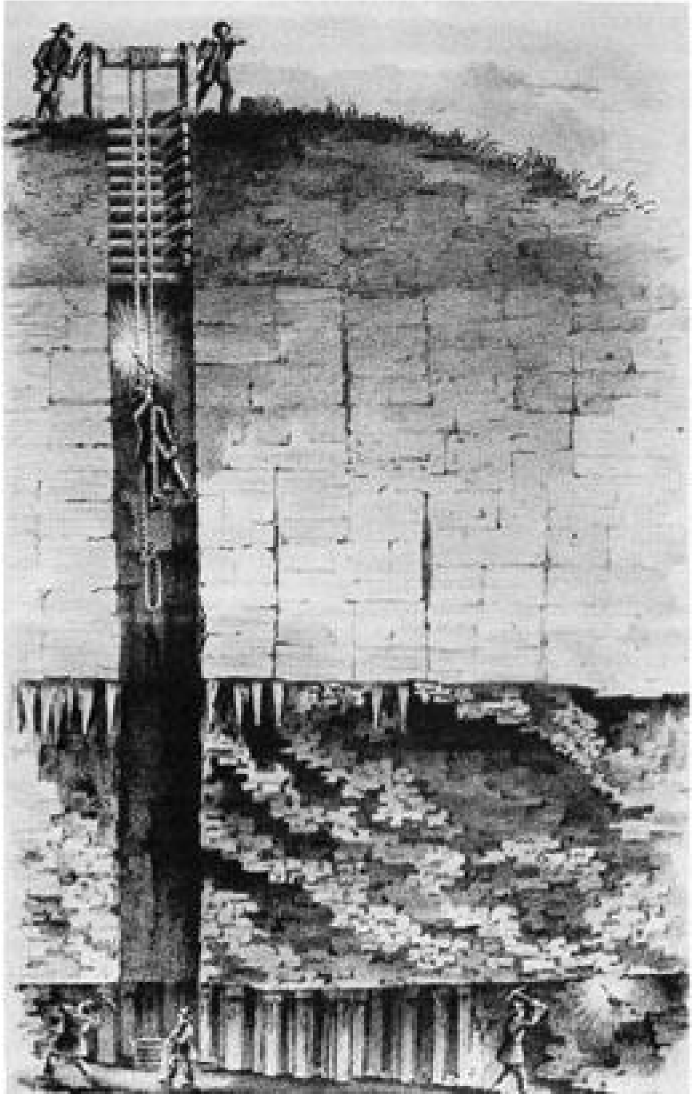

Figure 3-1 Lead mining as illustrated by David Dale Owen in 1844 (Owen [1844], 2005: electronic document).

As shown in the illustration by David Dale Owen, lead mining is not a complex endeavor (Figure 3-1). In 1819, on an excursion preceding his ventures above St. Louis in 1820, Henry Schoolcraft provides a glimpse at the informal nature lead mining while investigating the “mineralogy, geology, geography, antiquities, soil, climate, population and productions” newly available in Missouri to the United States with the Louisiana Purchase (Schoolcraft 1972). Schoolcraft wrote and submitted a report with the goal of better developing the mineral resources that had been casually producing for the French since the late 1600s. In the early nineteenth century, holes were dug by hand with a pick and shovel to approximately 15 feet to recover the ore. Speculation often served as a means of locating promising sites, sometimes with surface indications of lead ore. A shovel and bucket provided the means to bring ore to the surface where it subsequently underwent cleaning and breaking up large bits of ore into uniform size (Figure 3-1). A simple log furnace provided a means to smelt the ore (Schoolcraft 1972: 90). The mineworkers ranged from speculators, to farmers earning extra income, to slaves in some cases. Very few records were kept regarding the particulars of operating mines (Schoolcraft 1972: 113). The smelted lead manufactured into lead pigs, bars, and shot was then warehoused, sold or shipped down the Mississippi to New Orleans by entrepreneurs consolidating the production of the furnaces (Schoolcraft 1972: 121)

Most lead production in the United States at the turn of the nineteenth century centered in the Mississippi Valley, particularly in Missouri. There were small operations throughout the United States however, as noted by Henry Schoolcraft. For example, Schoolcraft makes note of a lead mine discovered in 1799 in Millersburg, Kentucky, approximately forty miles south of Limestone, Kentucky, presently known as Maysville on the Ohio River. Schoolcraft notes that the mine, known as Elliot's Mine, produced lead at an exceptional seventy-five percent of the cleaned ore processed. The Elliot Mine is described as a shaft forty feet deep sunk into a vein surrounded by white quartz in a bluish limestone (Schoolcraft 1972: 278-280).

The United States Government reserved one third of all lead ore sources, along with gold, silver, and copper, in the Ordinance of 1785 (Rabbitt 1979: 2, 35). Gold and silver occur in negligible quantities east of the Mississippi, so lead became the mineral of governmental and entrepreneurial focus. With the Louisiana Purchase of 1803, the United States received a massive parcel of mostly unexplored, unmapped land with only a vague idea of the minerals present. The United States Government, under the recommendation of Secretary of Treasurer, Albert Gallatin, reserved all mineral lands from sale (Rabbitt 1979: 20). The existing lead mines caused difficulties in reserving the mineral interests to the Government, so Congress changed the reservation to allow for the private leasing of lead lands in 1807 for three year periods and reserving a ten percent royalty on all smelted ores, payable at the smelter (Rabbitt 1979: 20).

The nature of lead mining made enforcing leases difficult and unpopular, as in Britain, leading to a provision allowing the government to sell the lead lands in 1829 (Rabbitt 1979: 2). Preceding the sale of the lead mines, government policy was to manage the lead mines as an element of national security (Rabbitt 1979). Missouri Statehood, in 1821, brought a change of lead lands management, transferring it from the Treasury Department to the War Department (Rabbitt 1979: 31). Pressure increased however, calling for the sale of lead mines. President James Monroe, in his 1822 address to Congress, emphasized the importance of lead to the security of the United States and suggested that lead mines should be managed by a skilled mineralogist (Rabbitt 1979: 32). In 1824, George Graham, Commissioner of the General Land Office recommended selling the lands for revenue and to promote efficient production from the mines (Rabbitt 1979: 32).

Little lead mining occurred west of the Mississippi until after the Black Hawk War of 1832 (Rabbitt 1979: 58). Thereafter, miners and farmers were eager to settle the newly available rich and fertile land of Wisconsin.

By the 1840s, lead production in the United States met domestic needs with surplus available for export (Rabbitt 1979). Missouri lead production peaked in 1845, and by 1849, the United States again imported lead (Rabbitt 1979: 87). The Civil War brought about a renewed urgency for recycling lead products for ammunition supply, especially in the North (Rabbitt 1979: 139). Mining also began changing rapidly to more industrialized deep mining ventures with the large capital investments necessary for production. In 1869, the discovery of deep lead ore deposits led to new mining methods assisted by technological advances that made them feasible (Rabbitt 1979: 174). Ores in Nevada, rich in silver, called for using a blast furnace rather than the crude furnaces that had remained functional since their development earlier in the century (Rabbitt 1979: 185-186). Rich lead mines in Nevada moved the center of lead ore production to the West (Rabbitt 1979). Substantial lead mining occurred further west in the late 1800s usually becoming established after gold mines began playing out. Rich ores were found in Utah, Idaho, and Montana in the United States and British Columbia in Canada (Fuller 1931: 307-308).

There are at least two rather anecdotal stories of Native Americans mining lead in the west undertaken specifically to smelt the ore for bullet production using simple technology. One story indicates that Native Americans used what became the rich Blue Bell mine on Kootenay Lake in British Columbia (Fuller 1931: 308). The second story, better documented, although still somewhat thin in detail, is found in the letters of Dr. John McLoughlin, chief factor at Fort Vancouver of the Columbia District of the Hudson's Bay Company. Dr. McLoughlin wrote to William Smith, Secretary of the Hudson's Bay Company in 1833 noting the native residents of the Queen Charlottes Islands (in present day British Columbia) mined, smelted, and molded enough locally available lead that they had no need to seek lead from the Hudson's Bay Company traders (Rich 1941: number 115). Although lacking hard evidence, the occurrence of Native American lead bullet production was thought to be accurate and included in scholarly notes by geographer Robert Brown who traveled the area in 1866 (Brown 1868: 386).

Lead Production and Manufacturing

Several artifact types were recovered from both Travelers' Rest and Fort Vancouver including lead ammunition, lead seals, bar lead, and fragments with unknown function. A discussion of lead ammunition manufacture and lead seal production and manufacture is included to explore the types of lead artifacts under investigation and to understand their fabrication history and subsequent use.

Ammunition Production and Manufacture

The use of lead as a projectile has its genesis with the Roman and Greek slings. Slings are a simple and effective apparatus used to propel rocks or other items known throughout the world for all of written history (Korfmann 1973: 42). As a weapon, it is not far removed from simply throwing a projectile. From Greek and Roman times, it is known that slings were used as an integral part of military campaigns in part because slingers likely achieved a greater range than archers (Korfmann 1973: 37).

The missiles used by slingers varied from available rocks to sun-dried clay “eggs” to biconical lead missiles (Korfmann 1973: 38). While rock projectiles are an economically efficient alternative to missiles manufactured from clay or lead, manufactured projectiles made from clay or lead result in a more standardized product leading to a more predictable range (Gowland 1912: 207; Korfmann 1973: 39). The antiquity of lead missiles is unknown; however, they first appear in the archaeological record in Greek and Roman times at about 500 BC (Korfmann 1973: 40). The lead missiles or bullets were manufactured by melting lead and casting it in molds. The molds often contain inscriptions representing the commanding general or the state. Occasionally, the lead bullets include slogans or ironic bits of script similar to those included on modern day bombs. In one instance, there is a lead bullet is inscribed with “ouch” (Korfmann 1973: 39).

David M. Robinson recovered a two-piece terra-cotta lead bullet mold at Olynthus, Greece in 1930(Figure 3-2). It was reconstructed to show the arrangement of the bullets and the process by which they were molded. In addition to the bullet mold, Robinson recovered approximately 500 lead bullets thought to have been the result of a siege by Macedonian troops in 348 B.C. Because of the inscriptions on the bullets, approximately 100 of them could be attributed to Olynthus defenders or to the Macedonian attackers (Figure 3-3).

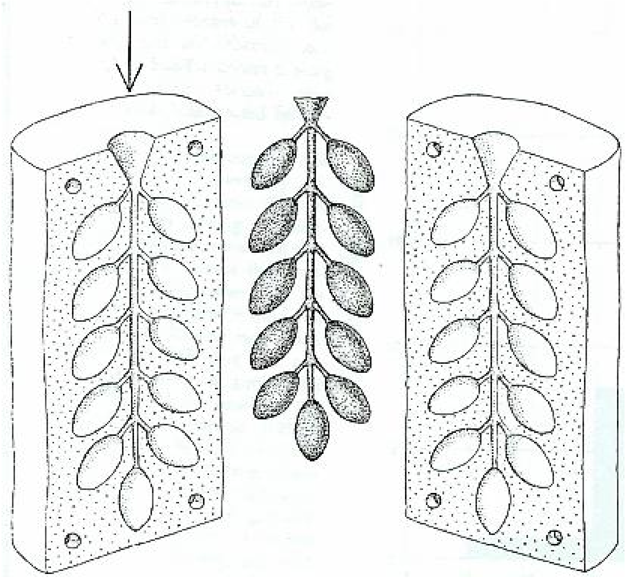

Figure 3-2 Terra cotta sling bullet mold from Greece (Korfmann 1973: 40).

Recent excavations at Stymphalos, Greece revealed a cache of 32 lead sling bullets. All but one of the bullets was inscribed (Figure 3-3). They date to approximately 315 B.C.

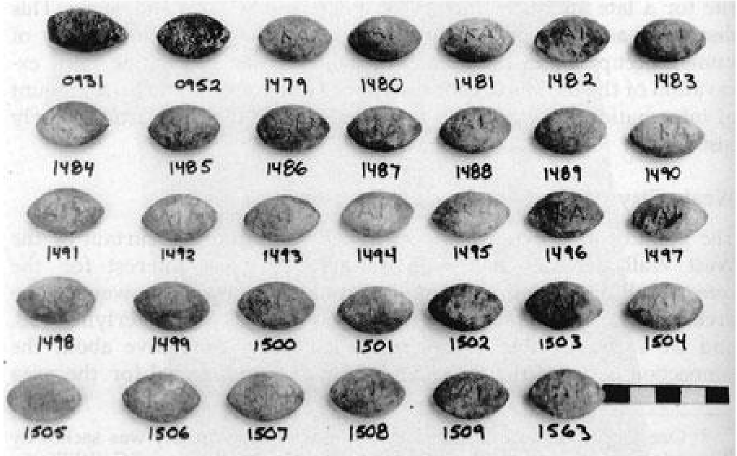

Figure 3-3 Inscribed lead sling bullets from Stymphalos (Williams et al. 1998).

Firearms of various technologies came into existence after the discovery of gunpowder in China and its adoption in the late sometime in the Middle Ages in Europe (Rosebush 1962: 3). Firearms, of any design, involve projecting a missile by use of gunpowder. The missile can be of various materials, including rocks, sticks, or iron.

However, lead became a preferred substance for several reasons: it is easily cast in uniform sizes and shapes, it does not corrode or rust, and it is inexpensive. Lead is also a good ammunition choice because it has a high density that provides better momentum, destructive power, and range than other materials with less density (Thornton et al. 2001: 30). It is soft enough to prevent damage to the barrel of the firearm, but hard enough to inflict severe damage to a target.

The lack of accuracy of early firearms rendered them ineffective as a target weapon; it was by arming a large number of soldiers with firearms expelling a barrage of lead that firearms became an effective weapon (Burt 1995: 32). Firearms and lead projectiles increased the size and formations of armies; not only did battlefield arrangements change, but large numbers of wagons and horses became necessary for hauling the heavy arms and ammunition supplies, influencing military logistics. Logistical changes included the need of passable routes for the heavy supply wagons and sufficient forage for horses.

Arms and ammunition require care to keep the systems functional and ready. Wet weather rendered firearms useless. Iron components of firearms succumbed to rust and fracture, requiring maintenance and oiling to keep them in working order (Bellesiles 1996: 434; Wright 1932: 92). Powder and cartridges could not ignite when damp (Wright 1933: 91). Conversely, while lead is durable and not usually subject to corrosion or destruction by storage or transportation, it is heavy and in particular cases requires time, labor, and fuel for manufacture into a useable product.

Firearms were uniquely crafted creations until standardization by mass production in the 1800s, therefore the size of the balls needed by the firearm owner varied by gun. The lead projectile needed to be just slightly smaller than the barrel, but not too small so that it would ricochet within the barrel when the gun fired.

Methods of ignition varied as firearm technologies evolved. Suffice it to note that there are a series of firearm designs that evolved over the last six hundred years. Waldo E. Rosebush designates eight major technologies in firearms: hand cannon, matchlock or firelock, wheellock, snaphance, miquelet, flintlock, percussion lock, and metallic cartridge (Rosebush 1962: 3). A detailed history of the development of firearms is beyond the scope of this work. However, a basic history of the broad categories and diversity of uniquely crafted firearms provides insight to the development of lead ammunition.

Early firearms, such as the hand cannon, often served to inflict psychological advantages rather than providing deadly intent due to the lack of accuracy and range. The noise, fire, and smoke served to impress fear into an enemy rather than accurately inflict harm (Peterson 1956, 2000: 19). The guns were primitive and served little purpose in projecting missiles. Crossbows or even simple bows employing arrows as projectiles were more accurate and efficient than the early firearms (Peterson 1956, 2000: 7). Matchlocks, requiring a lighted “match” in order to fire the heavy firearm, were cumbersome and difficult to load, necessitating a large amount of powder to project a lead ball. The matchlock was dangerous and ineffective in wet weather because of the need for the pre-lighted ignition (Peterson 1956, 2000: 18).

Wheellock and snaphaunce ignition systems developed to counter the need for the lighted “match” of the matchlock; the mechanism of each created a spark to ignite powder, rather than employing a slow burning fire. The wheellock system was similar in principle to the modern day cigarette lighter and, with its complex ignition system, was an expensive weapon (Peterson 1956, 2000: 23). The snaphaunce, less expensive than the complex wheellock, also had an intricate ignition system that included a cock, frizzen, pan, and spring in order to create a spark to ignite the powder. The miquelet, developed in Spain, employed a combined frizzen and pan and outer spring, was not a widely used firearm (Logan 1944: 21; 1959). Developments in the snaphaunce and the miquelet lead to the development of the more efficient flintlock.

Flintlocks, also known as fusils, show evidence of use by the beginning of the seventeenth century. Europeans continued their expanded presence in the New World with the assistance of these weapons. Native Americans also began to acquire firearms and by 1687, the Iroquois had possession of flintlocks. Flintlocks required a gunflint striking a portion of steel placed on the frizzen for powder ignition. Sheet lead or leather held the flint in place, clamped to a hammer cocked to a spring in the lock. They were widely adopted by standing armies and a common weapon of the Revolutionary War (Shields 1954: 24). Flintlock design remained relatively stable until the mid-nineteenth century (Lewis 1956, 1960: 5).

The flintlock employed either a smoothbore or a rifled barrel (Shields 1954: 24). Smoothbore, as the name implies, means that the interior of the barrel remained unaltered other than removing any irregularities that resulted from manufacture or use.

Smoothbore, long barreled weapons often carried by the infantry are known as muskets while the lighter version, often carried by officers, is known as a fusil. Rifling, or the spiral or straight grooving of the barrel interior, appeared first in Germany in the fifteenth century. The more accurate rifles first found use as hunting or sporting firearms, rather than as military gear. Although specialized corps of riflemen existed in some armies, it was not until the nineteenth century that armed forces employed rifles as standard issue (Lewis 1956, 1960: 7). German settlers brought rifled barrels to Pennsylvania, subsequently developing the distinctive "Kentucky Rifle" of the United States (Shields 1954: 12).

The Kentucky Rifles, actually manufactured in Pennsylvania, combined increased barrel length and a narrowed bore; used with a greased patch that facilitated a tight seal with a powder charge and lead ball, it provided superior accuracy particularly effective in the untamed wilderness of the frontier. The patch, by increasing velocity and pressure, allowed the hunter to use less powder and lead for an accurate shot (Shields 1954: 14). Rifles employed in the Revolutionary War changed the nature of fighting; the Kentucky Rifle found use as a sniper firearm (Shields 1954: 17).

Breechloading and percussion lock firearms developed with improvements in fulminate and the invention of metallic cartridges in the early nineteenth century, supplanting flintlocks by the 1850s (Lewis 1956, 1960: 11; Shields 1954: 67). These systems developed into a loading and ignition system in which a metal cartridge contained the bullet, powder and a chemical ignition. These self-contained systems utilized mass produced cartridges, eliminating the powder flask, balls, cartridge papers, and wadding. A tremendous amount of variation occurs within the percussion lock and metallic cartridge systems.

The Harper's Ferry 1803 Model Rifle, a flintlock, was developed and came into production after Congress authorized its manufacture in preparation for a possible war with France. Harper's Ferry records likely burned during the Civil War, so not much information remains concerning the firearm. The 1803 Model was thought to be similar to flintlock rifles supplied to the Lewis and Clark expedition. It is likely that the Corps carried its archetype (Rosebush 1962: 29). Incorporated in the design were components of the Kentucky Rifle, although failing to use the narrow bore. The 1803 Model, somewhat less accurate than a Kentucky Rifle, produced intense recoil. The rifles "muzzle loaded" using a flask of powder followed by inserting a lead ball. Various sized balls suited the rifles by employing a leather patch for a secure fit, however the standard was a .54 caliber ball weighing 0.5 ounce (Lewis 1956, 1960: 8-10; Shields 1954: 53).

Early firearm users found that it was difficult to obtain spherical lead projectiles. Non-spherical projectiles were unpredictable and inaccurate. One of the methods used to produce lead ball and shot prior to 1782 was to use bullet molds. The molds produced a seam on the projectile that interfered with its flight therefore requiring trimming. Shot was also obtained by pouring molten lead through a sieve into a container of water that often produced ovate rather than round projectiles (Minchinton 1990: 52).

The Colonies required arms, gun powder and ammunition at the opening of the Revolutionary War and throughout the quest for independence (York 1979: 26). Trade prohibitions launched before the Revolutionary War by the British, necessitated the colonies rely on alternative sources for lead ammunition. Benjamin Franklin seriously suggested using pikes and bows and arrows to cope with firearm supply shortages and to benefit from the efficiency and accuracy of the alternatives (Lewis 1956, 1960: 1). Guns and ammunition shipped by the French and Dutch through the West Indies and with Spain through Louisiana were crucial to supplying the American troops. (Huston 1991: 317; York 1979: 26). St. Eustatia, a Dutch-owned free port, was the center of clandestine trade with the colonies by 1774 (York 1979: 26). Don Bernado de Galvey, governor of Spanish owned Louisiana, facilitated trade of guns, ammunition, cloth, and quinine to the colonies by allowing their movement through Louisiana and into the Carolinas. While the countries themselves did not directly support the colonists need for supplies, merchants from Britain, France, Spain, Sweden, the Dutch Republic, and the West Indies recognized great profits from their trade with the Colonies (York 1979: 28).

Reliance on local sources meant working the known ore sources, discovering new ore sources, recycling existing leaden materials (Huston 1991: 104, 108). Colonists developed small lead mines in the New World at various locations including Virginia, Pennsylvania, Massachusetts, and Connecticut and used the product of the ores to manufacture ammunition prior to the outbreak of the Revolutionary War (Rabbitt 1979: 9; Smith 2003: 2). Shortages of lead ammunition pervaded despite clandestine trade and these adequate lead ore sources.

Pennsylvania history contains references to minor lead mining operations that may be indicative of the exploitation of these sources for small scale use. The ores did not occur in large economically viable quantities. It is thought that Conestoga tribal members enslaved by colonists mined lead in early day settlements of Lancaster County, Pennsylvania in the area of Pequea and Burnt Mills (Smith 2003: 2). Documents support accounts that Patriots mined lead in Sinking Valley, Pennsylvania for Revolutionary War needs in 1778. The Continental Army faced difficulties keeping supplied with expendable supplies, and in Pennsylvania actively sent out prospecting parties (Smith 2003: 2). Lead production from these mines was negligible, with only 1000 pounds being sold to the State (Smith 2003: 2). The reasons for the limited exploitation of the mines rested on the high costs of labor and transportation, difficulty in supplying the laborers with requisite supplies, and hostile Native Americans in the region (Smith 2003: 2).

An interesting genre of folk stories relate to secret sources of lead shown to early day colonists exists in the literature (Smith 2003: 2). The stories all follow the basic structure of an early blindfolded colonist lead by a grateful and generous Native American to an outcrop of pure lead ore. The colonist collects ore for a day, then is blindfolded again for the way home. While going home, the colonist leaves a trail of twigs or red string in hopes of returning to the rich lead source. The observant Native American noticing the markers confuses the colonist’s efforts to return to the mine by scattering his own markers.

Illegal methods of obtaining supplies employed by the Colonists included smuggling arrangements with British merchants, and capturing British supply ships, or raiding existing stores (Huston 1991: 111). The most efficient method of obtaining lead, although a short term solution, was through trade; it freed up labor and capital, while providing a finished or near finished product (Huston 1991: 111). The French were exceedingly novel in their approach to supporting the colonies while not appearing to directly engage in what was essentially a domestic problem of the British. Pierre A. C. Beaumarchais established “Hortaliz et Cie,” a mock company developed purely for providing the colonies with arms and ammunition and other supplies, while allowing the country itself to remain neutral. Hortaliz et Cie was equally funded by the French King Louis XVI and Spanish King Charles III (Huston 1991: 106). This fictitious corporation directly supplied the colonist with guns of uniform manufacture, bombs, shot, gunpowder, muskets, tents, and clothing (York 1979: 29).

Lead and iron ore deposits existed in the United States in sufficient quantities, but manufactured guns, gun makers, shot and balls, gun powder and components for gun powder continued to be scarce (York 1979: 26). Lack of standardized designs and manufacture of the hand built guns also created problems.

The scarcities of the Revolutionary War drove Alexander Hamilton to attempt to establish a reliable National system of military arms and supplies. He produced the “Report on Manufactures” to Congress in 1791 with the goal of establishing a catalog of manufacturers to be of use maintaining National security in the fledgling country (Huston 1991: 296). Hamilton’s ideas, however, met great resistance. His ideas of supporting manufacturers or industries in the National interest conflicted with the Jeffersonian ideals of agrarian independence (Huston 1991: 298). Modified in form and underlying ideals, Congress supported Secretary of War Henry Knox’s 1793 proposal that the federal production of arms would be preferable to relying on foreign sources that might turn hostile or inaccessible (Huston 1991: 298). National armories were established at

Springfield, Massachusetts and at Harper's Ferry, Virginia. The armories produced individually crafted muskets based on a common pattern (Huston 1991: 298). However, private contractors remained important suppliers to the United States Government, eventually evolving methods of mass production of arms with interchangeable rather than custom parts (Huston 1991: 299).

Baron von Steuben, the Prussian army officer credited with developing a system to train and lead American Revolutionary War soldiers, proscribed many matters of military deportment including the rule that the soldier was to be prepared with arms and ammunition. He asserted that "The preservation of the arms and ammunition is an object that requires the greatest attention" (Steuben [1794], 1985: 114). It was through the care of arms and ammunition that the enlisted soldier established pride in his endeavor and that the commanding officers established discipline. Von Steuben also proscribed that supervising officers inspect those arms and ammunition of the soldier to ensure that sufficient supplies were at hand and ready (Steuben [1794], 1985: 116 - 118). By the rules of the infant American military, the Quartermaster's duties required that he be in charge of accounting for and acquiring equipment, arms, ammunition, and provisions of the unit. He states:

> The preservation of the arms, accoutrements, and ammunition is of such essential importance, that he must be strictly attentive to have those of the sick, of the men on furlough, discharged, or detached on command without arms, taken care of and deposited with the brigade conductor, as directed in the regulations." (Steuben [1794], 1985: 134)

To the enlisted man, von Steuben instructed that clean and ready arms and ammunition were his responsibility (Steuben [1794], 1985: 116-117). Until after the

Revolutionary War, individual soldiers made up their own ammunition as needed with lead issued directly to them (Lewis 1956, 1960: 167; Wright 1931: 197). The reasoning was that the individual soldier knew his weapon and preferred size of ball. Powder, cartridge paper, bullet molds, and lead issued to the soldiers provided the necessary supplies for cartridge manufacture in the field. By 1781, the United States Government began contracting with Philadelphia manufacturers for musket cartridges, however, at different times and under certain circumstances, the enlisted men remained responsible for making up their cartridges (Lewis 1956, 1960: 167-168).

The basic gear for arming an individual Revolutionary War soldier consisted of the firearm, gunpowder, projectile, gunflints (for flintlocks), and optional wadding. By an Act, for the National Defence of the United States dated May 8, 1792, George Washington ordered the ready militia member supplied at his expense with:

> "A good musket or firelock, a sufficient bayonet and belt, two spare flints, and a knapsack, a pouch with a box therein to contain not less than twenty four cartridges, suited to the bore of his musket of firelock, each cartridge to contain a proper quantity of powder and ball; or with a good rifle, knapsack, shot pouch, and powderhorn, twenty balls suited to the bore of his rifle and a quarter pound of powder (Steuben [1794], 1985: Appendix)."

Inspections of arms and ammunition took place daily with enlisted men held financially responsible for a full accounting and good condition of their supplies (Steuben [1794], 1985: 15-16).

Projectiles evolved as the firearms did, but for the purposes of this investigation, it is sufficient to note that because of the various sizes and designs of firearms, various lead projectiles met those needs. Because early firearms were not of uniform design, ammunition necessarily was crafted for individual firearms (Wright 1932: 93). The size and design of these projectiles can be time diagnostic, although in the case of round balls and shot, chronology becomes difficult because they are used into the present day with various firearm designs. (Sutton and Arkush 1998, 1996: 176).

Ball ammunition manufacture in the field began by filling an iron kettle with a quantity of lead, then placing the kettle on a heat source. An inch thick layer of powdered charcoal covering the lead facilitated maintaining the temperature of the kettle contents. One hundred pounds of lead took about one to two hours to melt completely. Filling the molds required submerging an iron ladle into the melt, then pouring the molten lead then into cold brass molds. The first casting served to warm the molds; the resultant flawed balls necessitated return to the hot kettle. The molds consisted of double rows of 6 to 8 balls on each side. Once removed from the cooled molds, laborers removed the sprue or mold remnants with “nippers," then smoothed the balls in a rolling barrel. Quality control required measuring the diameter of the balls throughout the process. Identification of misshapen ammunition required a sheet iron screen, with any recognized flaws returned to the kettle or lead store for recasting. Flawed molds filled with copper to prevent their use (Lewis 1956, 1960: 175).

In the eighteenth and into the nineteenth centuries, the manufacture of balls in one hundred pound quantities required six men to complete in approximately 11 hours and resulted in about 3,200 musket balls (Lewis 1956, 1960: 175-176). By the mid-nineteenth century, production of balls included those made by compression machines

(Lewis 1956, 1960: 185). Cylindrical lead bars of specific diameter were fed into a cutting machine. The cut portion of lead then was dropped into a die, where the ball formation took place. Trimming the ball by hand followed then by gauging for roundness and size (Lewis 1956, 1960: 185).

The method of loading the early firearms commenced by pouring gunpowder over a ball held in the hand, then loading the ball and powder into the barrel of the gun often with wadding of various material (Rosebush 1962: 9; Sutton and Arkush 1998: 176). Of prime importance was keeping powder dry. Wet powder would not discharge predictably, if at all. The cartridge was developed and used by military units by the mid 1500s (Logan 1959: 1). Early cartridges consisted of measured powder enclosed within a paper wrapper. Subsequently, the ball was included within the wrapper (Logan 1959: 12). Later still, greased or waxed paper was used to keep the loaded powder dry. To load the cartridge, the user tore the open the paper, loaded the powder followed by the ball into the barrel of the firearm, and then rammed down the paper wad, completing the loading process.

Adding one or more round or conical balls to the powder and paper casing sped the process even more. The cartridges consisted of a single ball, a single ball and three buckshot, or twelve buckshot. Balls vary in size depending on the bore of the rifle, but by definition the are larger than buckshot. Smaller diameter round balls for military muskets measured approximately 13.33 mm (0.525 in.) in diameter, with 32 projectiles per pound and larger diameter round balls measuring approximately 16.26 mm (0.64 in.) with 18 projectiles per pound. Accuracy improved with advances in powder manufacture and the development of conical bullets beginning around 1825 (Hoyem 1981: 21; Sutton and Arkush 1998, 1996: 176).

In 1848, the conical Minié ball, designed by Captain Claude Etienne Minié, employed a sheet iron cup with grooves cut into the base and eliminated the problems of a loose fitting ball, thus providing a more accurate shot. Grease facilitated the loading of the Minié ball (Lewis 1956, 1960: 12). The successful Minié ball design proved to have a superior range and precision to the round ball and is one of the factors that changed the strategies and nature of battle during the Civil War (Weeks 1997: electronic document).

The Minié ball's shape, hollow base, slightly under bore diameter and incorporated grooves allow gas pressure to build on the projectile forcing it to expand. Because of the expansion of the Minié ball, no patch was required (Sporting Arms and Ammunition Manufacturers' Institute 2000: electronic document). The maxi ball has a solid base, has slightly a larger bore, and is also designed to be used without a patch. The maxi ball, like the Minié ball, has grooves. Lubricant facilitates loading and firing both the Minié and maxi balls. The term maxi ball seems to be a misnomer confused with the pronunciation of Minié and applied to large bore .50 caliber and above, solid based expanding bullets. Until the development of conical grooved ammunition in the early to mid-nineteenth century, the ammunition most commonly used were round balls or round shot (Knight 1997: 7; McDonald and Almgren 1980: 267; Ramage 1980: 10, 16-17, 20). The terminology for both is confusing. Despite the name "ball," the maxi ball and Minié ball actually have a conical bullet shape (Johnson and Haven 1943).

Shot are round projectiles average 7.6 mm (0.3 in), but vary in size from 1.2 to 5.84 mm (.04 to .23 in.) in diameter with nearly 4600 projectiles to the ounce for smaller shot and 24 projectiles to the ounce for larger shot (Hanson 2001: 10; Johnson and Haven 1943: 195; Lewis 1956, 1960: 175). Larger shot, known as buckshot, measures from 6.09 to 9.14 mm (.24 to .36 in) in diameter with 341 buckshot to the pound for the smaller projectiles and 103 buckshot to the pound for the larger shot. For purposes of this investigation, any round ball under 10 mm and smaller will be categorized as "shot" (Johnson and Haven 1943: 195). Throughout history, manufacturers used different classifications for shot and there is much variation between published tables (Hanson 2001: 10; Ramage 1980: 30).

In 1782, Bristol plumber William Watts developed and patented a method of manufacturing round shot by dropping the molten lead through a sieve at a great height allowing the lead to cool before reaching a container of water below (Minchinton 1990: 52). The larger the shot, the greater the height required for producing the round shot. Varying structures were constructed or employed to gain the required height to manufacture spherical shot including masonry towers constructed specifically for shot manufacture, abandoned mine shafts, and bridges and riverbanks of sufficient height.

Until 1808, the United States relied heavily on imported shot from Europe (Minchinton 1990: 54). In 1808, despite earlier unwillingness of government intervention in commerce, Thomas Jefferson imposed an embargo on foreign shot to promote local manufacture of ammunition. Shortly after the embargo was imposed, Americans began to construct their own shot towers in Philadelphia, New York, Baltimore, St. Louis and in the Mississippi Valley (Minchinton 1990: 54). Most shot towers were approximately 150 feet high, although the Merchant's Tower, constructed in 1828 at Baltimore, Maryland was 215 feet tall (Minchinton 1990: 54-55). Shot towers were so effective that they remain in use into the 21st century.

With the development of shot towers in the early 1800s, arsenic, antimony, and tin were added to molten lead to facilitate the manufacturing process. Arsenic allowed molten lead to flow smoothly in the liquid state, while antimony and tin allowed for harder lead projectiles less prone to deformation (Minchinton 1990: 54).

Shot and ball manufacture by hand continues to the present day by specialized collectors, period enthusiasts, and ammunition "reloaders." Lead is readily available from hardware and sporting goods stores. Shot and bullet molds are widely available through commercial retailers on the internet and in catalogs such as Ebay and Cabela's (Cabela's Incorporated 2004: electronic document; Ebay 2004: electronic document; Ramage 1980).

Modern lead bullet manufacture in the United States uses approximately 67% recycled lead, mostly from domestic sources (Buttigieg et al. 2003: 5028). The lead is processed into lots which weight between 20-100 tonnes per lot (Randich et al. 2002: 176). The manufacturer specifies antimony content per lot. For example, 0.22 caliber bullets, the most commonly manufactured ammunition in the United States, are manufactured with tolerable antimony content from 0.0% to 1.5 % antimony by weight. Specific acceptable levels of trace elements are determined by the manufacturer (Randich et al. 2002: 177). After molten lead has been processed by either addition or subtraction to obtain the desired alloying and trace element levels, the lead is then cast into lead pigs weighing approximately 65-70 lbs or cylindrical lead billets that are ready for extruding.

Lead pigs must be remelted by the manufacturer for fabrication into the billets before the extrusion and manufacturing processes can begin. Once the billet form is obtained, the lead is forced through a wire extruder with the wire then being wound onto spools. Extrusion, a process patented in 1797 initially for lead pipe manufacture, involves using hydraulic pressure to press solid metal into a desired form (Tylecote 1976: 154). The lead wire is then cut to the desired length. Once the basic length is achieved, the bullets are then stamped or molded into the desired form and assembled into cartridges with brass cases and powder, then packaged into boxes of 50 to 100 cartridges (Randich et al. 2002: 176-179).

Modern bullet manufacturing is designed to produce bullets uniform in shape and metal content. Variability in lead isotope signatures per lot occurs due to lead isotope variation present in whatever lead source is used. Because recycling accounts for so much of the lead used for modern bullet manufacture, the lead isotope signatures are almost assuredly the result of mixing. A study evaluating lead isotope characterizations of modern manufactured bullets specifically aimed at forensic cases concluded that bullets might not always possess the same characteristics of the parent “melt” material due to compositional variation that can occur. Additionally, lead isotope signatures can be similar between different “melts” due to the mixing of lead from various sources (Randich et al. 2002: 190).

Lead Seals

Lead seals are a specialized category of lead artifacts used as a method of identification in various capacities akin to a modern day barcode. Diane Adams presents a detailed study of lead seals recovered from Fort Michilimackinac, an early French fur trading fort (Adams 1989).

Lead seals seem to have served various identification purposes that included attachment to commodities such as cloth, salt, and tobacco. Other documented uses of lead seals include documentation of paid taxes, indication of bale or bundle composition, and corporate identification (Adams 1989: 18 -27). Adams believes that the seals recovered at Fort Michilimackinac likely served dual purposes; first, the seals identified the European maker of the cloth and second, the seals indicated the cloth quality.

The seals are generally circular disks, usually no larger than 30 mm (1.18 in.) in diameter that were attached, by various means, to trade merchandise often with a European origin. Numbers, names, or symbols, or a combination of these elements, were inscribed on the seal using various methods. In one method, the seals could be cast, with the identification information being part of the mold. The seals could also be stamped, with the stamp pressing the soft lead with the desired impression. The seals could also be scratched with whatever information was required.

The lead seal was attached to merchandise also using various methods depending on the design of the seal. These designs included a two disk seal connected by a flange whereby the seal could then be attached by folding, a single disk with a flange, and a single disk with a perforation for attachment by wire or cord (Adams 1989: 1).

Evidence suggests that lead seals, no matter what purpose they served, were casually abandoned once removed from the item or bundle to which they were attached. Adams notes, however, that there is some evidence that lead seals were recycled and processed into shot (Adams 1989: 35).

Bar and Pig Lead

Bar lead served as a convenient form for marketing lead to firearm owners who desired or needed to custom manufacture their own lead ammunition. Bar lead varied in size by manufacturer, but was molded in to thin "sticks" approximately 30.58 cm (12 in.) long by 1.27 cm (1/2 in.) wide and .95 cm (3/8 in.) thick, weighing approximately .45 kg (1 lb.). Major lead shot and ball manufacturers commonly produced lead bar and pigs with their name incorporated into the molds. The name in some cases serves to date lead bars based on the manufacturer's history.

Pigs, used for centuries beginning with the Romans, were also a convenient form for shipping lead (Hanson 1978). Pigs generally weighed between 29.5 – 31.75 kg (65-70 lbs.) and varied in dimensions and shape. In crude mining situations, pigs were manufactured in the field (Hanson 1978: 9). Lead bars were a necessity for gun owners manufacturing their own ammunition for their idiosyncratic firearms. Both lead bars and pigs were easier ship and less costly to purchase (Malone 1973: 57). Lead shot and balls were subject to spilling and could be difficult to ship, whereas bars and pigs were a more convenient shipping form (Hanson 1978: 7-11).

Use-life Context

Use-life context research considers the processes that may alter the chemical composition of the lead artifacts during their useful state. The use-life contexts are focused on lead recycling practices as a potential source of “mixed” metal sources.

Lead Recycling

Lead recycling was commonly practiced throughout history, as it is today, because lead is so easily converted into new products. The recycled product, or secondary lead, is chemically indistinguishable from lead produced directly from lead ore, known as primary lead (Thornton et al. 2001: 71).

The qualities of lead make it an ideal metal for recycling. Most lead recycling occurred as a continuing process during both pre-industrial production and industrial manufacturing. That is, it was and continues to be, common to recycle used lead products into new products. There are, however, exceptions; for example a farmer in Missouri after discovering a gourd of crushed galena ore at a Native American grave site, processed the lead into bullets for his personal use (Walthall 1981: 16).

Recycling lead occurs in a three to five step process. The first step is the collection of the material targeted for lead recycling and transporting the material if necessary. Step 2 involves sorting the material as needed and possibly processing the material into a suitable form for melting or re-smelting. Step 3 is the actual melting of the lead-containing material. In cases where the lead has been alloyed with other metals, it may be necessary to re-smelt the substance to remove undesired elements; this optional

Step 4 is necessary only in cases where re-smelting takes place. Step 5 is also optional. In this final step, alloying elements are added to the material to obtain the desired final product (Thornton et al. 2001: 73). Lead can be recycled repeatedly without any loss of material quality or integrity.

Lead recycling created its own widespread economy in pre-industrial Europe and continues as an industry to the present day (Burt 1995: 29; Woodward 1985: 175). Roger Burt provides estimates that seventy-five percent of present day lead products are the result of recycling. Burt concludes that lead recycling occurred at an even higher rates in earlier times (Burt 1995: 29). In a less industrial economy, people repaired and patched existing worn lead products or remelted and formed them into new products. Collected from windows, roofs, and plumbing, "old lead" had a marketable value for reuse (Woodward 1985: 183). Building materials proved expedient sources of lead in wartime situations for manufacture into bullets (Burt 1995: 33). It is known that in the mid-sixteenth century after King Henry VIII of England disbanded the monasteries of the kingdom, the amount of lead retrieved from the roofs and windows was so considerable that it depressed the lead trade in England and on the European continent (Burt 1995: 30; Woodward 1985: 184).

In the early history of the United States, documentation indicates that lead recycling continued. Anecdotes indicate that lead collection occurred, commonly for remelting and remolding into ammunition. Native Americans trading with the Hudson's Bay Company, collected lead foil packages used to ship tea and other perishables, then "chewed" the foil before further processing. This practice affected blood lead concentration of the chewers, both adults and children (Carlson 1996: 564-565). Lead, a scarce commodity during the Revolutionary War, prompted the Patriots to recycle lead from windows, clocks, and famously, a leaden statue of George III (Reynolds 1965: 65). Historical accounts of Daniel Boone at Boonesborough include a description of Kentuckians collecting approximately 56.70 kg (125 lbs.) of lead expended by Native American rifles after the siege of 1778. They subsequently fabricated the collected lead, including lead scraped off the palisades, into bullets (Bakeless 1992: 196).

Revolutionary War recruits collected their spent lead after unloading their muskets. In a secure camp, with little likelihood of confrontation, a loaded firearm constituted a dangerous implement and required unloading. The simplest method of unloading the firearm was to shoot it into a dirt bank, then retrieve the scarce lead for remolding (Wright 1932: 93).

Notwithstanding situations of lead scarcity, once expended, retrieval and recycling of bullet lead did not commonly occur (Burt 1995: 26). The development and widespread military use of firearms created a new factor in the lead mining economy; bullet lead created a market where recycling was not a frequent activity and the lead was generally lost.

Documentation of preparations for the Lewis and Clark Expedition show that at least 190.5 kg (420 lbs.) of sheet lead was purchased to serve two purposes; first as canisters to protect the precious powder from moisture and second, as the powder was consumed, to be recycled and melted down for use as ammunition (Jackson 1962: 80). The canisters, possibly an innovation of Meriwether Lewis, proved an excellent method of keeping powder dry. Lewis describes them in his journal as having been “a happy expedient which I devised of securing the powder by the means of the lead” (Moulton 2002-1990b: 265). While kegs of powder became damp or even destroyed by moisture, the powder contained in lead canisters sealed with cork and wax, remained intact and dry despite caching, accidents, and exposure to water (Moulton 2002-1988a: 53). Preparations for the expedition included the manufacture of 52 canisters from the 190.5 kg (420 lbs.) of sheet lead by George Ludlam, plumber of Philadelphia, for 50 cents each (Jackson 1962: 80). The lead canisters weighed approximately 3.6 kg (8 lbs.) and carried 1.8 kg (4 lbs.) of powder (Moulton 2002-1990b: 265).

The canisters were well distributed among the travelers, pirogues or canoes to ensure that if there was an accident, there would likely be sufficient reserves for the completion of the journey (Moulton 2002-1990: 272-273). Therefore, a portion of the ammunition present on the Expedition arrived in its final form through canister recycling. The fact that canisters were recycled does not prove they were initially made from lead that was from multiple sources. However, recycling occurred and manufacture from multiple lead ore sources cannot be ruled out.

Deposition

Deposition analysis is straight forward as lead artifacts are stable. Lead artifacts, in an archaeological context, are not normally subject to chemical alteration. They do develop a chemically distinct patina; however, the patina does not chemically alter the artifact as a whole. The patina commonly occurs as a build up or residue on lead artifacts, but represents an external chemical reaction not affecting the internal chemistry of the artifact. There are some specific conditions however, where lead does become unstable, subject to corrosion, and pitting.

Corrosion

Lead is one of the most stable metals and therefore naturally resistant to corrosion (Corrosion Doctors 2005: electronic document; Thornton et al. 2001: 50). Once exposed to oxygen, it produces a very thin patina of lead oxides (PbO and PbO_2), lead carbonates ($2PbCO_3$ or $Pb[OH]_2$), lead chloride ($PbCl_2$), lead sulfide (PbS) or lead sulfate ($PbSO_4$), thus forming a protective layer preventing the material from further decay (Hamilton 1999: electronic document; Plenderleith and Werner 1971: 267). This thin film is evident by the dull gray or white color of lead material. Before the advent of modern polymers, this stable nature rendered lead an exceptional material choice for roofing, cable sheathing, or tank lining where other materials exposed to water or acid would fail. In most archaeological conditions, including underwater conditions, lead artifacts remain stable after lead carbonate and lead oxide produce the protective layer (Corrosion Doctors 2005: electronic document).

There are exceptions to the stable quality of lead in certain instances, especially where acids or alkalis are present in specific environments. Water, water and oxygen, acids, bases, salts, or oils can cause a very slow corrosion, usually by electrochemical conversion (Corrosion Doctors 2005: electronic document; Thornton et al. 2001: 50). Lead corrosion occurs in specific conditions with specific aeration, humidity, temperature, and concentration of corrosive agents. Corrosion has been noted in cases where acidic wood occurs near lead material in areas of poor circulation, high humidity, and high temperatures (Schick et al. 1999: 50). These specific conditions cause lead to deteriorate and produce an abundance of lead carbonate powder ($2PbCO_3$ or $Pb[OH]_3$) (Hamilton 1999: electronic document; Schick et al. 1999: 48). Documentation of lead corrosion also includes alkali environments with specific aeration and humidity conditions. The documented case of lead corrosion in high alkali conditions occurred when calcium hydroxide $Ca(OH)_2$ solution (hydrated lime) formed at room temperature as the result of fresh Portland cement[8] mixing with water that comes into contact with lead (Corrosion Doctors 2005: electronic document).

Four artifacts of the thirty-eight undergoing analysis exhibit signs of corrosion; FV-SS-39525a, FV-SS-39525b, FV-SS-39525c, and FV-SS-39525d. These artifacts are pitted and somewhat diminished, losing their complete roundness. All four were recovered from the same context during the 1971-1975 excavations at the Fort Vancouver Sales Shop. These four artifacts are dated between 1829-1860 and assigned Hudson's Bay Company or United States Army affiliation and English or American manufacture or origin (Fort Vancouver National Historic Site 2005: Catalog number FOVA 39525). No patina is evident on these artifacts.

Recovery

As with use-life, recovery is not likely to chemically alter the lead artifacts and MURR controlled for any chemical cleaning by retrieving the analysis sample from the interior of the artifact. There is no indication within the archaeological reports that the artifacts were cleaned with anything other than water or treated with any preservative.

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[8] Portland cement is a specific compound of measured amounts of calcium compounds, silicon, aluminum, iron oxide, and gypsum. The material is mixed, then kiln cured.

Analyzing the artifact recovery process provides the opportunity to evaluate what can be learned about the artifacts based on the excavations. Of particular interest is the degree of control available that may lead to dating potential, thus providing insight in to the possible origins of the artifacts. Dating the lead artifacts is based on the degree of stratigraphic integrity of the excavations and on dating of associated artifacts. Excavations at Travelers' Rest, Fort Vancouver, the Florida Mission Sites, Rocky Mountain House, and Fort Clatsop are addressed. However, all of the artifacts except for the Travelers' Rest artifacts have been assigned a date range based on stratigraphy and associated artifacts. Additional information is presented on the control data introduced to this investigation by including the modern manufactured bullets from American Eagle and Winchester.

Archaeological Investigations at Travelers' Rest

Excavation efforts at Travelers' Rest conducted in 2003 under the direction of Daniel S. Hall of Western Cultural, Inc. were the culmination of much preliminary historical, geological, and remote sensing research. The excavation locations were selected using information gleaned from the Lewis and Clark journals, geomorphological information based on stream channel fluctuations, infra-red aerial photography, and magnetometer surveys. The excavation efforts focused on a large, intense magnetic anomaly located along the 1806 Lolo Creek channel. These excavations revealed two fire hearths (Hall et al. 2003: 217).

Magnetic susceptibility analysis of fire-cracked-rock from the hearth indicates that the hearth is the origin of the large anomaly, signifying an intense remnant thermal magnetization, a result of either repeated fires or a short-lived, intense fire. The small size of the charcoal lens indicates that an intense, short-lived fire is the more probable cause of the large anomaly. The excavation efforts at EU 57-01, west extension, level II, 10-20 centimeters below surface (cmbs), produced a small metal artifact, artifact number WC-TR-324, thought to be lead, located at the same level and adjacent to the hearth (Hall et al. 2000: 199).

Historical research was undertaken in order to determine the possible source of the lead provided to Meriwether Lewis by Brigadier General William Irvine, Purveyor of the Office of Public Stores during the preparation for the transcontinental exploration. No historical documentation of the source of the lead purchased for the Expedition has been discovered.

Traveler' Rest Artifacts

Initial laboratory analysis of the artifacts was conducted by Western Cultural, Inc. using the basic system set out by Mark Q. Sutton and Brooke S. Arkush (1998). The artifacts were lightly brushed to remove dirt, weighed, measured, described, catalogued, photographed in most cases, and finally, stored in polyethylene bags. Determination of lead metal content relied on the application of commonly understood elemental qualities of lead such as color, weight, and form. The formal elemental analysis of the artifacts is presented in the next section. Dating the eight lead (metal) artifacts was attempted by investigating the manufacture dates of the artifacts, through dating other artifacts, and by submitting charcoal samples recovered in association with the artifacts to radiocarbon dating.

The artifact catalog includes information on the location and depth of recovery, noting in specific cases artifacts recovered because of metal detector hits (WC-TR-318a, WC-TR-318b, and WC-TR-325). Artifact descriptions include dimensions and weight using the imperial system of measurement. The physical descriptions for metal artifacts include the general descriptor “metal,” an artifact count, and more specific identifying descriptors such as “lead blob, possible fired bullet fragment” (WC-TR-172) or “metal, lead maxi ball base, worked (1) molding, striations, sliced tip” (WC-TR-321). The investigator’s name or initials are included, as is the date of recovery and note indicating whether the artifact was collected (Hall et al. 2003: 263 & 271).

Seven artifacts, in addition to artifact WC-TR-324, were identified as lead and submitted for analysis. Table 3-1 provides a summary of artifact descriptions and excavation results.

Artifact Number	Excavation Location and Designation	Artifact Recovery Level [1]	Description	Dimensions & Weight	Associated Artifacts	
					Level	Artifact Descriptions
WC-TR-172	EU 27-01	I	Metal, lead blob, possibly fired bullet fragment	7 x 10 x 7 mm (9/32 x 13/32 x 9/32”) 3.74 g (0.13 oz.)	I	12 nails, single bone, small amount of fire cracked rock (FCR).
					II	Possible hearth feature with FCR, charcoal and ash. 25 nails, horseshoe segment, glass, single reduction flake.
WC-TR-318a	EU 57-01, southwest extension (metal detector hit)	8-13 cmbs (3-5”)	Metal, lead blob, worked, melted.	15 x 10 x 4 mm (19/32 x 13/32 x 5/32”) 1.74 g (.06 oz.)	I	Small amounts of charcoal
WC-TR-318b			Larger piece with stem. Likely spent maxi ball.	24 x 18 x 10 mm 15/16 x 23/32 x 13/32”) 27.44 g (.97 oz.)	II	Chert reduction flakes, bone, glass, charcoal, and FCR.
WC-TR-320	SP-52-01 (metal detector hit)	8 cmbs (3”)	Metal, lead, flattened ball, fired.	18 x 17 x 9 mm (23/32 x 11/16 x 3/8”) 13.78 g (0.48 oz.)	N/A	NA
WC-TR-321	EU 57-07, north extension	III	Metal, lead maxi ball base, worked. Molding, striations, sliced tip.	16 (diam.) x 12 mm 5/8 x 15/32”) 19.8 g (0.69 oz.)	I	N/A
					II	N/A
					III	Possible hearth feature. Charcoal, FCR, micro-flakes, and two bone fragments. Charcoal sample 342.
					IV	Charcoal, some FCR, one flake, and one bone fragment.
					V	Charcoal
					Shovel probe 50 - 95 cmbs (19.7 -37.4”)	N/A

Table 3-1 Travelers’ Rest artifact summary (n = 8).

Artifact Number	Excavation Location and Designation	Artifact Recovery Level [1]	Description	Dimensions & Weight	Associated Artifacts	
					Level	Artifact Descriptions
WC-TR-324	EU 57-01	II	Metal lead, flat, melted. Originally identified as a hardened pool of melted lead. Analysis revealed the artifact to be mainly composed of tin.	60 x 43 x 6 mm (2 3/8 x 1 11/16 x 1/4") 54.72 g (1.93 oz.)	I	Two nails, one screw, and bits of wire and wood.
					II	Large hearth. Charcoal, five chert reduction flakes, three nails, a .22 shell casing, wire, tin, assorted other metal, 11 pieces of curved glass, small blue bead (artifact no. 319), 16 bone fragments (2 burned).
					III	Charcoal.
WC-TR-325	EU 57-01, north extension (metal detector hit)	8-13 cmbs (3-5”)	Metal, lead, circular, tabular, worked. Incomplete hole, off-center with 3/16” diameter.	18 (diam.) x 9 mm (23/32 (diam.) x 3/8”) 24.78 g (.86 oz.)	I	Some FCR and single glass sherd.
					II	N/A
WC-TR-327	EU 41-01	I	Metal, lead blob, striations.	12 x 7 x 6 mm (15/32 x 9/32 x 1/4") 2.2 g (.08 oz.)	I	Some charcoal and a single bone.
					II	Charcoal, bone fragment, and ungulate tooth.
					III	N/A
					Shovel probe 40 - 110 cmbs (15.8 – 43.3”)	N/A

Table 3-1 continued. Travelers’ Rest artifact summary (n = 8).

The eight artifacts cannot be absolutely dated and because the field site has been used for agricultural purposes throughout the historic period, relative dating is difficult. In several excavation units, recent and historic artifacts are mixed with prehistoric artifacts indicating a compromised stratigraphy. In several cases, prehistoric artifacts are above recent and historic debris (See Table 2, Hall et al. 2003: 141). Because of the mixed artifact assemblage, it is problematic to associate any of the artifacts with the Lewis and Clark Expedition. One artifact (WC-TR-321) and possibly another (WC-TR-318b) however, are identified as maxi balls, indicating a *terminus post quem* of the mid-nineteenth century.

Historical documents related to the Lewis and Clark Expedition were used as a means to further consider the relationship of the recovered artifacts as evidence linking the site to the Expedition (Hall et al. 2003: 195-199). Of particular value was the inventory of supplies and goods required for the Expedition drawn up by Meriwether Lewis (Jackson 1978: 1:69-101; Office of the Quartermaster General List of Indian Presents Purchased by Meriwether Lewis in Preparation for the Expedition to the West, 1803 1947, 2005: electronic document; List of Purchases Made by Meriwether Lewis in Preparation for the Expedition to the West, ca. 1803 1947, 2005: electronic document). The journals provided information on various supplies, and relevant for this investigation, the lead canisters and ammunition carried by the Expedition and their use throughout the journey. However, historical documents research provided limited evidence, and no direct evidence, linking any artifacts recovered from Travelers' Rest to the Expedition.

The artifact with the strongest possible association with Lewis and Clark recovered at the site was the blue bead (artifact number WC-TR-319), recovered from EU-57-01, west extension, Level II, 10 to 20 cmbs (3.94 to 7.87 in.). Artifact number WC-TR-324 was also recovered within this unit and level. Blue beads figured prominently with the Corps, as well as with fur traders and other explorers, as an item of trade and good will with Native Americans. Unfortunately, there is no precise description of the blue beads carried by the Corps. Additionally, the compromised stratigraphy, as evidenced by the presence of a modern .22 shell casing, provides only a suspect association. The blue bead serves as merely circumstantial evidence, rather than a direct link (Hall et al. 2003: 199-203).

Finally, the lead artifacts are considered within the context of three charcoal samples submitted for radiocarbon dating recovered from hearth features excavated at the site. The samples were collected from EU-53-04, Level VI, 50 to 60 cmbs (19.69 to 23.62 in.); EU-57-07, north extension, Level III, 20 to 27 cmbs (7.87 to 10.63 in.); and EU-61-01, south extension, Level II, 10 to 20 cmbs (3.94 to 7.87 in.) (Hall et al. 2003: 182).

Sample number 28, from EU-53-04, provided a radiocarbon date of 998 ± 39 years BP or a calibrated date of AD 981 to 1157 at a 95% confidence interval (Hall et al. 2003: 184). Hall indicates that the hearth feature is prehistoric and not associated with the Lewis and Clark Expedition. No lead artifacts considered in this investigation were recovered from the sample location.

Sample number 342, from EU-57-07, north extension rendered a date of 130 ± 35 years BP with a calibrated date of AD 1670 to 1960 at a 95% confidence interval. This sample was collected from the unit and level where artifact number WC-TR-321, the maxi ball, was recovered. Hall indicates that the date falls between 1785 and 1820, thus placing the charcoal sample within the range of the Lewis and Clark expedition (Hall et al. 2003: 183). However, the presence of the maxi ball indicates a mid-nineteenth century date and likely compromised stratigraphy.

Sample number 381, from EU-61-01, south extension provided a date of 179 ± 38 years BP with a calibrated date of AD 1650 to 1950 at a 95% confidence interval. Hall indicates a one sigma date range of 1733 to 1809 and possible association with the Lewis and Clark Expedition (Hall et al. 2003: 183). However, Hall also indicates that the sample was recovered from the plow zone. A nail was also recovered from this level indicating a date later than that provided by the radiocarbon sample.

In summary, of the eight artifacts considered for investigation, only two, WC-TR-318b, and WC-TR-321, thought to be the remains of maxi balls, indicate a *terminus post quem* of the mid-nineteenth century. The remaining artifacts could have occurred as early as the first part of the nineteenth century as a result of the Lewis and Clark Expedition or through Native American trade along the Columbia and Missouri Rivers. The artifacts could also have occurred as late as the present age. The stratigraphy of the investigation area has been compromised by agricultural activities and does not provide a reliable method of relative association. The compromised stratigraphy also lends doubt to the integrity of the radiocarbon dates.

Archaeological Investigations at Fort Vancouver

Archaeological investigations at Fort Vancouver include three main areas of investigation: Fort Vancouver, Kanaka Village, and the Unites States Army Barracks.

Fort Vancouver itself includes the stockade-enclosed Hudson's Bay Company fur-trading post and supply depot founded in 1824-1825 and demolished in the 1860's. Kanaka Village, represents the ethnically diverse Fort Vancouver employees' housing site outside the stockade established by about 1832 and also demolished in the 1860's. The United States Army Barracks were first occupied in 1849 and remain standing (Hussey 1957: 1; Thomas et al. 1984: 1, 30, 49).

Investigations commenced to locate the site of Fort Vancouver in 1947 under supervision of the National Park Service and direction of Louis R. Caywood (Caywood 1947: ii; United States National Park Service Division of Publications 1981: 124). Excavations have occurred at various times over the last sixty years to locate Fort Vancouver structures for reconstruction purposes, to determine the location of Kanaka Village, and to mitigate highway construction at the Kanaka Village/Vancouver Barracks site (Caywood 1947: ii; Thomas et al. 1984: 7-8). Secondary to locating the structures, studies based on the excavations were generated to understand settlement patterns, occupants' ethnicity, architectural patterns, and continuing to build a research database of preceding archaeological work (Thomas et al. 1984: 11).

Fort Vancouver Artifacts

Through more than fifty years of archaeological activities, the National Park Service at Fort Vancouver established a standardized system of artifact laboratory methods and analysis (Thomas et al. 1984: 22). The procedures for artifact receipt, cataloging and labeling, classification, curation, and assemblage analysis are designed to minimize artifact loss due to misplacement, deterioration, or neglect, and to allow for rapid artifact processing. Relevant to this study, the catalog numbers for artifacts collected post -1971 at Fort Vancouver aim to provide field data associated with each artifact. The catalog numbers indicated the site designation, operation number, and arbitrary serial number (Thomas et al. 1984: 22).

Thirty artifacts identified as lead were randomly selected from the many thousands of lead artifacts in the Fort Vancouver collections recovered from the Fort Vancouver and Kanaka Village/Vancouver Barracks operations (Tables 3-2, 3-3, and 3-4). Of the thirty artifacts, twenty artifacts were selected from areas within the Fort Vancouver grounds including those from the Sales Shop (SS and SS2996, n = 11), Indian Trade Store (ITS, n = 7), the Indian Trade Store privy (ITSp*,* n = 2). Ten of the thirty selected artifacts were recovered from Operation 14 within the Kanaka Village/Vancouver Barracks location (OP14, n = 10). The 30 artifacts have been dated and in some cases assigned cultural affiliation and probable place of manufacture based on stratigraphy or provenience, and associated artifacts[9].

Ammunition makes up two thirds (n = 20) of the artifact total. Four of the artifacts classified as ammunition are balls (FV-SS-39525a-d) and sixteen of the artifacts are identified as shot (FV-ITSp-119384, FV-ITSp-119523, FV-OP14-15277a-f, FV-OP14-78970a-b, FV-OP14-78973, FV-SS2996-168a-e). Two of the artifacts are baling seals (FV-SS-8061 and FV-SS-8062), one is a portion of lead bar (FV-SS-8062), with the remaining portions described as lead fragments (n = 7) (FV-ITS-120281, FV-ITS-121428a-b, FV-ITS-121624a-c, FV-ITS-121765). Because FV-OP14-78973 is larger than

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[9] Variations of artifact descriptions such as “Ammunition, shot” or “Lead shot” are due to the idiosyncrasies of the Fort Vancouver artifact database. The terms here are those used within the database.

shot by the definition used here, it is re-categorized as “ball” for the remainder of the analysis.

Artifact Number	Excavation Location and Designation	Date/Origin	Original Description	Dimensions & Weight
FV-SS-8061	Sales Shop Accession # 135, Field number 19252	1829-1860, Hudson's Bay, English	Seal, Bale: lead bale seal, distorted	26 x 18 x 3 mm (1 x 23/32 x 1/8") 6.18 g (0.22 oz.)
FV-SS-8062	Sales Shop Accession # 135, Field 18554	1829-1860, Hudson's Bay, English	Lead: lead, rectangular bar	60 x 28 x 10 mm (2 3/8 x 1 3/32 x 13/32") 178.0 g (6.28 oz.)
FV-SS-39525a	Sales Shop Accession # 135, Field 18125	1829-1860, Hudson's Bay or US Army, Euro-American	Shot, lead: cast, round, lead, ball	13 mm (1/2") 11.60 g (0.41 oz.)
FV-SS-39525b	Sales Shop Accession # 135, Field 18125	1829-1860, Hudson's Bay or US Army, Euro-American	Shot, lead: cast, round, lead, ball	13 mm (1/2") 13.70 g (0.48 oz.)
FV-SS-39525c	Sales Shop Accession # 135, Field 18125	1829-1860, Hudson's Bay or US Army, Euro-American	Shot, lead: cast, round, lead, ball	13 mm (1/2") 14.18 g (0.50 oz.)
FV-SS-39525d	Sales Shop Accession # 135, Field 18125	1829-1860, Hudson's Bay or US Army, Euro-American	Shot, lead: cast, round, lead, ball	13 mm (1/2") 12.74 g (0.45 oz.)
FV-SS2996-168a	No catalog number, Sales Shop, Lot 168, Spec 6, Unit D4E, Level 5	1829-1860, Hudson's Bay, English	Lead shot	10 mm (13/32") 5.40 g (0.19 oz.)
FV-SS2996-168b	No catalog number, Sales Shop, Lot 168, Spec 6, Unit D4E, Level 5	1829-1860, Hudson's Bay, English	Lead shot	8 mm (5/16") 2.96 g (0.10 oz.)
FV-SS2996-168c	No catalog number, Sales Shop, Lot 168, Spec 6, Unit D4E, Level 5	1829-1860, Hudson's Bay, English	Lead shot	5 mm (7/32") .72 g (0.03 oz.)
FV-SS2996-168d	No catalog number, Sales Shop, Lot 168, Spec 6, Unit D4E, Level 5	1829-1860, Hudson's Bay, English	Lead shot	5 mm (7/32") .60 g (0.02 oz.)
FV-SS2996-168e	No catalog number, Sales Shop, Lot 168, Spec 6, Unit D4E, Level 5	1829-1860, Hudson's Bay, English	Lead shot	5 mm (7/32") .56 g (0.02 oz.)

Table 3-2 Fort Vancouver Sales Shop artifact summary (n = 11).

Artifact Number	Excavation Location and Designation	Date/Origin	Original Description	Dimensions & Weight
FV-ITS-120281	Indian Trade Store Accession # 135, Lot 3178, Field 29721	1829-1920, Hudson’s Bay or US Army, unknown origin	Lead fragment	19 x 16 x 2 mm (3/4" x 5/8 x 3/32”) 2.10 g (0.07 oz.)
FV-ITS-121428a	Indian Trade Store Accession # 135, Lot 3228, Field 31549	1829-1920, Hudson’s Bay or US Army, unknown origin	Lead fragment	46 x 7 mm (1 13/16 x 9/32") 13.84 g (0.49 oz.)
FV-ITS-121428b	Indian Trade Store Accession # 135, Lot 3228, Field 31549	1829-1920, Hudson’s Bay or US Army, unknown origin	Lead fragment	16 x 14 x 2 mm (5/8 x 17/32 x 3/32”) 2.50 g(0.09 oz.)
FV-ITS-121624a	Indian Trade Store Accession # 135, Lot 3237, Field 31843	1829-1920, Hudson’s Bay or US Army, unknown origin	Lead fragment	50 x 8 x 3 mm (2 x 5/16 x 1/8”) 10.98 g(0.39 oz.)
FV-ITS-121624b	Indian Trade Store Accession # 135, Lot 3237, Field 31843	1829-1920, Hudson’s Bay or US Army, unknown origin	Lead fragment	17 x 11 x 5 mm (11/16 x 7/16 x 3/16”) 3.64 g(0.13 oz.)
FV-ITS-121624c	Indian Trade Store Accession # 135, Lot 3237, Field 31843	1829-1920, Hudson’s Bay or US Army, unknown origin	Lead fragment	11 x 8 x 3 mm (7/16 x 5/16 x 1/8”) 1.12 g(0.04 oz.)
FV-ITS-121765	Indian Trade Store Accession # 135, Lot 3243, Field 32071	1829-1920, Hudson’s Bay or US Army, unknown origin	Lead fragment	33 x 13 x 2 mm (1 5/16 x 1/2 x 3/32”) 6.80 g(0.24 oz.)
FV-ITSp-119384	Indian Trade Store Privy Accession # 135, Lot 2990, Field 27479	1829-1860, Hudson’s Bay, English	Shot, lead	8 mm(5/16”) 2.76 g(0.10 oz)
FV-ITSp-119523	Indian Trade Store Privy Accession # 135, Lot 2998, Field 27664	1829-1860, Hudson’s Bay, English	Shot, lead	8mm(5/16”) 2.36 g(0.08 oz.)

Table 3-3 Fort Vancouver Indian Trade Store and Indian Trade Store Privy artifact summary (n = 9).

Artifact Number	Excavation Location and Designation	Date, Affiliation, Manufacture	Original Description	Dimensions Weight
FV-OP14-15250	Accession # 1813, Field K81/14-206-23	1830-1860, Hudson's Bay or US Army, Euro-American	Seal, packing	30 diameter x 1 mm (1 3/16 diameter x 1/32") 7.92 g(0.28 oz.)
FV-OP14-15277a	Operation 14 Accession # 1813, K81/14-324-10	1830-1860, Hudson's Bay or US Army, Euro-American	Ammunition, shot	10 mm(13/32") 5.4 g(0.19 oz.)
FV-OP14-15277b	Operation 14 Accession # 1813, K81/14-324-10	1830-1860, Hudson's Bay or US Army, Euro-American	Ammunition, shot	9 mm(3/8") 4.84 g(0.17 oz.)
FV-OP14-15277c	Operation 14 Accession # 1813, K81/14-324-10	1830-1860, Hudson's Bay or US Army, Euro-American	Ammunition, shot	8 mm(5/16") 2.92 g(0.10 oz.)
FV-OP14-15277d	Operation 14 Accession # 1813, K81/14-324-10	1830-1860, Hudson's Bay or US Army, Euro-American	Ammunition, shot	7 mm(9/32") 2.30 g(0.08 oz.)
FV-OP14-15277e	Operation 14 Accession # 1813, K81/14-324-10	1830-1860, Hudson's Bay or US Army, Euro-American	Ammunition, shot	8 mm(5/16") 2.54 g(0.09 oz.)
FV-OP14-15277f	Operation 14 Accession # 1813, K81/14-324-10	1830-1860, Hudson's Bay or US Army, Euro-American	Ammunition, shot	8 mm(5/16") 3.18 g(0.11 oz.)
FV-OP14-78970a	Operation 14 Accession # 1813, K81/14-158-15	1830-1860, Hudson's Bay or US Army, Euro-American	Lead shot	10 mm(13/32") 5.28 g(0.19 oz.)
FV-OP14-78970b	Operation 14 Accession # 1813, K81/14-158-15	1830-1860, Hudson's Bay or US Army, Euro-American	Lead shot	9 mm(3/8") 4.98 g(0.18 oz.)
FV-OP14-78973	Operation 14 Accession # 1813, K81/14-143-4	1830-1860, Hudson's Bay or US Army, Euro-American	Shot, lead	11 mm (7/16") 9.68 g(0.34 oz.)

Table 3-4 Kanaka Village/Operation 14 artifact summary (n = 10).

While the exact origin of lead used to fabricate the artifacts is unknown, it is likely that the lead originated in England. The vertically structured Hudson's Bay Company was, above all else, a money making enterprise with fur trade posts that were usually supplied with manufactured goods purchased from British merchants and shipped aboard British ships (Caywood 1947: 6; Newman 1998: 12). Shot was usually purchased from British shot manufacturers from Bristol (Gooding 2003: 112; Hanson 1978: 7).

Other Investigations

Lead isotope analysis data is included from investigations undertaken using artifacts recovered from Rocky Mountain House in Alberta, O'Connell Mission and San Luis Mission in Florida, the single artifact, discussed previously, recovered from Fort Clatsop in Oregon, and modern manufactured bullets.

Rocky Mountain House Artifacts

Lead isotope analysis was undertaken by the Department of Geology, University of Alberta to study sources of lead exposure in humans at Rocky Mountain House in Canada using six artifacts recovered from excavations in 1979 (Table 3-5) (Carlson 1996: 557-567). Rocky Mountain House consisted of five forts variously occupied between 1799 – 1875 by both the North West Company and Hudson's Bay Company. The site is located near the present day town of Rocky Mountain House on the North Saskatchewan River in Alberta, Canada. (Carlson 1996: 564; Thomson 2004: personal communication).

Catalog Number	Artifact Description	Context	Site Location	Location of recovery (Unit and Level)	Weight and Dimensions of Artifact	Other Information
15R/14V6-32 Sample A1	Rolled Copper Sheet	1835-1865, HBC Fort	Map 83B/7 Grid 11UPJ E638400 N5803200	Unit 14V, lot 6	Unavailable	Copper sheathing fragment. Occupation layer of structure 1.
15R/15H1-4 Sample A2	Copper Kettle handle lug	1835-1865 HBC Fort	Map 83B/7 Grid 11UPJ E638400 N5803200	Unit 15H, lot 1	48mm x 49mm	Initial plowing to present.
15R/15V2-38 Sample A4	Lead gun ball	1835-1865 HBC Fort	Map 83B/7 Grid 11UPJ E638400 N5803200	Unit 15V, lot 2	Unavailable	Structure 1: Beneath building rubble and above occupation layer.
15R24S1-10 Sample A5	Lead gun shot	1835-1865 HBC Fort	Map 83B/7 Grid 11UPJ E638400 N5803200	Unit 24S, lot 1	Diam. 4.6mm	Initial plowing to present. Within area of Feature 8.
1R.FcPr-2:1871 Sample A7	Copper kettle handle lug	1865-1875 HBC Fort	Map 83B/7 Grid 11UPJ E638500 N5803100	Test trench #6. This trench was later assigned provenience 1R14A1.	Unavailable	N/A
16R10M3 Sample A8	Lead gun shot	1799-1821 NW Company Fort	Map 83B/7 Grid 11UPJ E637900 N5802250	Unit 10M, lot 3	Unavailable	N/A

Table 3-5 Rocky Mountain House, Alberta artifact summary (n = 6).

Florida Mission Site Artifacts

Lead isotope data were used from a study of lead ammunition recovered during excavations from two Florida mission sites both near Tallahassee, Florida. O'Connell Mission, also known as the San Pedro y San Pablo de Patale Mission site, underwent excavation beginning in the late 1960s with additional work in the 1990s. Mission San Luis de Talimali has undergone excavation since the 1940s and continues to the present. The lead isotope investigation was undertaken by Sarah Ann Workman to fulfill thesis requirements at Florida State University (Workman 1999). The goal of the study was to distinguish between Spanish and British lead artifacts using lead isotope analysis. The analysis, completed on fourteen lead ball artifacts at the Geochemistry Department of Florida State University, had mixed results ultimately leading the investigator to conclude that provenience provided the best evidence of the origin of the lead artifacts. The data are used with her permission (Table 3-6 and Table 3-7) (Workman 2004: personal communication).

Artifact Number	Excavation Location and Designation	Date/Origin	Original Description	Dimensions & Weight
FS-OMS-765	O'Connell Mission Site, 554N, 496E, Z2A, L2	1633 -1704, British	Lead ball	14.9 mm (19/32") 17.1 g (.6 oz.)
FS-OMS-846	O'Connell Mission Site, 518N, 494E, Z2A, L1	1633 -1704, British	Lead ball	12.9 mm (1/2") 8.2 g (.29 oz.)
FS-OMS-877	O'Connell Mission Site, 512N, 492 E, Z2A, L1	1633 -1704, British	Lead ball	14.9 mm (19/32") 15.6 g (.55 oz.)
FS-OMS-906	O'Connell Mission Site, 512N, 486E, Z2B, L1	1633 -1704, British	Lead ball	12.9 mm (1/2") 10.3 g (.36 oz.)
FS-OMS-915	O'Connell Mission Site, 510N, 482E, Z2A, L1	1633 -1704, British	Lead ball	15.1 mm (19/32") 16.3 g (.58 oz.)
FS-OMS-1251	O'Connell Mission Site, 508N, 482E, Z1, L1	1633 -1704, British	Lead ball	14.6 mm (19/32") 15.9 g (.56 oz.)
FS-OMS-2357	O'Connell Mission Site, 526N, 510E, Z1, L1	1633 -1704, British	Lead ball	14.6 mm (19/32") 17.5 g (.62 oz.)

Table 3-6 O'Connell Mission Site, Florida artifact summary (n = 7).

Artifact Number	Excavation Location and Designation	Date/Origin	Original Description	Dimensions & Weight
FS-MSL-9660	Mission San Luis, Blockhouse, 484N, 370E, A105, L3	1656 – 1704, Spanish	Lead ball	20.3 mm (13/16”) 46.3 g (1.63 oz.)
FS-MSL-9798	Mission San Luis, Blockhouse 496N, 381E, Z2, L2	1656 – 1704, Spanish	Lead ball	19.6 mm (3/4”) 43.7 g (1.54 oz.)
FS-MSL-9803	Mission San Luis, Blockhouse 496N, 381E, Z2, L2	1656 – 1704, Spanish	Lead ball	14.9 mm (19/32”) 19.1 g (.67 oz.)
FS-MSL-9987a	Mission San Luis, Blockhouse 488N, 386E, A213, L1	1656 – 1704, Spanish	Lead ball	16.4 mm (21/32”) 25.5 g (.9 oz.)
FS-MSL-9987b	Mission San Luis, Blockhouse 488N, 386E, A213, L1	1656 – 1704, Spanish	Lead ball	19.5 mm (3/4") 43.8 g (1.55 oz.)
FS-MSL-9987c	Mission San Luis, Blockhouse 488N, 386E, A213, L1	1656 – 1704, Spanish	Lead ball	20.6mm (13/16”) 50.4 g (1.78 oz.)
FS-MSL-9997	Mission San Luis, Blockhouse, 488N, 374E, Z2, L2	1656 – 1704, Spanish	Lead ball	19.8 mm (13/16”) 45.5 g (1.6 oz.)

Table 3-7 Mission San Luis, Florida artifact summary (n = 7).

Fort Clatsop Lead Ball

Lead isotope characterization data for a lead ball recovered from archaeological excavations at Fort Clatsop under the direction of Dr. Ken Karsmizki is also used for comparison. Fort Clatsop, near Astoria, Oregon, where Lewis and Clark wintered with their men in 1805-1806 prior to their return trip, underwent archaeological investigation and excavation in 1996 by Montana State University, Museum of the Rockies archaeologists under the direction of Ken Karsmizki.

The lead musket ball is described as "a piece of lead, flattened on one side and rounded on the other that is suspected to be a musket ball" (Rasmussen 1997). A material sample collected from the musket ball was analyzed by Geospec Consultants Limited of Edmonton, Alberta (Rasmussen 1997). This analysis was undertaken to determine the ore source of the lead ball recovered during the excavations (Rasmussen 1997: electronic document). Dr. Ronald Farquhar of the Geophysics Division of the Department of Physics, University of Toronto determined that chemical data indicated the lead sample likely came from an area near the Buick Mine in Missouri (Farquhar 1997: personal communication). Farquhar, however, is hesitant to "pinpoint" the mine as a source (Farquhar 1997: personal correspondence).

According to a website featuring the Buick Mine, it was discovered in 1960 and began operations in 1969 (Aber 2000-2002: website). Further research and analysis of the source area, and lead musket ball would be beneficial to understand the lead isotope data. To date, no formal report of the analysis of this artifact has been produced, however, the document reporting the lead isotope ratio data was made available for this project (Farquhar 1997: personal communication)

Modern Manufactured Bullets

Lead isotope data also were assembled from a study on bullet characterizations done by the Department of Chemistry and the Department of Geosciences at the University of Arizona. In this study, lead isotope characterizations of bullets from around the world were examined as "pools" of data. It was determined that it is possible to distinguish bullets from different "pools" based on country of origin despite the widespread practice of using recycled lead to manufacture modern bullets (Buttigieg et al. 2003: 5022-5029). For purposes of this thesis, only modern bullet data from eleven American manufactured bullets are included: seven American Eagle bullets (AE-111-113, AE-121-123, AE-132-133, and AE-141-143), and four Winchester bullets (Win 1-4) (Buttigieg et al. 2003: 5026).

Elemental Analysis

In the fifth step in the framework, the chemical analysis is undertaken. The complete chemical analysis results for each artifact are presented in Appendix B.

Twenty-six elements, measured as parts per million (ppm), commonly encountered in lead ammunition were targeted for analysis (Marshall 1980, 2002: 49). Of the twenty-six elements selected, fourteen were either not present or occurred at levels below the level of detection (LOD) available on the instrument (Table 3-8). The mean limit of detection is calculated for all the elements is calculated for the thirty-eight samples (*n* = *38*). The remaining twelve elements under consideration include common lead alloy elements arsenic (As), tin (Sn), and antimony (Sb) (Table 3-9).

Element	Mean LOD PPM	Standard error of the mean	Standard deviation
Na Sodium	4817.716	194.511	1199.046
Mg Magnesium	185.573	1.759	10.842
Al Aluminum	290.114	7.656	47.195
S Sulfur	2645.346	37.310	229.992
Ti Titanium	25.490	.151	.930
V Vanadium	10.762	.309	1.907
Cr Chromium	95.742	10.535	64.940
Mn Manganese	18.481	.368	2.268
Co Cobalt	9.114	.423	2.608
Zn Zinc	142.721	6.918	42.651
Ni Nickel	376.378	4.120	25.396
Sr Strontium	7.614	.293	1.808
Te Tellurium	1.549	.078	.485
Ba Barium	6.650	.185	1.138

Table 3-8 Elements targeted for analysis that were not present or occurred below the instrument level of detection (LOD) and omitted from further consideration.

Element	Mean LOD PPM	Standard error of the mean	Standard deviation
Ca Calcium	652.697	40.536	249.880
Fe Iron	132.167	2.193	13.520
Cu Copper	16.504	1.271	7.832
As Arsenic	11.535	1.913	11.792
Ag Silver	2.355	.379	2.335
Cd Cadmium	.805	.049	.301
Sn Tin	53.176	1.875	11.557
Sb Antimony	23.721	.100	.617
Pt Platinum	441.391	23.240	143.261
Au Gold	23.95	1.762	11.282
Bi Bismuth	.979	.046	.282
Pb Lead	273.150	1.871	11.536

Table 3-9 Elements occurring above levels of detection and included for analysis.

Significantly, during sample preparation, the sample "WC-TR-324" was found to be dissimilar to the rest of the artifacts. Subsequent x-ray fluorescence (XRF) analysis showed that this sample consisted of nearly 90% tin (Sn) (Higgins 2004). It was digested via a similar technique by adding pre-mixed 1:1 HCl: HNO3 to the metal powder. This revelation during sample preparation was significant to this study because WC-TR-324 is the artifact originally identified as the "lead puddle" at Travelers' Rest. It indicates a significant error with the original premise of sourcing the material and using the information as a line of evidence linking the Travelers' Rest site to the Lewis and Clark expedition.

The initial artifact analysis identifying artifacts as "lead" proved to be 95% correct with thirty-six of the thirty-eight artifacts identified as being mainly composed of lead. Two artifacts (WC-TR-324 and FV-SS-120281) of the thirty-eight artifacts submitted for elemental analysis were determined to be less than 95% lead. Artifact WC-TR-324, the melted "puddle" was determined to be 89.5% tin, 7.65% antimony, 1.74 % copper with trace amounts of lead, zinc, platinum, silver, and arsenic. Lead occurs at .223% in artifact WC-TR-324. Artifact FV-SS-120281, described as a fragment, is composed of 58% tin and 40.7 % lead with antimony, copper, iron, platinum, and gold occurring as trace elements.

The remaining Travelers' Rest and Fort Vancouver artifacts are composed of more than 95.8% lead, with some artifacts being composed of nearly 100% lead (with trace elements also present). The average mean for the Travelers' Rest artifacts, excluding artifact WC-TR-324, is 98.8 % lead with artifact WC-TR-172 (anomalous portion) measuring 100% lead (maximum) and artifact WC-TR-318A (fragment) measuring 97.5% lead (minimum). The average mean for the Fort Vancouver artifacts, excluding FV-SS-120281, is 97.9 % with a maximum lead content of 100% for artifacts FV-ITS-121624c (fragment), FV-SS2996-168c (shot), FV-SS2996-168d (shot), FV-SS2996-168e (shot), and FV-OP14-78973 (shot), and a minimum lead content of 95.8% for FV-ITS-121428B (fragment).

Chapter 4
DATA INTERPRETATION

The final step, data interpretation using quantitative and statistical methods, serves to identify and investigate possible structure present within the chemical and isotopic data. The first steps of quantitative analysis are tenuous and can generally be described as prospecting (Kachigan 1986: 377). The researcher tries various approaches and methods until a combination is found that seems to explain the data in a reasonable fashion. Several investigative approaches are available to use, beginning initially with visual inspection of the data to look for obvious outliers and possible patterns within the data. The best way to plot an investigative direction is to actually try various approaches to see what may develop and provide a meaningful interpretation (Kachigan 1986: 377).

Data

The data under consideration are the lead isotope characterizations from artifacts recovered from excavations at Travelers' Rest, Fort Vancouver, Rocky Mountain House in Alberta, Canada, Fort Clatsop, Oregon, and from the O'Connell Mission and San Luis Mission in Florida. Additionally, lead isotope data from modern manufactured bullets of the American Eagle Manufacturing and Winchester Manufacturing are used. The modern manufactured bullets provide control data for recycled lead. Additional data are provided by the bulk and trace element characterizations of artifacts from Travelers' Rest and Fort Vancouver.

Visual inspection provides the researcher clues as to what approaches might work. Multivariate approaches can then be applied to further investigate possible structure and relationships present in the data, to strengthen suppositions about outliers, and to raise new questions regarding the data. The three lead isotope ratios provide a data structure that lends itself to straightforward analysis. Two methods, trivariate plotting and multivariate cluster analysis, are commonly and easily employed for the analysis of the three variables (Baxter and Buck 2000: 689-690). Multivariate cluster analysis is also appropriate for investigating the bulk and trace element data, the lead isotope data, and other artifact characterizations. Discriminant analysis is an appropriate method to analyze the cluster analysis results.

Visual Inspection

Visual inspection serves to identify those values that seem to meet expected outcomes, group together, or appear to be inconsistent with the bulk of the data (Baxter and Buck 2000: 695). There are several ways of accomplishing visual inspection, the simplest is to examine the data and note any obvious outliers. Among the variation present in the data, are those shown by the elements copper (Cu), tin (Sn), and antimony (Sb) (Table 4-1). Copper and tin occur in larger proportions in shot as compared with ball. Conversely, antimony makes up a larger composition in ball than it does in shot. In contrast, arsenic (As), gold (Au), and lead (Pb) occur at relatively consistent levels throughout the artifact categories.

Artifacts	Cu Copper (PPM)	Cu %	As Arsenic (PPM)	As %	Sn Tin (PPM)	Sn %	Sb Antimony (PPM)	Sb %	Au Gold (PPM)	Au %	Pb Lead (PPM)	Pb %
All lead artifacts (n = 38)												
Mean	856.08389	.0856	320.96667	.0321	14411.56667	1.4412	2617.58611	.2618	22.48889	.0022	980370.55556	98.037
Standard error of the mean	484.064324		91.179787		2192.522810		609.756325		4.256688		2117.767136	
Standard deviation	2904.385945		547.078721		13155.136863		3658.537952		25.540128		12706.602816	
Ball artifacts (n = 5)												
Mean	27.16900	.0027	454.18750	.0454	8382.77500	.8383	3161.17500	.3161	16.23750	.0016	984092.00000	98.409
Standard error of the mean	27.147291		249.220230		3763.565900		2155.421079		11.179381		3969.616012	
Standard deviation	76.784134		704.901258		10644.971877		6096.451446		31.620063		11227.769604	
Shot artifacts (n = 15)												
Mean	1878.34453	.1878	229.09333	.0229	21503.12000	2.1503	2341.72667	.2342	21.94667	.0022	974871.66667	97.487
Standard error of the mean	1121.262065		52.940667		2979.940308		235.150670		6.921291		3227.448009	
Standard deviation	4342.629305		205.038322		11541.259184		910.734627		26.806046		12499.852392	

Table 4-1 Variation in element occurrences of characterized artifacts (n = 38).

Variations in size are also observed by visual inspection. Focusing only on ball and shot, the entire range of size varies from 13 mm (1/2 in.) to 5 mm (7/32 in.). Results of examining size characteristics are presented in Table 4-2.

	All Ball and Shot Diameter (mm)	Ball Diameter (mm)	Shot Diameter (mm)
Count (n =)	23	5	15
Mean	9.05	12.60	7.87
Standard error of the mean	.583	.4	.446
Standard deviation	2.605	.894	7.727

Table 4-2 Frequency statistics for ball and shot diameter of artifacts under consideration (n = 23).

Bivariate and Trivariate Analysis

Bivariate plotting, commonly employed with lead isotope analysis, depicts correlations between variables, groups of data, and obvious outliers. However, the three lead isotope ratios transmit well to trivariate plotting in three dimensions. A slight disadvantage exists with trivariate plots in that portraying data in three dimensions on paper can be difficult, although not impossible. Distorting effects can be controlled by carefully considering the visual presentation of three dimensions and, although not used here, by including computer formats that allow rotation in order to view the three sides in tandem with two dimensional illustrations (Baxter and Buck 2000: 699).

The lead isotope data for artifacts from Fort Vancouver, Fort Clatsop, Travelers' Rest, the Florida Mission sites, and Rocky Mountain House are portrayed in three dimensions in a trivariate plot in Figure 4-1.

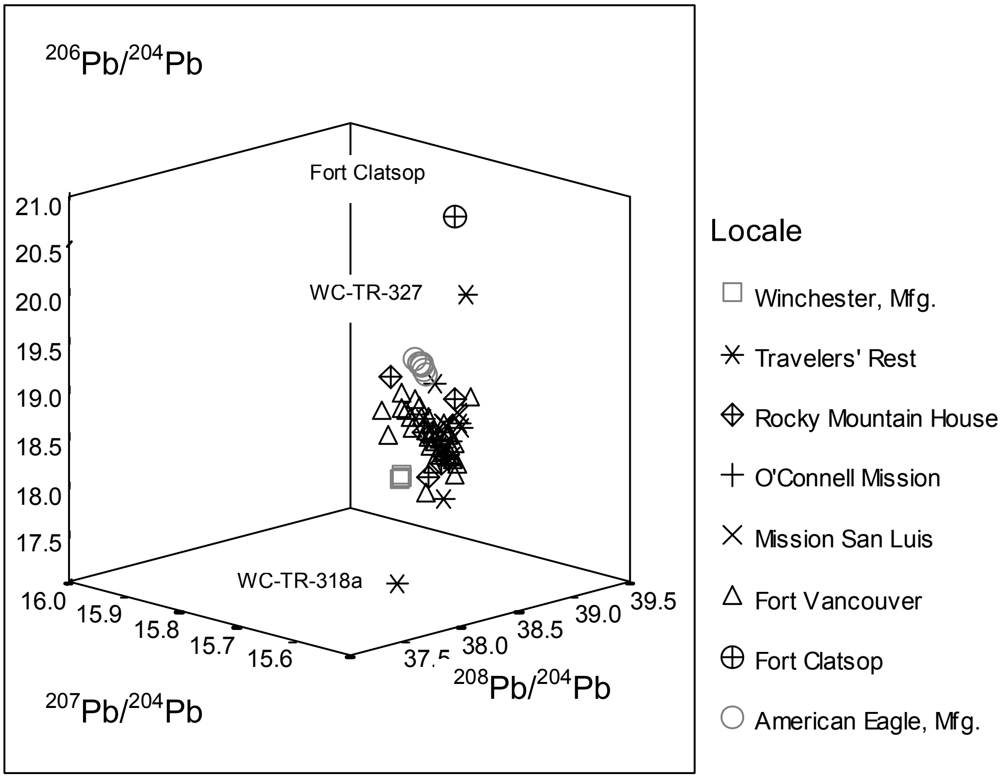


Figure 4-1 Trivariate plot of all artifacts (n = 76) under consideration (numbered data points discussed in text). The lead isotope ratios serve as the three axes: x-axis is $^{207}Pb/^{204}Pb$, y-axis is $^{206}Pb/^{204}Pb$, and z-axis is $^{208}Pb/^{204}Pb$.

Several observations can be made relative to the first three dimensional portrayal of the data. First, the Fort Clatsop artifact appears distant from the remainder of the artifacts. Its closest neighbor is artifact number WC-TR-327, described as a fragment with striations, is also distant from the bulk of the artifacts and recovered from Travelers' Rest. Artifact WC-TR-318A, a worked and melted lead piece, is also an outlier. The second observation from the three dimensional view of the data is that while the American Eagle and Winchester bullet samples cluster within the main group of artifacts, they also cluster tightly together in their respective groups. The third observation from the three dimensional view is that the non-lead artifacts also cluster within the main group and are not differentiated based on their lead isotope ratios.

In the Figure 4-2, the American Eagle and Winchester data and the non-lead artifacts data are removed from consideration because they represent cases known to contain recycled lead or in which lead an incidental element rather than a bulk element.

The non-lead artifacts indicate that even minute portions of lead have lead isotope signatures and that the researcher should be wary of attempting to determine the parent ore source or identifying similarities and dissimilarities any artifact based on lead isotope signatures alone. The Fort Clatsop artifact, WC-TR-327, and WC-TR-318A remain as outliers.

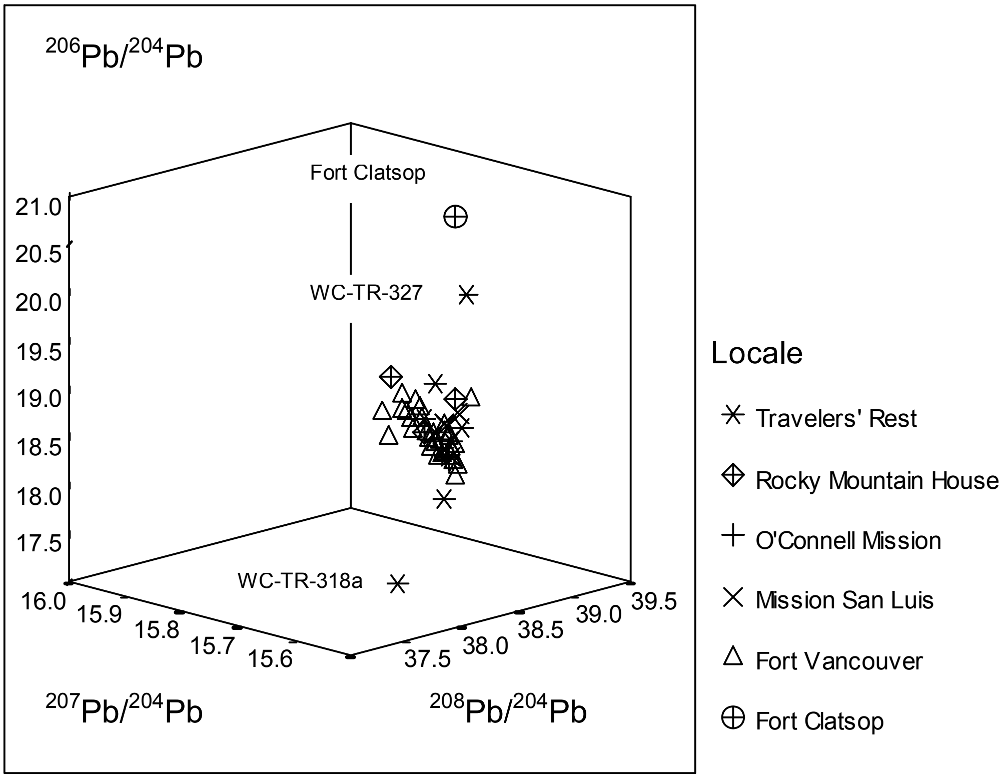


Figure 4-2 Trivariate plot of lead artifacts only (non-lead artifacts and modern bullets excluded) (n = 56). The lead isotope ratios serve as the three axes: x-axis is ^{207}Pb/^{204}Pb, y-axis is ^{206}Pb/^{204}Pb, and z-axis is ^{208}Pb/^{204}Pb.

The final trivariate plot, shown in Figure 4-3, portrays the artifacts that will be further analyzed using the trace element data. The Fort Clatsop, Florida Mission, and Rocky Mountain House data are removed from further consideration because there are no trace element data available for further analysis.

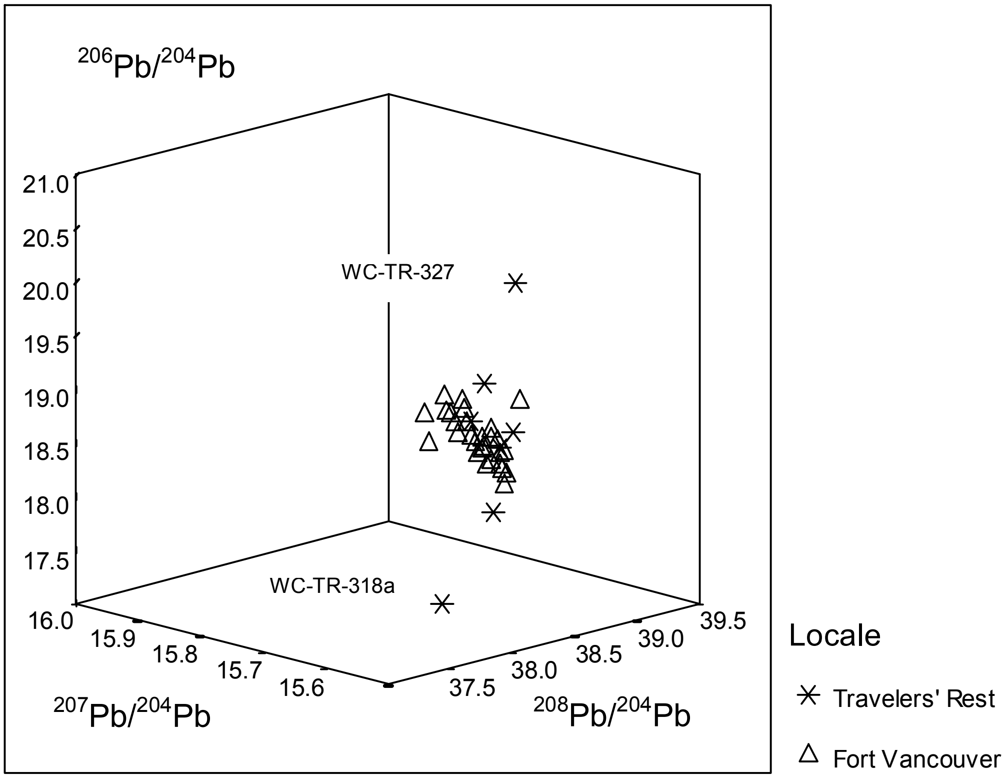


Figure 4-3 Trivariate plot of the lead Fort Vancouver and Travelers' Rest artifacts (n = 36). The lead isotope ratios serve as the three axes: x-axis is ^{207}Pb/^{204}Pb, y-axis is ^{206}Pb/^{204}Pb, and z-axis is ^{208}Pb/^{204}Pb.

Multivariate Analysis

Multivariate analysis examines the relationships that may exist between two or more variables in a given set of data (Kachigan 1986: 5). It consists of various methods used to investigate the relationships present within the matrix. The concept of distance between objects in the matrix of variables and between cases is basic to understanding the various methods of multivariate analysis.

Distance refers to the measure of similarities (or dissimilarities) present within different case/variable objects that exists in the data matrix. Euclidean distance is commonly used to measure the similarities between objects in the data matrix. It is determined by measuring the values of two objects with a given number of variables and applying the Pythagorean Theorem to determine the hypotenuse distance between the object values, thus providing a basis to determine a measure of similarity (Kachigan 1986: 405). Measurements of similarity must be obtained for each pair of objects within the data matrix (Kachigan 1986: 404).

Euclidean distance is commonly applied to cluster analysis and principal component analysis. It is not an appropriate approach for certain data sets, especially those with correlated variables. In the situation where variables are strongly correlated, Mahalanobis distance, measuring distance as a value based on the centroids within a variable set, is a better measuring choice. The mathematical definition of Mahalanobis distance is an advanced statistical topic (Kachigan 1986: 371), however, Baxter and Buck recommend that Mahalanobis distance be used with lead isotope data in a trivariate analysis (Baxter and Buck 2000: 700-701, 712). SPSS statistical software provides

Mahalanobis distance as an available option. Another option for measuring distance is using squared Euclidean distance that tends to exaggerate the distance and provides for more distinct clustering in the case of cluster analysis.

Cluster Analysis

Cluster analysis is a multivariate statistical approach that consists of numerous techniques for exploring the relationships between cases and variables and for identifying non-random subsets of data (Kachigan 1986: 402). The goal of cluster analysis is to group objects into subsets with a small amount of variation within subsets and a large amount of variation between subsets (Kachigan 1986: 402). The cluster analysis techniques rely on two basic concepts; first, measuring dissimilarity or similarity between cases within a data matrix; and second, employing a systematic method of grouping cases based on their dissimilarities or similarities (an algorithm).

There are two main approaches to clustering the data; first is hierarchic agglomerating and second is partitioning. Hierarchic agglomeration begins by considering each case as a unique cluster, then clustering the cases based on specific conditions into larger clusters until one group includes all the cases. Partitioning distributes cases repeatedly into groups based on specific conditions, until reaching a determined degree of allocation success.

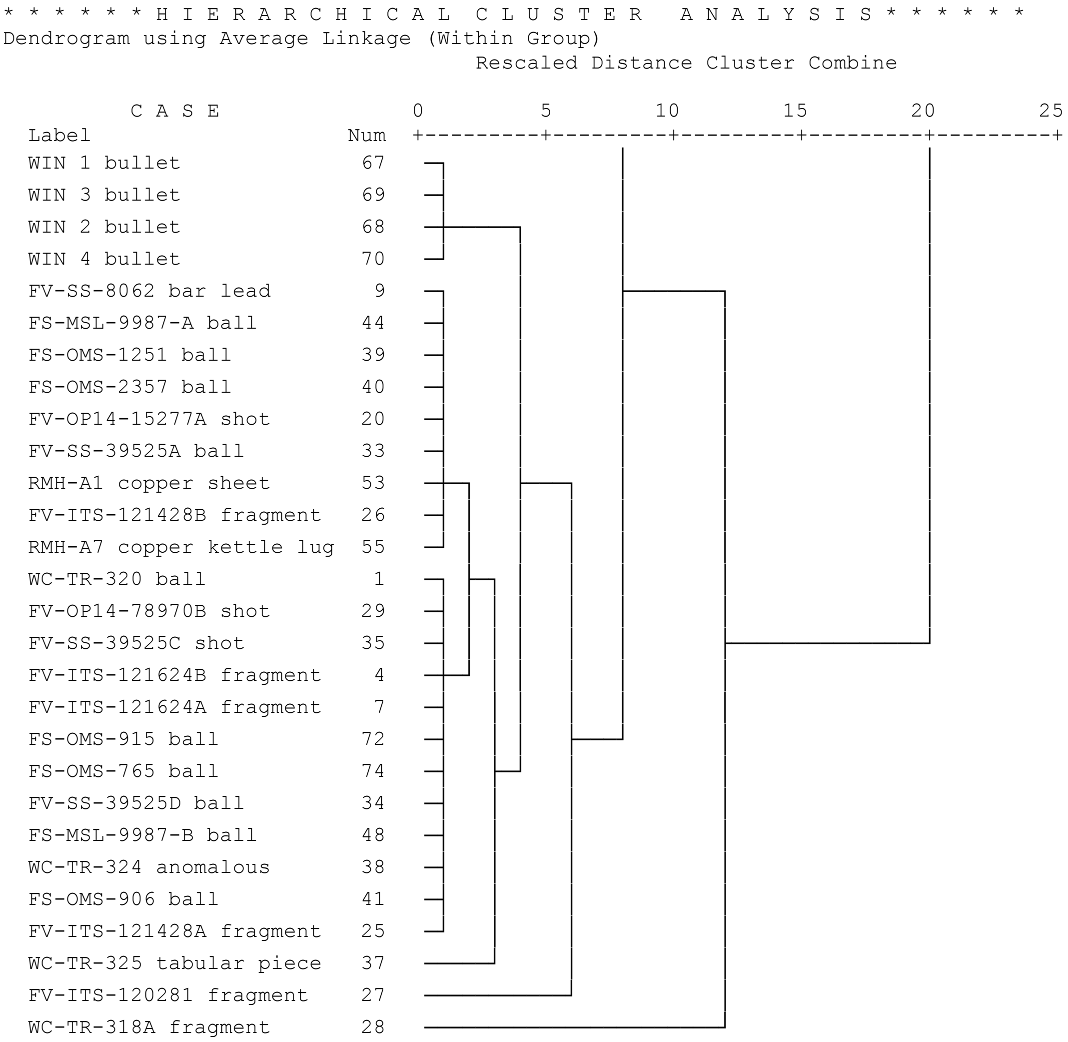
Cluster analysis, as with other multivariate methods, relies on a matrix of cases and variables, in this case artifacts and their chemical characterizations (variables). A measure of similarity or dissimilarity between objects within the matrix is determined, and then a framework (or algorithm) is established to determine subgroups within the datasets. Differences between the subsets can then be compared by identifying the variables that provide the most significance for determining the clustered subsets. Several techniques can be applied for determining both the measures of similarity and the method of clustering. There are no specific rules for choosing a technique for a given dataset, rather experimentation and inference will provide the researcher the appropriate analysis.

Cluster analysis is widely used for archaeometry problems. The clustered subsets are helpful for determining whether artifacts group in a way provides the researcher new information that was not previously observed. The clusters may group based on origin, manufacture, or possible use, depending on the nature of the selected variables.

The groupings viewed in the trivariate plots (Figures 4.1 – 4.3) are investigated further using cluster analysis. A series of cluster analyses created using the lead isotope data produce diagrams showing patterns indicating clusters by recovery location and artifact form. The first cluster diagram shown in Appendix C, show patterns using within groups linkage and squared Euclidean distance to maximize the differences between groups while emphasizing the similarities of group membership (Partial view of Appendix C, Figure 4-4). Lead isotope values were standardized to Z-scores, to eliminate discrepancies of measurement based on scale differences. The series of diagrams, portrayed in Appendices C-E and in Figures 4-6, 4-7, 4-8. and 4-9, show progress from mixed patterns to those where patterns of meaningful information, based on recovery location and artifact form, are teased out.

A partial cluster diagram run on all the artifacts and modern bullets, shown in Figure 4-4, demonstrates two things: first, groupings do not reflect provenance and second, including artifacts composed of material other than lead is problematic. The entire diagram, Appendix C, portrays the very distinct clustering of American Eagle (AE) and Winchester (WIN) bullets. Further clustering occurs with the lead artifacts from Florida and Fort Vancouver grouping together. The artifact from Fort Clatsop remains an outlier, although it is grouped closely to the control data from American Eagle and artifact WC-TR-327 from Travelers' Rest. However, most of the clusters seem to contain a random assortment of artifacts. Tin artifact WC-TR-324 is included in a cluster with artifacts from the Florida Mission sites and Fort Vancouver.

Partial view of Appendix C, Lead Isotope Data on All Artifacts Under Consideration.



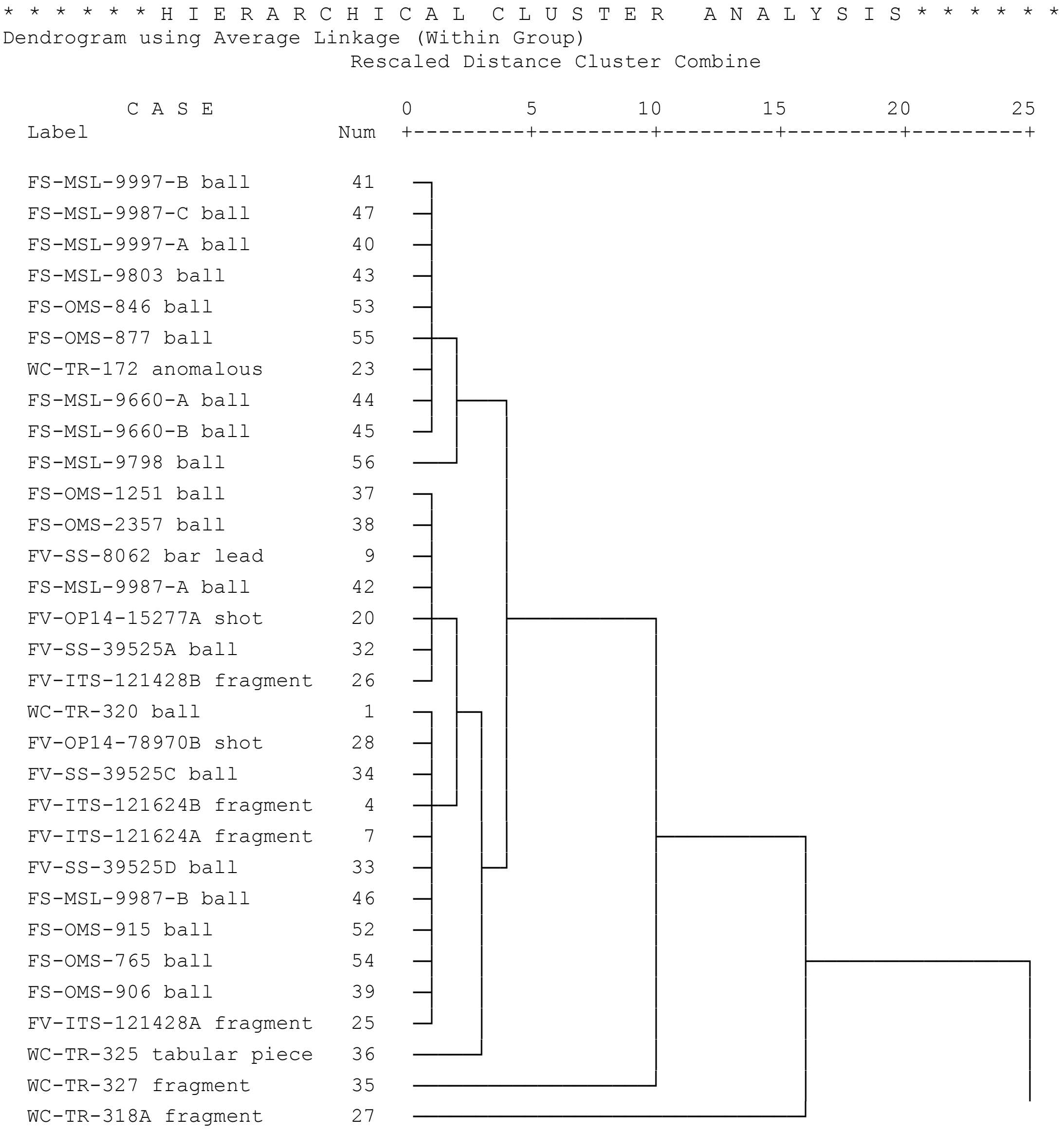
```
* * * * * * H I E R A R C H I C A L   C L U S T E R   A N A L Y S I S * * * * * *
Dendrogram using Average Linkage (Within Group)
                                     Rescaled Distance Cluster Combine

          C A S E                  0         5        10        15        20        25
  Label                     Num   +---------+---------+---------+---------+---------+
  WIN 1 bullet               67
  WIN 3 bullet               69
  WIN 2 bullet               68
  WIN 4 bullet               70
  FV-SS-8062 bar lead         9
  FS-MSL-9987-A ball         44
  FS-OMS-1251 ball           39
  FS-OMS-2357 ball           40
  FV-OP14-15277A shot        20
  FV-SS-39525A ball          33
  RMH-A1 copper sheet        53
  FV-ITS-121428B fragment    26
  RMH-A7 copper kettle lug   55
  WC-TR-320 ball              1
  FV-OP14-78970B shot        29
  FV-SS-39525C shot          35
  FV-ITS-121624B fragment     4
  FV-ITS-121624A fragment     7
  FS-OMS-915 ball            72
  FS-OMS-765 ball            74
  FV-SS-39525D ball          34
  FS-MSL-9987-B ball         48
  WC-TR-324 anomalous        38
  FS-OMS-906 ball            41
  FV-ITS-121428A fragment    25
  WC-TR-325 tabular piece    37
  FV-ITS-120281 fragment     27
  WC-TR-318A fragment        28
```

Figure 4-4 Portion of cluster analysis based on lead isotope data for all artifacts (see Appendix C for complete diagram) (n = 76).

To further investigate the archaeological samples, the non-lead artifacts and the control data provided by the modern bullets are removed. The resulting cluster diagram shows more organization and some patterns within the artifact type and location. A partial diagram is presented in Figure 4-5 (complete results in Appendix D).

Partial view of Appendix D – Lead isotope data cluster diagram (non-lead and recycled artifacts removed)



```
* * * * * * H I E R A R C H I C A L   C L U S T E R   A N A L Y S I S * * * * * *
Dendrogram using Average Linkage (Within Group)
                            Rescaled Distance Cluster Combine

        C A S E            0         5        10        15        20        25
  Label                Num  +---------+---------+---------+---------+---------+

  FS-MSL-9997-B ball        41
  FS-MSL-9987-C ball        47
  FS-MSL-9997-A ball        40
  FS-MSL-9803 ball          43
  FS-OMS-846 ball           53
  FS-OMS-877 ball           55
  WC-TR-172 anomalous       23
  FS-MSL-9660-A ball        44
  FS-MSL-9660-B ball        45
  FS-MSL-9798 ball          56
  FS-OMS-1251 ball          37
  FS-OMS-2357 ball          38
  FV-SS-8062 bar lead        9
  FS-MSL-9987-A ball        42
  FV-OP14-15277A shot       20
  FV-SS-39525A ball         32
  FV-ITS-121428B fragment   26
  WC-TR-320 ball             1
  FV-OP14-78970B shot       28
  FV-SS-39525C ball         34
  FV-ITS-121624B fragment    4
  FV-ITS-121624A fragment    7
  FV-SS-39525D ball         33
  FS-MSL-9987-B ball        46
  FS-OMS-915 ball           52
  FS-OMS-765 ball           54
  FS-OMS-906 ball           39
  FV-ITS-121428A fragment   25
  WC-TR-325 tabular piece   36
  WC-TR-327 fragment        35
  WC-TR-318A fragment       27
```

Figure 4-5 Portion of cluster analysis based on lead isotope data for all known lead artifacts (see Appendix D for complete diagram) (n = 56).

There is some indication of the artifacts clustering by location, particularly with artifacts recovered from Florida and Fort Vancouver. Applying Hancock's Conclusion Matrix (Table 2.3) assists with interpreting the data by focusing the analysis on looking at the form of the artifact rather than the recovery location. When the artifact form is looked at, rather than recovery location, the data clusters distinctly by categories: ball and shot. The Fort Clatsop ball remains an outlier. Additionally, the Rocky Mountain House artifact RMH-A8 is also an outlier. RMH-A8 is a portion of shot associated with the North West Company dating to 1799 – 1821. Travelers' Rest artifacts WC-TR-325, WC-TR-327, and WC-TR-318a also occur as outliers. These artifacts are fragments with no indication of their intended or original form.

Next, artifacts of unknown type or form are removed from the data analysis. The results, shown in Figure 4-6, depict the remaining artifacts including twenty-five ball artifacts, the two maxi balls, seventeen shot artifacts, two bale seals, and the portion of bar lead.

Lead isotope data cluster diagram (ball, bale seal, bar lead, and shot)

```
* * * * * * H I E R A R C H I C A L  C L U S T E R   A N A L Y S I S * * * * * *
Dendrogram using Average Linkage (Within Group)
                                Rescaled Distance Cluster Combine
```

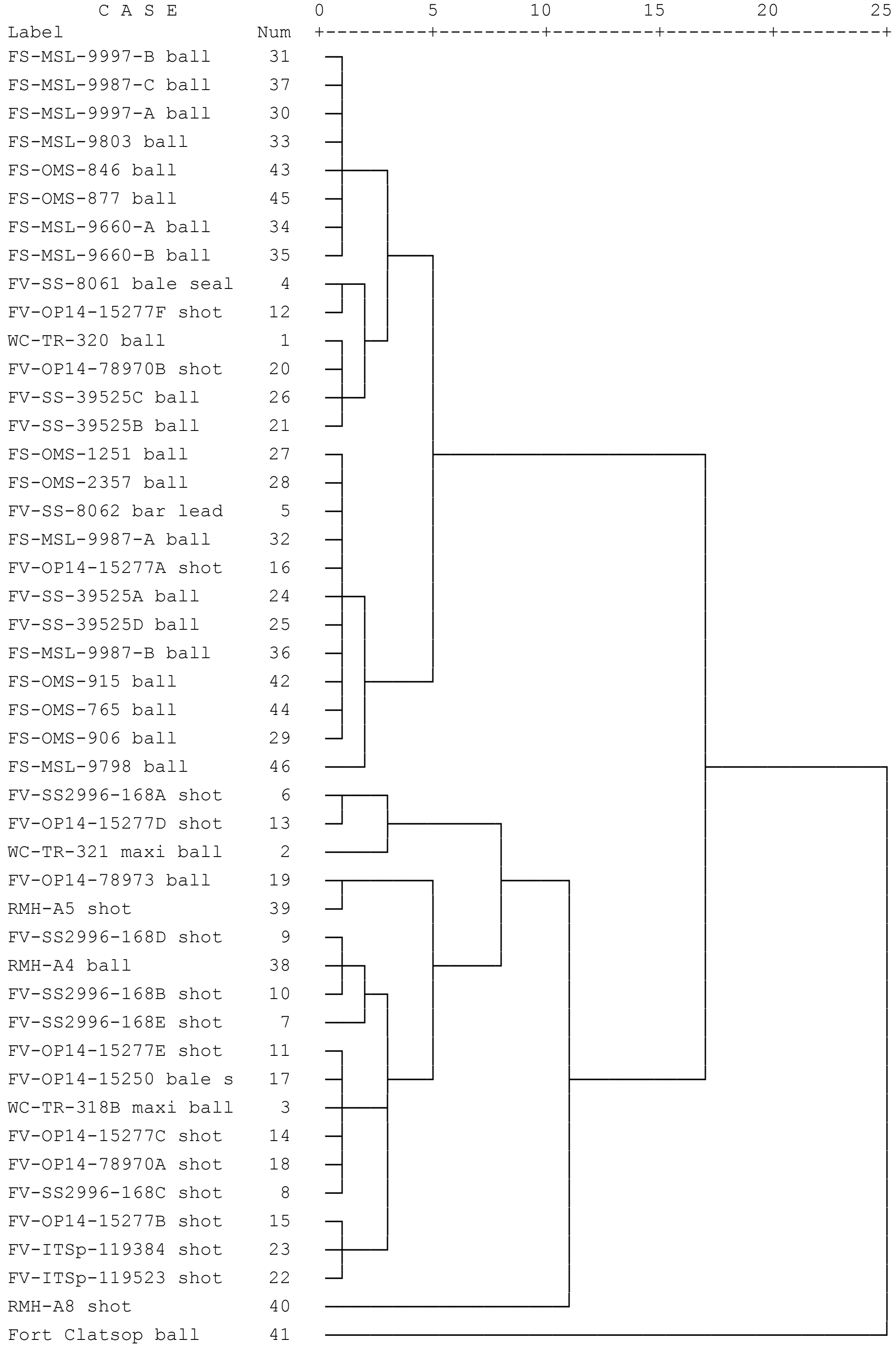


Figure 4-6 Cluster diagram run with lead isotope data on ball, bale seal, bar lead and shot only (n = 46).

The resulting cluster diagram reveals a distinct pattern of ball and shot clustering together, often by locality, while the Rocky Mountain artifact RMH-A8 and the Fort Clatsop ball remain as outliers. Moving from the top of the cluster diagram, Mission San Luis and O'Connell Mission balls form a distinct cluster. The next cluster is not quite so distinct, but includes a bale seal and two balls from the Sales Shop, two pieces of shot from Operation 14, and one ball from Travelers' Rest. The next cluster is composed mainly of balls, except for the bar lead. Recovery locations include O'Connell Mission, the Sales Shop, Operation 14, and Mission San Luis. The remaining clusters are composed mainly of shot from the Sales Shop, Operation 14, and the Indian Trade Store Privy. Additionally, a Rocky Mountain House ball occurs and a maxi ball from Travelers' Rest in the clusters dominated by Fort Vancouver artifacts. These two ball artifacts and a bale seal are the only artifacts not described as shot that occur in the clusters.

In order to refine the last cluster analysis comparison, artifacts lacking trace element data are eliminated from analysis. A cluster analysis is run using only the lead isotope data of the remaining artifacts. The results are presented in Figure 4-7. The cluster diagram in demonstrates clusters occurring most commonly by form. There does not appear to be much clustering by location. There are few distinct outliers particularly, the Travelers' Rest maxi ball (WC-TR-321).

Lead isotope data only

```
* * * * * * H I E R A R C H I C A L  C L U S T E R   A N A L Y S I S * * * * * *
Dendrogram using Average Linkage (Within Group)

                                     Rescaled Distance Cluster Combine
```

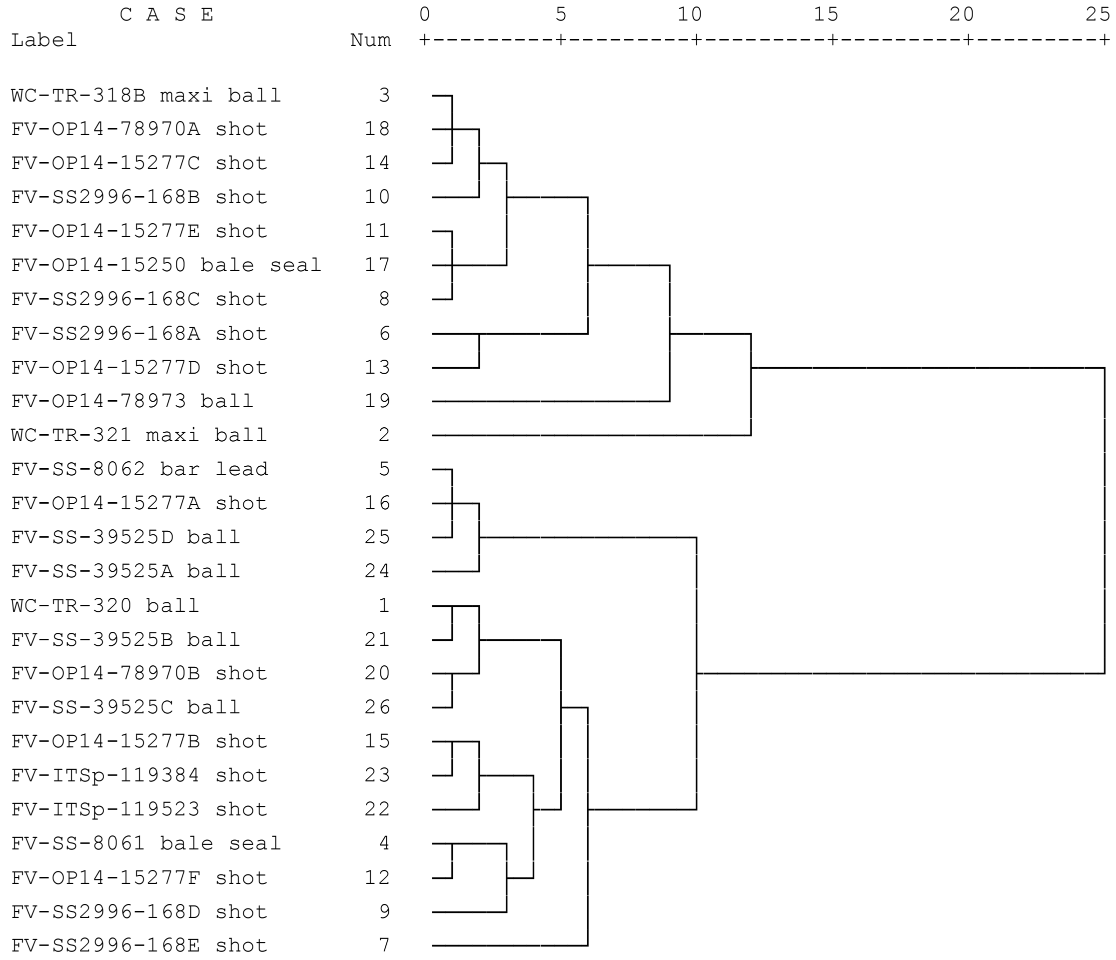
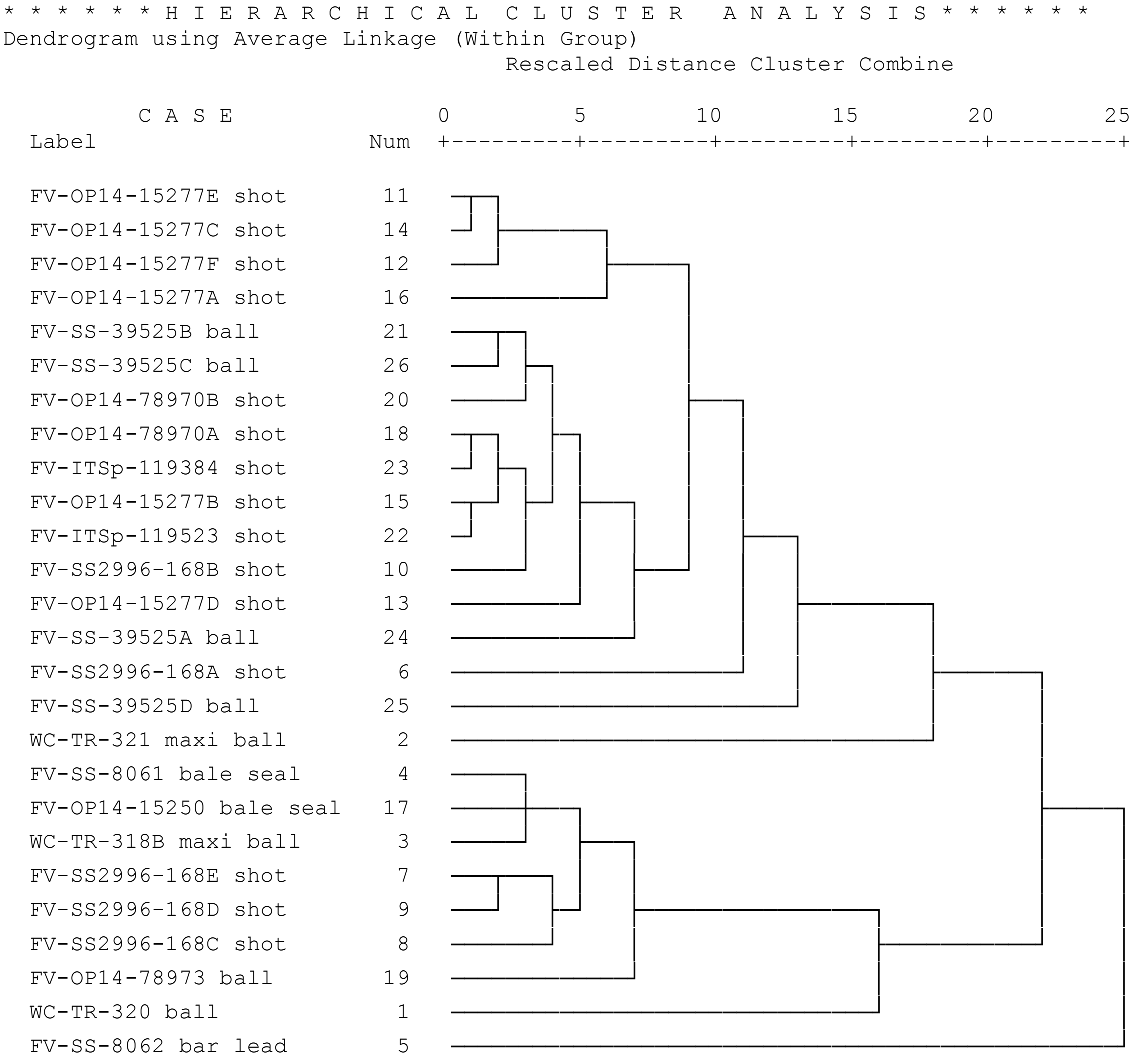


Figure 4-7 Cluster diagram run with lead isotope data for selected artifacts from Fort Vancouver and Travelers' Rest (n = 26).

Next, a cluster analysis is run using bulk element, trace element, and the lead isotope data as presented in Figure 4-8. The cluster diagram demonstrates some artifacts clustering not only by form, but by location as well. However, the clusters are indistinct. Of particular note is that the Operation 14 shot clusters near the top of the diagram and the Sales Shop shot clusters near the bottom.

Bulk element, trace element, and lead isotope data



```
* * * * * * H I E R A R C H I C A L   C L U S T E R   A N A L Y S I S * * * * * *
Dendrogram using Average Linkage (Within Group)
                                     Rescaled Distance Cluster Combine

         C A S E              0         5        10        15        20        25
  Label                  Num  +---------+---------+---------+---------+---------+

  FV-OP14-15277E shot     11
  FV-OP14-15277C shot     14
  FV-OP14-15277F shot     12
  FV-OP14-15277A shot     16
  FV-SS-39525B ball       21
  FV-SS-39525C ball       26
  FV-OP14-78970B shot     20
  FV-OP14-78970A shot     18
  FV-ITSp-119384 shot     23
  FV-OP14-15277B shot     15
  FV-ITSp-119523 shot     22
  FV-SS2996-168B shot     10
  FV-OP14-15277D shot     13
  FV-SS-39525A ball       24
  FV-SS2996-168A shot      6
  FV-SS-39525D ball       25
  WC-TR-321 maxi ball      2
  FV-SS-8061 bale seal     4
  FV-OP14-15250 bale seal 17
  WC-TR-318B maxi ball     3
  FV-SS2996-168E shot      7
  FV-SS2996-168D shot      9
  FV-SS2996-168C shot      8
  FV-OP14-78973 ball      19
  WC-TR-320 ball           1
  FV-SS-8062 bar lead      5
```

Figure 4-8 Cluster diagram run using bulk element, trace element, and lead isotope results for ball, bar lead, bale seals, and shot artifacts from Travelers' Rest and Fort Vancouver (n = 26).

The quantitative analysis was continued deriving a final cluster diagram using bulk element and trace element data but without the lead isotope data (Figure 4-9). The resulting diagram shows distinct clusters of similar form artifacts clustering from recovery location. Most distinctly, the Sales Shop 2996 shot artifact clustering near the top, the bale seals clustering together, and the distinct Operation 14 shot clusters in the center of the diagram. There are some distinct outliers, particularly a maxi ball (WC-TR-321), a ball (WC-TR-320), and the bar lead (FV-SS-8062).

Bulk and trace element data only

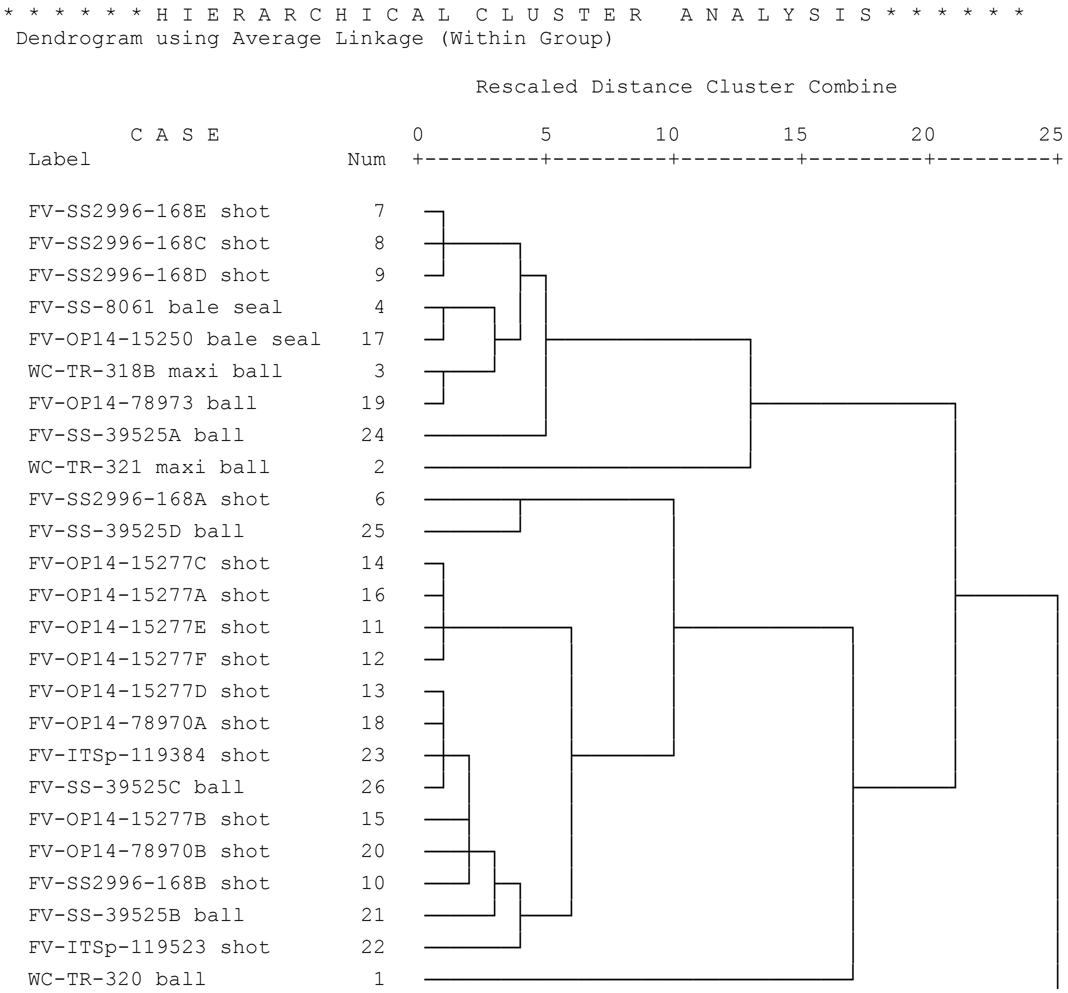


Figure 4-9 Cluster diagram run with bulk element and trace element results for ball, bar lead, bale seals, and shot from Travelers' Rest and Fort Vancouver artifacts (n = 26).

One of the disadvantages of cluster analysis is that the method can force structure on to data where none exists. Comparing the cluster analysis results with discriminant analysis provides a method to verify the cluster analysis results (Baxter and Buck 2000: 707), the topic of the next section.

Discriminant Analysis

Discriminant analysis is used for identifying relationships between qualitative criteria and quantitative predictor variables using prior assumptions about grouping (Kachigan 1986: 357). It can be employed to determine whether groups of artifacts are chemically distinct and provides a method of investigating cluster analysis results (Baxter and Buck 2000: 709). Further, it can be used to assign characterized artifacts to groups (Baxter and Buck 2000: 709). As with other statistical approaches, several methods exist in order to produce discriminant analysis. One of the most common methods used for archaeometric problems is Fisher's linear discriminant analysis (LDA). LDA uses a given set of variables to narrow parameters for group assignment and to maximize distance between groups.

The initial grouping of data represents the most significant difference between cluster analysis and discriminant analysis. Discriminant analysis identifies groupings and attempts to identify variables that differentiate the groups, whereas cluster analysis assumes no prior groupings and then clusters the datasets into differentiated subsets. Discriminant analysis was undertaken on twenty-six artifacts using just the lead isotope data and identifying the four categories of form for classification; ball, bale seal, bar lead, and shot. The analysis employed Fisher's linear discriminant functions and within group membership. The results are presented in Table 4-3.

		Artifact Form	Predicted Group Membership				n = Total
			Ball	**Bale Seal**	**Bar Lead**	**Shot**	
Original	Count	Ball	6	0	1	1	8
		Bale seal	0	1	0	0	1
		Bar lead	0	0	2	0	2
		Shot	3	1	1	10	15
		-------------	--------------	--------------	--------------	--------------	--------------
	%	Ball	75.0	.0	12.5	12.5	100.0
		Bale seal	.0	100.0	.0	.0	100.0
		Bar lead	.0	.0	100.0	.0	100.0
		Shot	20.0	6.7	6.7	66.7	100.0

73.1% of original grouped cases correctly classified.

Table 4-3 Classification results: predicted group membership of artifacts based on lead isotope analysis alone (n =26).

73.1% of the artifacts were grouped in their predicted category regardless of location based on their lead isotopes signatures alone. Of the twenty-six classified artifacts the seven misclassified cases include the ball from Travelers' Rest (WC-TR-318b), several portions of shot from Fort Vancouver (FV-SS2996-168b, FV-SS2996-168c, and FV-OP14-15277F), and lead balls also from Fort Vancouver (FV-OP14-15277a and FV-SS-39525d).

The effectiveness of using bulk element, trace element, and lead isotope data was examined using the same discriminant analysis. The results are presented in Table 4-4.

		Artifact Form	Predicted Group Membership				n = Total
			Ball	Bale Seal	Bar Lead	Shot	
Original	Count	Ball	8	0	0	0	8
		Bale seal	0	1	0	0	1
		Bar lead	0	0	2	0	2
		Shot	0	0	0	15	15
		-------------	-------------	-------------	-------------	-------------	-------------
	%	Ball	100.0	.0	.0	.0	100.0
		Bale seal	.0	100.0	.0	.0	100.0
		Bar lead	.0	.0	100.0	.0	100.0
		Shot	.0	.0	.0	100.0	100.0

100.0% of original grouped cases correctly classified.

Table 4-4 Classification results: predicted group membership of artifacts based on bulk element, trace element, and lead isotope analysis (n = 26).

Using the all of the available chemical characterization data, correctly classifies 100% of the artifacts to their assigned form.

To investigate whether bulk and trace element data alone produce reliable results, the discriminant analysis is run a final time without the lead isotope data. The results are presented in Table 4-5.

		Artifact Form	Predicted Group Membership				n = Total
			Ball	Bale Seal	Bar Lead	Shot	
Original	Count	Ball	7	0	0	1	8
		Bale seal	0	1	0	0	1
		Bar lead	1	0	1	0	2
		Shot	1	0	0	14	15
		-------------	-------------	-------------	-------------	-------------	-------------
	%	Ball	87.5	.0	.0	12.5	100.0
		Bale seal	.0	100.0	.0	.0	100.0
		Bar lead	50.0	.0	50.0	.0	100.0
		Shot	6.7	.0	.0	93.3	100.0

88.5% of original grouped cases correctly classified.

Table 4-5 Classification results: predicted group membership using only bulk element and trace element analysis (n = 26).

For the analysis of the 26 artifacts using only bulk element and trace element data, three artifacts are misclassified.. A ball (FV-SS-39525C) is misclassified as shot, a single shot (FV-ITSp-119523) is misclassified as ball, and a bale seal (FV-SS-39525c) is misclassified as ball.

One of the constraints of discriminant analysis is that group membership is limited to pre-determined categories. In this example, the cases were broken down into four groups; ball, bale seal, bar lead, and shot. Artifacts with unknown form, such as anomalous portions, would be forced the artifacts to fall into contrived categories whether or not those categories were valid. For example, an anomalous portion of lead may be classified as a "bale seal" of the four possible categories, when indeed it was actually a portion of plumbing, a category not considered.

Discriminant analysis is run a last time using all thirty-eight artifacts categorizing them by location and artifact form using bulk element, trace element, and lead isotope analysis. The results are presented in Table 4-6. Remarkably, 94.7% of the artifacts are correctly assigned by location and form. The two misclassified artifacts are FV-ITS-121624c and FV-ITS-121765, both fragments and both wrongly assigned to shot, possibly indicating the fragments could be composed of recycled shot.

			Predicted Group Membership												Total
		Artifact Form and Location	**TR-frag**	**TR-ball**	**TR-tab.**	**SS-bale**	**SS-bar**	**SS-ball**	**ITSp-shot**	**ITS-frag**	**OP14-bale**	**OP14-shot**	**OP14-ball**	**SS2996-shot**	**n =**
Original	Count	Travelers' Rest-frag	4	0	0	0	0	0	0	0	0	0	0	0	4
		Travelers' Rest-ball	0	3	0	0	0	0	0	0	0	0	0	0	3
		Travelers' Rest-tab	0	0	1	0	0	0	0	0	0	0	0	0	1
		SS-bale seal	0	0	0	1	0	0	0	0	0	0	0	0	1
		SS-bar lead	0	0	0	0	1	0	0	0	0	0	0	0	1
		SS-ball	0	0	0	0	0	4	0	0	0	0	0	0	4
		ITSp-shot	0	0	0	0	0	0	2	0	0	0	0	0	2
		ITS-fragment	0	0	0	0	0	0	0	5	0	1	0	1	7
		OP14-bale seal	0	0	0	0	0	0	0	0	1	0	0	0	1
		OP14-shot	0	0	0	0	0	0	0	0	0	8	0	0	8
		OP14-ball	0	0	0	0	0	0	0	0	0	0	1	0	1
		SS2996-shot	0	0	0	0	0	0	0	0	0	0	0	5	5
		----------------------------	---------	---------	---------	----------	-------	---------	-------	-----------	--------	---------	----------	----------	------------------
	%	Travelers' Rest-frag	100.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	100.0
		Travelers' Rest-ball	.0	100.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	100.0
		Travelers' Rest-tab	.0	.0	100.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	100.0
		SS-bale seal	.0	.0	.0	100.0	.0	.0	.0	.0	.0	.0	.0	.0	100.0
		SS-bar lead	.0	.0	.0	.0	100.0	.0	.0	.0	.0	.0	.0	.0	100.0
		SS-ball	.0	.0	.0	.0	.0	100.0	.0	.0	.0	.0	.0	.0	100.0
		ITSp-shot	.0	.0	.0	.0	.0	.0	100.0	.0	.0	.0	.0	.0	100.0
		ITS-fragment	.0	.0	.0	.0	.0	.0	.0	71.4	.0	14.3	.0	14.3	100.0
		OP14-bale	.0	.0	.0	.0	.0	.0	.0	.0	100.0	.0	.0	.0	100.0
		OP14-shot	.0	.0	.0	.0	.0	.0	.0	.0	.0	100.0	.0	.0	100.0
		OP14-ball	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	100.0	.0	100.0
		SS-shot	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	100.0	100.0

94.7% of original grouped cases correctly classified.

Table 4-6 Classification results: predicted group membership based on artifact form and location using bulk element, trace element, and lead isotope analysis (n = 26).

Quantitative analysis proves helpful to identify patterns of meaning within the data. In this case, chemical analysis is relevant to artifact form. Teasing out meaning requires applying various quantitative methods by trial and error to find patterns within the data. In this investigation, it was helpful to first identify clusters within the data. Once clusters were identified, it proved helpful to eliminate cases based on the understanding of those clusters. For example, the modern manufactured bullets were eliminated from the analysis after it was apparent that those cases clustered as a distinct group. Additionally, cases in which only lead isotope ratios were available were also eliminated. By comparing the success of classification based on form using discriminant analysis, it was found that using a full range of variables that include bulk element, trace element, and lead isotope ratios provides the highest classification success.

Chapter 5
DISCUSSION

Hancock's Six Steps for Successful Chemical Analysis

The goal of this thesis is to place chemically characterized historic artifacts within a broader data context by applying Hancock's six step framework. This chapter discusses the findings of the artifacts' historical, use-life, deposition, and recovery contexts, the elemental analysis, and data interpretation.

While Hancock's six steps serve to organize the elemental analysis in a framework that considers the elemental changes a given artifact undergoes from manufacture, use-life, deposition, and finally recovery it might be beneficial to alter consideration of the steps so that they were organized in a manner that is better suited to the archaeological process. For example, deposition and recovery are perhaps a more logical starting point. The next step could be use-life, in which the artifact were examined and attributes tabulated. Next, the chemical analysis would occur. Only when the archaeological data and artifact attributes were known would the historical research begin. The final step could be to use all of the aforementioned research to assist with the data analysis. The altered organizing framework would look as shown in Table 5-1.

Hancock's Six Steps	Suggested Questions
Deposition	What are the environmental conditions in which the artifact was recovered?
Recovery	What information is available from the recovery? How has the object been treated since it's archaeological recovery?
Use-life	How was the object altered during it's use-life?
Elemental Analysis	What methods are used to chemically characterize the object? What are the results of the chemical analysis?
Historical contexts	What are the raw materials used for fabricating the artifact? What raw materials were historically available for it's fabrication?
Data Interpretation	What do similarities and differences in the data mean? How are historical, use-life, deposition, and recovery contexts interpreted in light of the chemical data?

Table 5-1 Alternative organizing framework for successful artifact analysis.

Historical Analysis of Artifacts

Round lead balls and shot have been used as ammunition since the advent of firearms and are used into the present day by period enthusiasts. Round balls and shot recovered in Pacific Northwest archaeological contexts indicate a broad date range and are not effective as stand-alone time markers. They are most valuable when placed in a context of diagnostic cultural material or features.

It is possible that artifact WC-TR-324 was indeed part of the Lewis and Clark expedition. Perhaps the artifact occurred as the result of melting one or more of the numerous tin rings, cups, horns, or sheets, or even the pewter buttons that Lewis and Clark expedition carried (Jackson 1978: 69-99). Unfortunately, there is no data analysis available that unquestionably links the artifact to the expedition.

Dating the material recovered from Travelers' Rest is difficult because of the mixed artifact assemblage. As mentioned earlier, prehistoric artifacts occur with recent and historic artifacts indicating mixing and compromised stratigraphy. The mixing likely occurred due to plowing, which is estimated to have disturbed the ground to Level IV, 40 cmbs (15.7”). However, the maxi balls are datable artifacts indicating that the site was used by Euro-Americans by at least the mid-nineteenth century.

Areas of additional historical research into lead production and trade would be beneficial. Of particular interest are lead supplies as they relate to nineteenth century fur trade. There are numerous inventories, ships logs, and account books relating to business conducted by the fur companies. Archaeological investigations and research of Missouri River and Mississippi River fur trade era steamship wrecks could prove to be a valuable resource if lead commodities were found onboard. Documents relating those lead commodities to their suppliers could prove extremely valuable when combined with chemical analysis.

Research into other commodities supply and trade would also be beneficial. For example, two of the artifacts were composed of significant amounts of tin. Research into the production and supply of tin may shed light on historic artifacts recovered from archaeological contexts and subsequently undergoing chemical analysis.

Use-life Analysis

There is no chemical method of determining whether a lead artifact was produced or manufactured with recycled lead. As shown by using the lead isotope ratios to produce the cluster diagram in Appendix C, bullets of modern manufacture with recycled lead material fall within the historical artifacts, presenting three indiscernible possibilities. Additionally, bulk element and trace element analysis are both incapable of discerning whether artifacts are composed of mixed ore sources. The first possibility is that the lead artifacts are all manufactured of recycled lead, the second is that none of the artifacts are manufactured of recycled lead but still have a similar signature to those of recycled lead, and the third is that some of the artifacts are manufactured of recycled lead and some are manufactured from a single source.

Deposition Analysis

While corrosion and the development of patina may occur or develop on lead artifacts, these processes are external and do not affect the interior artifact composition. Although not addressed in this investigation, including information such as soil or matrix descriptions would prove beneficial to understanding the depositional environment of the recovered artifacts. This information may explain any present or possibly future degradation of the artifact.

Recovery Analysis

The artifacts were treated to light cleaning with no documentation or indication of chemical cleaning. If any chemical cleaning did occur, MURR laboratories procedures provide assurance that analyzed samples were retrieved from the uncontaminated interior to control for any external contamination that might be present. Part of the recovery analysis was to evaluate the archaeological contexts of the undated Travelers' Rest artifacts. This evaluation of the archaeological contexts served to investigate the degree of stratigraphic control available for dating artifacts. The analysis revealed that there was such a degree of mixing within the probable plow zone of the excavated units that it is difficult to ascertain dates based on stratigraphy and associated artifacts.

Classifying artifacts can be a complicated endeavor. It is interesting to note that there is no precise definition of where shot (and buckshot) and ball diverge to form distinct categories and there is considerable variation within categories. Further data on identifying characteristics of these categories would be helpful in discerning them. For example, as seen in Table 4-1, copper, tin and antimony vary according to artifact category, possibly the result of differing manufacture and alloying techniques.

Elemental Analysis

Of the twenty-six elements targeted for analysis, only eleven proved to occur at levels above the instruments LOD. Future analysis may benefit from streamlining the targeted elements and only consider those eleven or the variability of trace elements in lead. However, until there is more data, it is likely beneficial to consider all twenty-six. It is interesting to note that while lead commonly occurs with zinc as a natural ore component, zinc did not occur in any of the samples collected from the lead artifacts. However, zinc did occur in a trace amount in artifact WC-TR-324. It may be that zinc does occur as an element in some lead objects. It would be unwise to decide the elements for analysis based solely on the limited number of artifacts sampled for this project.

The fact that two (WC-TR-324 and FV-SS-120281) of the thirty-eight artifacts submitted for elemental analysis were composed of mostly of tin and had less than 50% lead as a constituent prove the problems identifying metal objects. However, given the population of sampled artifacts (n=38), 95% of the artifacts were correctly identified as being composed of over 95% lead.

Variation of elemental composition occurs by artifact category, as presented in Table 4-1 and as reflected by the cluster analyses. The variation could possibly occur due to differing manufacture techniques used for fabricating shot and ball. Further investigation of the elemental variation of these artifact categories and others, such as bar lead and bale seals, would likely prove beneficial to future research. It may be that various manufacturers use specific alloys, for example antimony, arsenic, and tin, for the fabrication of specific products.

Quantitative Analysis

Modern manufactured bullets and a limited number of artifacts with similar provenience group together. Grouping also occurs by artifact type; that is, the artifacts group by the manufacturing or production type that produced ball or shot. Bulk element, trace element, and lead isotope analyses are valuable methods of artifact analyses that combined with the development of a database of historical artifacts may lead to a better understanding of lead trade at historical archaeological sites. Producing an analysis that includes the historic, use-life, deposition, and recovery contexts, in addition to elemental analysis, helps to examine the origin and composition questions more thoroughly.

Applying discriminant analysis using bulk element, trace element, and lead isotope analysis to artifact form and location has a surprisingly high success rate. A success rate of 100% is extraordinary using simply artifact form. And, as shown in Table 4-6, broadening the analysis to include location also has a very high success rate (94.7%). The two artifacts that were misclassified were both fragments that were wrongly categorized as shot. One of the simplest explanations being that the fragments' original form may have been shot.

Placing the artifacts within a broader context does provide a more relevant interpretation of the lead isotope data. It may indeed be appropriate to designate the source of the Fort Clatsop artifact to Missouri, as no other artifacts are similar to it. When viewed among the other artifacts, it is unique. It may represent a lead ball manufactured or produced from lead different enough from artifacts found in the area that it might be reasonable to attempt finding its lead ore source. However, no site report is available for this artifact. Understanding the deposition and recovery contexts of the Fort Clatsop lead ball is necessary for a complete analysis.

The grouping of the ball and the shot has a potential explanation derived from the fabrication methods addressed in the historical contexts. This study presents only a limited number of balls and shot for examination, a future project such as this would benefit from a larger sample of artifacts.

A ball, because of the idiosyncratic nature of fire arms, was more likely produced by the individual meeting the size requirements of a given fire arm. Production likely occurred on an individual basis with production supplies purchased in portable amounts as needed. Conversely, shot was more likely fabricated as a result of large-scale manufacture. Shot, because of its size and function, is used in multiple quantities rendering individual production inefficient and unlikely. Shot manufacture is likely the result of limited number of manufacturers using established lead ore supplies then shipped to suppliers in finished form. Researching ships' logs, receiving documents, inventories and sales documents is likely to provide information regarding the nature of shipping ball and shot. Additionally, historical accounts of ball and shot use, perhaps lurking in personal journals, may also provide useful information into this line of inquiry.

Sourcing is not a viable line of research inquiry for the remaining artifacts as evidenced by the grouping of historical artifacts with modern manufactured bullets known to be composed of recycled lead. Relevant to this study is that while both American Eagle Manufacturing and Winchester Manufacturing use recycled lead, it is possible to group bullets to their respective manufacturer.

It would be of particular value to have a larger database of characterized artifacts to investigate the potential and limitations of the proposed design of artifact analysis. It would be particularly useful to further investigate how this larger database related to recovery location.

Investigating the data provided some insights into the possibilities and limitations of using bulk element, trace element, and lead isotope analysis. At the end of the quantitative analysis, the artifact type was reduced to only four; ball, shot, bar lead, and bale seal. Obviously, using a limited database of characterized artifacts also limits the investigation.

Five steps for Successfully Determining a Parent Ore Source

Because it was discovered that there is no way to determine whether the artifacts were manufactured with recycled material or pure ore sources, it is an exercise in futility to try and assign the artifacts a source ore. Despite the existence of lead isotope databases identifying the lead isotope signatures of ore sources (steps 1-4), it becomes apparent that sourcing is not an option if the researcher can not determine the integrity of the parent material. The quantitative analysis reveals that sourcing is not a compelling line of research as indicated by the grouping of the modern manufactured bullets being interspersed with the groupings of historic lead artifacts. Modern bullets are manufactured with almost 70% recycled lead. While the modern manufactured lead bullets cluster as a group, they also cluster within the historic lead artifacts and do not generate unique signatures that would indicate they are indistinguishable from those artifacts.

Additionally, manufacturers and metallurgists regularly alloy lead with other metals to dilute or to exploit lead's softness and corrosion resistance. Antimony, arsenic, and bismuth added to lead during the manufacturing process increase pouring and casting qualities and improve hardness and ductility. (Light 2000: 12). Tin and silver constitute common alloys with lead as well. Any mineral component added to molten lead is likely to have it’s own lead isotope signatures leading to a composite characterization.

As an exercise in sourcing, lead isotope ratio data from artifacts recovered at Fort Vancouver locale, SS2996, were placed in the context of ore sources, producing the dendrogram in Figure 5-1. There are a wide variety of possible ore sources ranging from Utah to Connecticut and Massachusetts to North Carolina. Given that these five shot pieces are very similar to each other, it is unlikely that they came from the locales indicated.

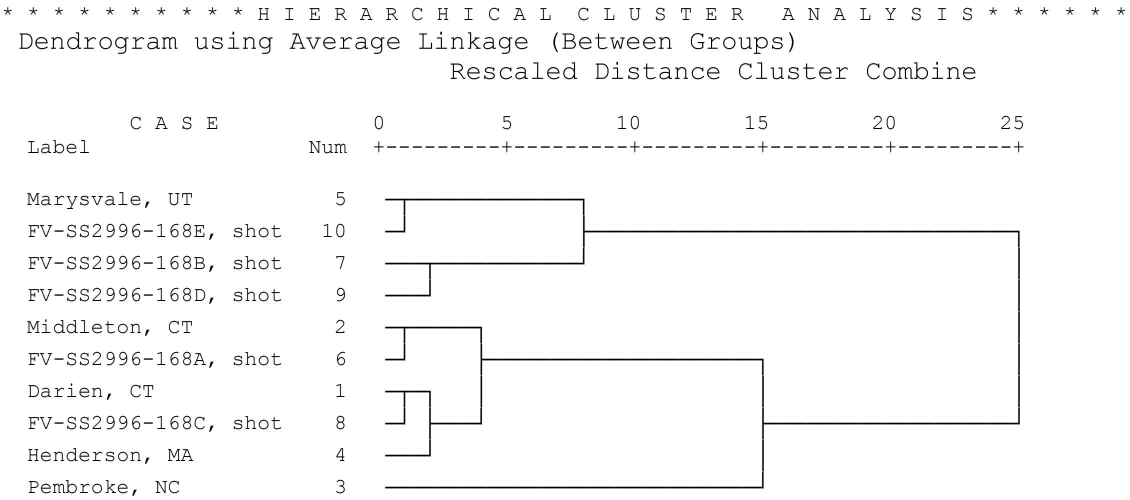


Figure 5-1 Cluster diagram: Fort Vancouver artifacts from SS2995 (n = 5) placed in context with lead ore sources (n = 5) (Russell and Farquhar 1960: Columbia analysis).

Additionally, RMH-A8, the lead shot associated with the North West Company and dated to 1799 to 1821, is most closely matched to the Waldorf Mine at Argentine Pass in Colorado. The earliest explorers in Colorado were members of the Zebulon Pike Expedition of 1806 to 1807(Chittenden 1986, 1935: 84). While it is not outside the realm of all possibilities that the lead came from Colorado, it is also not very likely.

However, those outliers that don't fit with the bulk of the artifacts may have sourcing potential. Because the Fort Clatsop lead ball is so different from the remaining artifacts, it may indeed be the result of a direct chain from mine to smelter to production. This is an area where more work could be done, perhaps starting with artifacts with known production sites, such as lead bars produced in Missouri for the fur trade.

Therefore, Reeves's and Brooks's five steps for determining the parent ore source using chemical analysis can not be applied to this particular problem because it is impossible to distinguish between the modern and historic artifacts based on bulk element, trace element, and lead isotope analyses. The data also suggests that the historic artifacts are likely to be manufactured from recycled and mixed lead material.

Chapter 6
CONCLUSIONS

This thesis has attempted to address the question of whether advanced chemical analysis is a useful method of artifact analysis that allows characterized artifacts to be placed in a broader context. The goal of the exercise is to derive meaningful patterns of information. The problem was addressed using bulk element, trace element, and lead isotope chemical analysis to characterize artifacts recovered from the suspected location of Travelers' Rest and from artifacts recovered at Fort Vancouver. The analysis was broadened to include lead isotope data from previous investigations on artifacts from Fort Clatsop, Rocky Mountain House, O'Connell Mission, and San Luis Mission. Lead isotope data from modern manufactured bullets were also used to investigate the problem and serve as control data for the lead isotope analysis.

This investigation was framed to understand the historical, use-life, deposition, recovery contexts, and elemental characteristics of the artifacts by applying a six step framework suggested by Hancock (2000). Once the artifacts were placed within the first five contexts, the resulting data were then subjected to quantitative analysis.

It is clear that placing a given artifact in a broader context of characterized artifacts is a valid method of inquiry. Comparing artifacts within trivariate plots and through cluster analysis, the researcher is able to identify artifacts that are similar to others and cluster groups or instead are outliers and dissimilar to other artifacts. Importantly, data tends to cluster by artifact form and recovery location.

Bulk elemental analysis proved invaluable for developing a historical inquiry and developing a valid comparative analysis. Knowing the bulk elements of a given artifact is important for investigating the historical context of the artifact. In this study, the historical investigation of lead mining and manufacture provided information on recycling that proved relevant to the elemental analysis. Namely, it was demonstrated that lead is commonly recycled and has been commonly recycled through history. Knowing the bulk elements is also important for quantitative analysis, particularly when using lead isotope analysis because lead isotopes are ubiquitous occurring in metal artifacts regardless of the bulk composition. A characterized artifact, even when not mainly composed of the material targeted for investigation, may still cluster with those artifacts because of intermediate values, particularly when recycling is a potential factor.

Obtaining the trace element composition of an artifact is important for providing a “tighter” analysis. That is, despite alterations of trace elements due to smelting and manufacture, they remain helpful in providing additional variables and produce more accurate discriminant analysis for artifact characterizations.

Lead isotope analysis has proved valuable to further understand the chemical signature of an artifact, but especially when placed in a broader context of other characterized artifacts. It is important to know the bulk composition of artifacts to eliminate comparing artifacts that are dissimilar at the basic composition level. Using the control data supplied by the modern manufactured bullets of known recycled lead content, it became evident that it is impossible to discern those artifacts that have intermediate lead isotope signatures due to the mixing of ore and metal sources.

The inability to identify recycling weakens the ability of the researcher to pursue sourcing an artifact. The research demonstrated that it was not possible to apply the framework needed for successful sourcing because it was not possible to determine whether a given artifact was fabricated directly from an ore source. In the case of the Travelers' Rest artifacts, it is not possible to unequivocally state that they were manufactured from a pure source. Additionally, there is no indication using bulk element, trace element, or lead isotope analysis that links the artifacts to the Lewis and Clark expedition; nor is there any indication using chemical analysis that the artifacts are linked to Native Americans, fur traders, miners, or homesteaders. The strongest dating association provided by any of the lead artifacts at Travelers' Rest is the maxi ball. It provides a *terminus post quem* to some time around the Civil War.

The second part of the first question addressed in this thesis was to determine whether it is possible to distinguish patterns of information from characterized artifacts. Meaningful patterns were produced from the quantitative analysis of the characterized artifacts: in particular, it is possible to distinguish between batches of manufactured material (American Eagle and Winchester) and to distinguish artifact form (ball versus shot). A broader database likely would provide additional categories of form, such as bar lead and bale seals as well as distinguishing artifacts by recovery location.

The second question addressed by this thesis was whether it is possible to source an artifact to its parent ore. While there are little data to compare, determining the ore source of an artifact is problematic. It is likely that so many lead commodities were the product of alloying, recycling, and mixed ore production, that it is impossible to determine the mine source of an artifact. Unfortunately, there is no way to determine whether a given object was produced from mixed sources. One potential avenue to further investigate source possibilities is to characterize material from known lead bar and ammunition producers and their source mines.

Lead Identification in the Field and Laboratory

One of the most valuable pieces of information determined from this study is that it is prudent before attempting to group artifacts by chemical signature, to first chemically identify the bulk elemental content of metal artifacts. The discovery that artifact WC-TR-324 was not lead, but rather an almost pure tin artifact, revealed a significant problem with initial laboratory description and classification. In most cases, it is difficult to identify specific bulk metals in the lab without advanced chemical analysis. The fact that the first lead isotope analysis did not reveal this error also identifies problems with lead isotope analysis when not executed in tandem with bulk elemental analysis.

Identification of the bulk elements allows the researcher to proceed with the investigation using Hancock's Six Steps. It is then possible to develop relevant avenues of investigation for the historical, use-life, deposition, and recovery contexts. Once these contexts are understood, the researcher can then proceed with data interpretation.

This study, which began with the misidentification of artifact WC-TR-324, also suggests steps for initial laboratory analysis that may then lead more sophisticated lead isotope and trace element analysis. First, metal qualities should be understood before classifying materials. Lead is a soft, malleable, generally non-corrosive metal, with a dull gray or white patina that can be scratched with a fingernail and produces a dark streak on paper (Plenderleith and Werner 1971: 266). Simple laboratory tests including using magnet, scratch, and streak tests can be conducted to test for these qualities. Second, metals are rarely pure. Alloyed metal artifacts are likely more common than elementally pure artifacts, especially in an historical context. Laboratory analysis should take into account that the suggested tests are likely to best serve descriptive rather than diagnostic purposes. In cases where the description still leaves room for doubt, such as with the "melted puddle," WC-TR-324, it may be better to error on the conservative side and classify the material as simply "metal" or "unknown metal" rather than to misclassify the artifact. If the basic artifact description is consistent with known material, such as lead balls, it is likely more acceptable to classify the artifact as "lead." If a more precise determination of metal content is required, more advanced investigations into the bulk element, trace element, and lead isotope analyses of the artifacts are the best methods to fully understand artifact composition.

Bulk Element, Trace Element, and Lead Isotope Analysis

Bulk element, trace element, and lead isotope analysis are powerful analytical tools when applied to lead artifacts. Bulk element analysis is fundamental to identifying the main composition of an artifact. In the case of artifact WC-TR-324, it was necessary to identify the bulk components to establish basic historical contexts. The artifact was first identified as lead, which instigated a wild goose chase of sorts, following a line of historical inquiry that was not relevant. While the results of this project suggest that generally an investigator will correctly identify an artifact as lead (95%), employing an advanced analysis technique is desirable to eliminate doubt.

Bulk element, trace element, and lead isotope analyses have proved particularly appropriate to identify chemical distinctions between lead ball and lead shot ammunition. One line of inquiry could begin with developing a database of historically known lead ore sources with historically known lead artifacts. This database could then be used to compare and understand lead artifacts with unknown provenance. It is imperative to maintain excellent archaeological records of artifact provenience to assist with understanding the depositional and recovery contexts. These contexts along with historical and use-life contexts provide the basis for the elemental and quantitative analysis.

Future research studying ships' logs, inventories, receiving and sales documents, and historical accounts may provide valuable information to build both the historical and the use-life contexts of lead.

Lead: An Element of Success

On the return trip, Lewis and Clark encountered Joseph Dickson and Forest Hancock working their way up the Missouri with designs to establish fur trading relationships with Native Americans. Lewis provided them not only with information about what to expect upriver on their forthcoming journey, but also gave them goods they might use including "a couple of pounds of powder and lead." When Corps member John Colter decided to join these hunters, the Corps, wishing him every advantage, also provided him with small trade items, including additional powder and lead.

Lead served as one of the basic commodities allowing Euro-Americans to settle and dominate the Western Frontier. Lead served to ensure hunting success and bodily protection, while also serving as an item of trade and often as a means to develop advantageous relationships with Native Americans. While heavy, it was cheap, durable, and malleable. For archaeologists, lead has the desirable characteristic of excellent preservation. Using advanced investigative techniques, lead can be characterized for a more detailed artifact description allowing the archaeologist to link artifacts within and between assemblages. The archaeologist then has the potential to understand how lead artifacts fit into the daily lives of those who once relied on the material for survival and success. The capability to derive useful and relevant information of lead's role in the changing Western Frontier is enhanced as more carefully excavated lead artifacts are chemically characterized with the resulting information available in a readily accessible database.

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APPENDIX A - Lead isotope data for artifacts and locations as presented in Figure 1-1.

Location **Reference**	^{206}Pb/^{204}Pb	^{207}Pb/^{204}Pb	^{208}Pb/^{204}Pb
Montgomery County, AR (Russell and Farquhar 1960)	18.36	15.61	38.6
Roxbury, CT (Russell and Farquhar 1960)	18.38	15.70	38.5
Denboe Point, ME (Russell and Farquhar 1960)	18.40	15.65	38.3
Quincy, Fallon Quarry, MA (Russell and Farquhar 1960)	18.41	15.75	38.4
Olive Hill, KY (Doe and Rohrbough 1977)	18.50	15.65	38.5
Olive Hill, KY (Doe and Rohrbough 1977)	18.55	15.65	38.5
Travelers Rest, MT (Geochron Laboratories 2003)	18.54	15.63	38.5
Lake District, ENG (Doe and Rohrbough 1977)	18.34	15.54	38.2
Shropshire, ENG (Doe and Rohrbough 1977)	18.38	15.61	38.3
North Midlands, ENG (Doe and Rohrbough 1977)	18.48	15.62	38.5
North Midlands, ENG (Doe and Rohrbough 1977)	18.42	15.57	38.4
North Pennines, ENG (Doe and Rohrbough 1977)	18.42	15.56	38.3
North Pennines, ENG (Doe and Rohrbough 1977)	18.42	15.52	38.3
North Pennines, ENG (Doe and Rohrbough 1977)	18.34	15.54	38.2
Mendip Hills, ENG (Doe and Rohrbough 1977)	18.32	15.55	38.3
Kootenay, BC (Russell and Farquhar 1960)	18.37	15.69	38.4
Kootenay, BC (Russell and Farquhar 1960)	18.48	15.72	38.4
Grayson County, VA (United States Geological Survey 1992)	18.51	15.72	38.4
Smyth, Wash.or Grayson County, VA (United States Geological Survey 1992)	18.51	15.72	38.4
Fort Clatsop, OR (Geospec Consultants Limited 1997)	20.37	15.79	39.4

APPENDIX B - Bulk element, trace element, and lead isotope data for nineteenth century artifacts and lead isotope data for comparative artifacts and modern manufactured bullets.

Bulk element, trace element, and lead isotope data for nineteenth century artifacts and lead isotope data for comparative artifacts and modern manufactured bullets.

Location Reference	Sample ID	Artifact Descript.	Ca Calcium	Fe Iron	Cu Copper	As Arsenic	Ag Silver	Sn Tin	Sb Antimony	Pt Platinum	Au Gold	Bi Bismuth	^{208}Pb Lead	^{208}Pb %	^{206}Pb/ ^{204}Pb	^{207}Pb/ ^{204}Pb	^{208}Pb/ ^{204}Pb
Travelers' Rest (Guthrie 2004: electronic document)	WC-TR-172	anomalous portion	718.6	0.0	0.0	0.0	5.5	0.0	41.9	877.5	31.0	1557	998427	100	18.737	15.619	38.58083369
Travelers' Rest (Guthrie 2004: electronic document)	WC-TR-318A	fragment	1195.9	0.0	260.7	518.6	18.5	6896.0	14597.8	2676.3	20.7	2531	975266	97.5	17.535	15.527	37.56225611
Travelers' Rest (Guthrie 2004: electronic document)	WC-TR-318B	fragment	2386.3	0.0	28.5	0.0	16.7	0.0	282.6	2608.4	0.0	181	995006	99.5	18.545	15.733	38.82321487
Travelers' Rest (Guthrie 2004: electronic document)	WC-TR-320	ball	2088.8	0.0	2137.3	0.0	22.1	80.3	0.0	2971.9	15.6	2076	994989	99.5	18.488	15.649	38.64206369
Travelers' Rest (Guthrie 2004: electronic document)	WC-TR-321	maxi ball	1006.2	0.0	0.0	0.0	32.2	922.5	17573.5	3591.1	0.0	704	978215	97.8	18.719	15.786	39.19547178
Travelers' Rest (Guthrie 2004: electronic document)	WC-TR-324	anomalous portion	2208.2	0.0	16566.8	568.5	10.7	881772.2	75416.4	6373.3	0.0	34.9	2304	0.230	18.326	15.632	38.40209209
Travelers' Rest (Guthrie 2004: electronic document)	WC-TR-325	tabular drilled object	1336.8	0.0	33.4	371.6	168.9	2307.1	1653.5	5848.5	0.0	1358	989124	98.9	18.163	15.564	38.15516226
Travelers' Rest (Guthrie 2004: electronic document)	WC-TR-327	fragment	789.8	0.0	44.7	0.0	11.3	96.1	6822.1	5876.4	0.0	58.8	986898	98.7	19.723	15.733	39.193
Fort Vancouver (Guthrie 2004: electronic document)	FV-SS-8061	bale seal	3168.8	0.0	300.8	90.5	74.5	3081.3	1288.3	0.0	43.9	13.5	992298	99.2	18.538	15.688	38.615
Fort Vancouver (Guthrie 2004: electronic document)	FV-SS-8062	bar lead	1976.4	0.0	2649.0	0.0	32.5	1327.6	277.7	4217.7	49.4	8.43	989562	99.0	18.439	15.612	38.447

Bulk element, trace element, and lead isotope data for nineteenth century artifacts and lead isotope data for comparative artifacts and modern manufactured bullets.

Location Reference	Sample ID	Artifact Descript.	Ca Calcium	Fe Iron	Cu Copper	As Arsenic	Ag Silver	Sn Tin	Sb Antimony	Pt Platinum	Au Gold	Bi Bismuth	^{208}Pb Lead	^{208}Pb %	^{206}Pb/^{204}Pb	^{207}Pb/^{204}Pb	^{208}Pb/^{204}Pb
Fort Vancouver (Guthrie 2004: electronic document)	FV-SS-39525A	ball	0.0	156.7	463.3	235.4	81.5	4978.0	5461.9	6224.6	23.0	17.8	983507	98.4	18.378	15.599	38.444
Fort Vancouver (Guthrie 2004: electronic document)	FV-SS-39525B	ball	897.0	0.0	267.3	47.7	114.1	15978.4	646.6	4373.7	0.0	26.7	978276	97.8	18.466	15.667	38.599
Fort Vancouver (Guthrie 2004: electronic document)	FV-SS-39525C	ball	1223.8	0.0	473.5	91.5	137.5	27903.5	856.7	2909.2	0.0	104	966970	96.7	18.452	15.640	38.600
Fort Vancouver (Guthrie 2004: electronic document)	FV-SS-39525D	ball	813.9	1362.2	217.2	46.4	94.9	17199.5	468.1	3393.2	0.0	24.6	976619	97.7	18.431	15.630	38.466
Fort Vancouver (Guthrie 2004: electronic document)	FV-ITSp-119384	shot	1835.1	0.0	508.5	519.0	135.4	24962.0	1552.7	2332.6	0.0	62.6	969618	97.0	18.469	15.691	38.786
Fort Vancouver (Guthrie 2004: electronic document)	FV-ITSp-119523	shot	0.0	683.6	337.2	222.4	129.3	25390.0	1398.4	3205.1	19.3	68.8	970297	97.0	18.484	15.708	38.870
Fort Vancouver (Guthrie 2004: electronic document)	FV-ITS-120281	fragment	477.4	153.0	5852.9	383.9	372.2	577634.0	5886.7	701.1	113.3	1083	406703	40.7	18.334	15.539	37.866
Fort Vancouver (Guthrie 2004: electronic document)	FV-ITS-121428A	fragment	680.3	0.0	304.4	28.3	175.0	10429.0	1219.2	0.0	66.2	26.5	987838	98.8	18.365	15.648	38.525
Fort Vancouver (Guthrie 2004: electronic document)	FV-ITS-121428B	fragment	1498.2	0.0	373.3	31.9	232.7	40960.3	1098.0	0.0	46.1	78.5	957688	95.8	18.284	15.596	38.407
Fort Vancouver (Guthrie 2004: electronic document)	FV-ITS-121624A	fragment	0.0	279.8	631.6	1309.2	124.4	30134.9	2163.4	0.0	34.0	80.7	967723	96.8	18.497	15.652	38.512
Fort Vancouver (Guthrie 2004: electronic document)	FV-ITS-121624B	fragment	0.0	1076.7	371.2	138.6	107.0	7527.9	2435.9	908.7	25.3	15.5	988279	98.8	18.445	15.662	38.528

Bulk element, trace element, and lead isotope data for nineteenth century artifacts and lead isotope data for comparative artifacts and modern manufactured bullets.

Location Reference	Sample ID	Artifact Descript.	Ca Calcium	Fe Iron	Cu Copper	As Arsenic	Ag Silver	Sn Tin	Sb Antimony	Pt Platinum	Au Gold	Bi Bismuth	^{208}Pb Lead	^{208}Pb %	^{206}Pb/ ^{204}Pb	^{207}Pb/ ^{204}Pb	^{208}Pb/ ^{204}Pb
Fort Vancouver (Guthrie 2004: electronic document)	FV-ITS-121624C	fragment	977.7	0.0	211.4	0.0	37.0	126.3	0.0	0.0	19.1	< LOD	998694	100	18.592	15.774	38.663
Fort Vancouver (Guthrie 2004: electronic document)	FV-ITS-121765	fragment	0.0	0.0	696.1	1180.3	110.8	23557.1	1908.9	1494.5	14.8	81.3	973439	97.3	18.490	15.679	38.593
Fort Vancouver (Guthrie 2004: electronic document)	FV-OP14-15250	bale seal	1546.1	0.0	236.7	0.0	87.9	2763.8	311.1	3081.1	0.0	8.0	992293	99.2	18.596	15.764	38.784
Fort Vancouver (Guthrie 2004: electronic document)	FV-OP14-15277A	shot	0.0	0.0	770.6	1003.5	130.5	31281.3	2241.5	0.0	0.0	76.6	967102	96.7	18.414	15.604	38.426
Fort Vancouver (Guthrie 2004: electronic document)	FV-OP14-15277B	shot	1247.5	312.4	442.5	257.8	125.1	25969.5	3151.4	0.0	39.9	58.5	969879	97.0	18.467	15.680	38.778
Fort Vancouver (Guthrie 2004: electronic document)	FV-OP14-15277C	shot	0.0	0.0	788.9	1013.0	122.4	31832.9	3722.2	0.0	0.0	72.3	964772	96.5	18.528	15.737	38.822
Fort Vancouver (Guthrie 2004: electronic document)	FV-OP14-15277D	shot	0.0	0.0	338.6	320.3	135.1	25504.2	1505.6	0.0	0.0	64.9	972753	97.3	18.576	15.790	39.040
Fort Vancouver (Guthrie 2004: electronic document)	FV-OP14-15277E	shot	0.0	124.5	562.0	1014.2	127.0	30416.1	2034.3	1519.4	50.8	82.1	965785	96.6	18.573	15.764	38.817
Fort Vancouver (Guthrie 2004: electronic document)	FV-OP14-15277F	shot	0.0	0.0	588.6	1150.5	122.3	22715.7	3011.2	1407.6	0.0	61.1	972878	97.3	18.503	15.684	38.665
Fort Vancouver (Guthrie 2004: electronic document)	FV-OP14-78970A	shot	0.0	0.0	440.5	364.0	139.6	22866.2	2474.7	925.0	0.0	55.2	974448	97.4	18.542	15.726	38.830
Fort Vancouver (Guthrie 2004: electronic document)	FV-OP14-78970B	shot	3286.5	0.0	481.4	448.8	128.9	27118.1	3924.8	1067.0	0.0	82.0	959380	95.9	18.432	15.648	38.675

Bulk element, trace element, and lead isotope data for nineteenth century artifacts and lead isotope data for comparative artifacts and modern manufactured bullets.

Location Reference	Sample ID	Artifact Descript.	Ca Calcium	Fe Iron	Cu Copper	As Arsenic	Ag Silver	Sn Tin	Sb Antimony	Pt Platinum	Au Gold	Bi Bismuth	^{208}Pb Lead	^{208}Pb %	^{206}Pb/ ^{204}Pb	^{207}Pb/ ^{204}Pb	^{208}Pb/ ^{204}Pb
Fort Vancouver (Guthrie 2004: electronic document)	FV-OP14-78973	ball	0.0	0.0	217.7	14.6	39.5	0.0	0.0	663.8	91.3	95.7	999154	100	18.716	15.700	39.063
Fort Vancouver (Guthrie 2004: electronic document)	FV-SS2996-168A	shot	0.0	1199.2	383.2	376.6	135.6	23241.3	3300.2	0.0	53.2	62.8	972171	97.2	18.618	15.810	39.005
Fort Vancouver (Guthrie 2004: electronic document)	FV-SS2996-168B	shot	0.0	0.0	256.8	66.4	98.8	31249.5	1197.6	0.0	76.4	74.3	970286	97.0	18.582	15.728	38.686
Fort Vancouver (Guthrie 2004: electronic document)	FV-SS2996-168C	shot	0.0	0.0	404.0	671.5	36.3	0.0	1320.6	0.0	39.4	50.6	998441	100	18.622	15.747	38.845
Fort Vancouver (Guthrie 2004: electronic document)	FV-SS2996-168D	shot	0.0	0.0	380.9	375.3	48.4	0.0	2601.0	0.0	50.2	54.2	997146	100	18.485	15.724	38.673
Fort Vancouver (Guthrie 2004: electronic document)	FV-SS2996-168E	shot	0.0	0.0	349.3	655.4	34.8	0.0	1689.7	0.0	0.0	95.2	998119	100	18.413	15.743	38.552
Rocky Mountain House (Carlson 1996: 564)	RMH-A1	copper													18.38	15.62	38.41
Rocky Mountain House (Carlson 1996: 564)	RMH-A2	copper													18.5	15.69	38.69
Rocky Mountain House (Carlson 1996: 564)	RMH-A4	ball													18.47	15.71	38.7
Rocky Mountain House (Carlson 1996: 564)	RMH-A5	ball													18.67	15.73	39.08
(Carlson 1996: 564)	RMH-A7	copper													18.21	15.64	38.39
Rocky Mountain House (Carlson 1996: 564)	RMH-A8	shot													18.59	15.89	39.31

Bulk element, trace element, and lead isotope data for nineteenth century artifacts and lead isotope data for comparative artifacts and modern manufactured bullets.

Location Reference	**Sample ID**	**Artifact Descript.**	**Ca** Calcium	**Fe** Iron	**Cu** Copper	**As** Arsenic	**Ag** Silver	**Sn** Tin	**Sb** Antimony	**Pt** Platinum	**Au** Gold	**Bi** Bismuth	**^{208}Pb** Lead	**^{208}Pb %**	**^{206}Pb/ ^{204}Pb**	**^{207}Pb/ ^{204}Pb**	**^{208}Pb/ ^{204}Pb**
American Eagle (Buttigieg et al. 2003: 5026)	AE 113	bullet													19.191	15.706	38.661
American Eagle (Buttigieg et al. 2003: 5026)	AE 121	bullet													19.209	15.709	38.673
American Eagle (Buttigieg et al. 2003: 5026)	AE 142	bullet													19.208	15.709	38.671
American Eagle (Buttigieg et al. 2003: 5026)	AE 111	bullet													19.231	15.717	38.668
American Eagle (Buttigieg et al. 2003: 5026)	AE 112	bullet													19.202	15.697	38.627
American Eagle (Buttigieg et al. 2003: 5026)	AE 133	bullet													19.184	15.674	38.543
American Eagle (Buttigieg et al. 2003: 5026)	AE 141	bullet													19.196	15.685	38.578
American Eagle (Buttigieg et al. 2003: 5026)	AE 122	bullet													19.208	15.702	38.64
American Eagle (Buttigieg et al. 2003: 5026)	AE 143	bullet													19.208	15.706	38.658
American Eagle (Buttigieg et al. 2003: 5026)	AE 123	bullet													19.213	15.707	38.656
American Eagle (Buttigieg et al. 2003: 5026)	AE 132	bullet													19.202	15.699	38.637
Winchester (Buttigieg et al. 2003: 5026)	WIN 1	bullet													18.266	15.646	38.200
Winchester (Buttigieg et al. 2003: 5026)	WIN 2	bullet													18.268	15.651	38.215
Winchester (Buttigieg et al. 2003: 5026)	WIN 3	bullet													18.267	15.648	38.204
Winchester (Buttigieg et al. 2003: 5026)	WIN 4	bullet													18.248	15.647	38.176
Fort Clatsop (Farquhar 1997: personal communication)	Fort Clatsop	ball													20.368	15.792	39.399

Bulk element, trace element, and lead isotope data for nineteenth century artifacts and lead isotope data for comparative artifacts and modern manufactured bullets.

Location Reference	Sample ID	Artifact Descript.	Ca Calcium	Fe Iron	Cu Copper	As Arsenic	Ag Silver	Sn Tin	Sb Antimony	Pt Platinum	Au Gold	Bi Bismuth	^{208}Pb Lead	^{208}Pb %	^{206}Pb/^{204}Pb	^{207}Pb/^{204}Pb	^{208}Pb/^{204}Pb
O'Connell Mission (Workman 1999: 61, 103)	FS-OMS-765	ball													18.502	15.635	38.513
O'Connell Mission (Workman 1999: 61, 103)	FS-OMS-846	ball													18.649	15.648	38.595
O'Connell Mission (Workman 1999: 61, 103)	FS-OMS-877	ball													18.619	15.636	38.56
O'Connell Mission (Workman 1999: 61, 103)	FS-OMS-906	ball													18.51	15.63	38.473
O'Connell Mission (Workman 1999: 61, 103)	FS-OMS-915	ball													18.465	15.631	38.506
O'Connell Mission (Workman 1999: 61, 103)	FS-OMS-1251	ball													18.457	15.612	38.413
O'Connell Mission (Workman 1999: 61, 103)	FS-OMS-2357	ball													18.452	15.606	38.412
Mission San Luis (Workman 1999: 74, 103)	FS-MSL-9660-A	ball													18.773	15.641	38.684
Mission San Luis (Workman 1999: 74, 103)	FS-MSL-9660-B	ball													18.781	15.65	38.704
Mission San Luis (Workman 1999: 74, 103)	FS-MSL-9798	ball													18.744	15.588	38.512
Mission San Luis (Workman 1999: 74, 103)	MS-MSL-9803	ball													18.667	15.649	38.61
Mission San Luis (Workman 1999: 74, 103)	FS-MSL-9987-A	ball													18.464	15.608	38.439
Mission San Luis (Workman 1999: 74, 103)	FS-MSL-9987-B	ball													18.454	15.631	38.466
Mission San Luis (Workman 1999: 74, 103)	FS-MSL-9987-C	ball													18.66	15.659	38.63
Mission San Luis (Workman 1999: 74, 103)	FS-MSL-9997-A	ball													18.666	15.66	38.642
Mission San Luis (Workman 1999: 74, 103)	FS-MSL-9997-B	ball													18.665	15.657	38.63

Appendix C – Lead isotope data cluster diagram (all artifacts and modern bullets)

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* * * * * * H I E R A R C H I C A L  C L U S T E R   A N A L Y S I S * * * * * *
Dendrogram using Average Linkage (Within Group)
                                     Rescaled Distance Cluster Combine

          C A S E                 0         5        10        15        20        25
  Label                      Num  +---------+---------+---------+---------+---------+

  AE 121 bullet               57
  AE 142 bullet               58
  AE 143 bullet               64
  AE 123 bullet               65
  AE 113 bullet               56
  AE 111 bullet               59
  AE 122 bullet               63
  AE 132 bullet               66
  AE 112 bullet               60
  AE 133 bullet               61
  AE 141 bullet               62
  WC-TR-327 fragment          36
  Fort Clatsop ball           71
  FV-SS2996-168A shot         10
  FV-OP14-15277D shot         17
  WC-TR-321 maxi ball          2
  FV-OP14-78973 ball          24
  RMH-A5 shot                 51
  WC-TR-318B maxi ball         3
  FV-OP14-15277C shot         18
  FV-OP14-78970A shot         22
  FV-SS2996-168C shot         12
  FV-ITSp-119523 shot         31
  FV-OP14-15277E shot         15
  FV-OP14-15250 bale seal     21
  FV-ITS-121624C fragment      6
  RMH-A8 shot                 52
  FS-MSL-9660-A ball          46
  FS-MSL-9660-B ball          47
  FS-MSL-9997-B ball          43
  FS-MSL-9987-C ball          49
  FS-MSL-9997-A ball          42
  FS-MSL-9803 ball            45
  FS-OMS-846 ball             73
  FS-OMS-877 ball             75
  WC-TR-172 anomalous         23
  FS-MSL-9798 ball            76
  FV-OP14-15277B shot         19
  FV-ITSp-119384 shot         32
  FV-ITS-121765 fragment       5
  FV-SS-39525B ball           30
  FV-OP14-15277F shot         16
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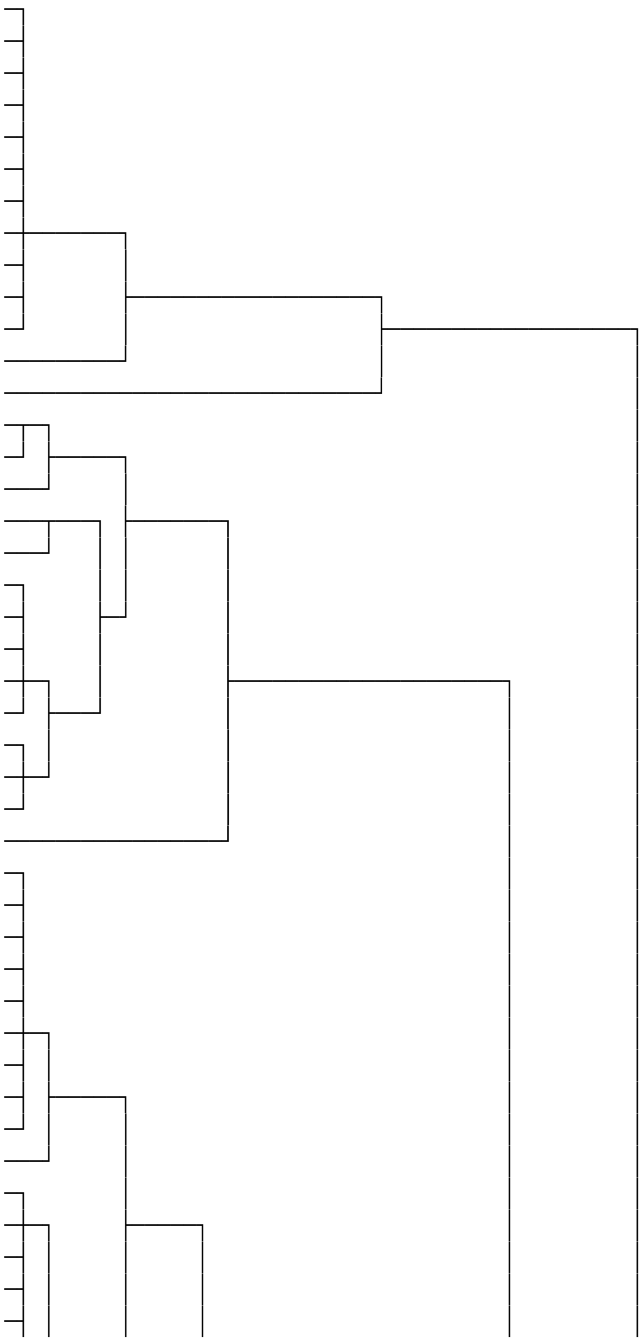

Appendix C - continued

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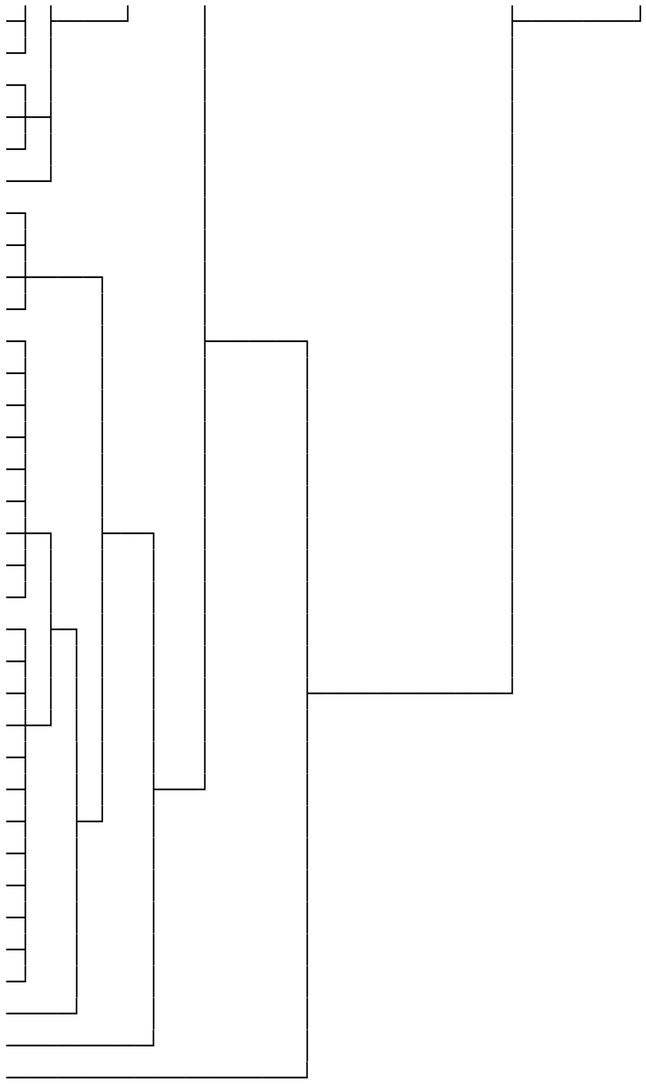
* * * * * * H I E R A R C H I C A L   C L U S T E R   A N A L Y S I S * * * * * *

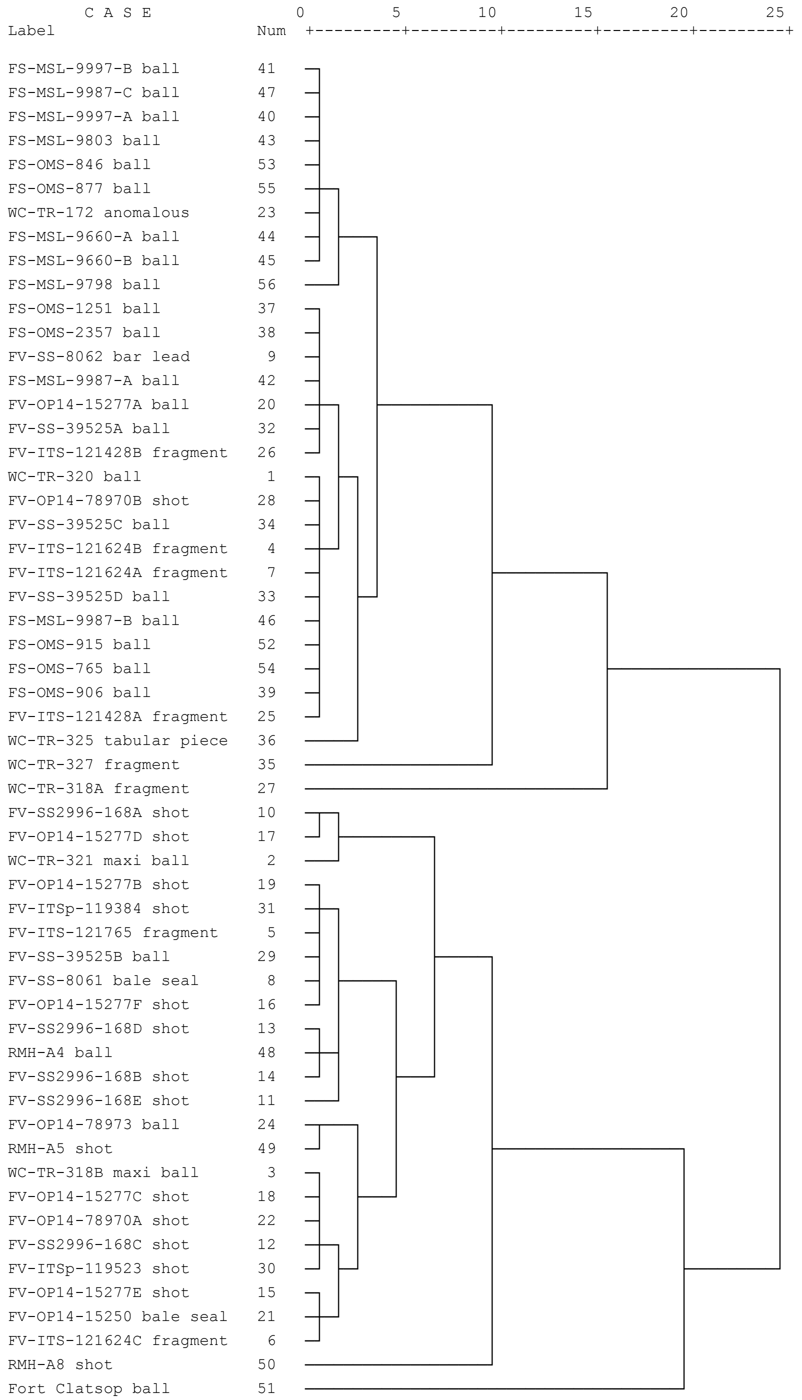
         C A S E              0         5        10        15        20        25
  Label                     Num  +---------+---------+---------+---------+---------+

  RMH-A2 copper kettle lug   54
  FV-SS-8061 bale seal        8
  FV-SS2996-168D shot        13
  RMH-A4 ball                50
  FV-SS2996-168B shot        14
  FV-SS2996-168E shot        11
  WIN 1 bullet               67
  WIN 3 bullet               69
  WIN 2 bullet               68
  WIN 4 bullet               70
  FV-SS-8062 bar lead         9
  FS-MSL-9987-A ball         44
  FS-OMS-1251 ball           39
  FS-OMS-2357 ball           40
  FV-OP14-15277A ball        20
  FV-SS-39525A ball          33
  RMH-A1 copper sheet        53
  FV-ITS-121428B fragment    26
  RMH-A7 copper kettle lug   55
  WC-TR-320 ball              1
  FV-OP14-78970B shot        29
  FV-SS-39525C ball          35
  FV-ITS-121624B fragment     4
  FV-ITS-121624A fragment     7
  FS-OMS-915 ball            72
  FS-OMS-765 ball            74
  FV-SS-39525D ball          34
  FS-MSL-9987-B ball         48
  WC-TR-324 anomalous        38
  FS-OMS-906 ball            41
  FV-ITS-121428A fragment    25
  WC-TR-325 tabular piece    37
  FV-ITS-120281 fragment     27
  WC-TR-318A fragment        28
```



Appendix D – Lead isotope data cluster diagram (non-lead and recycled artifacts removed)

```
* * * * * * H I E R A R C H I C A L   C L U S T E R   A N A L Y S I S * * * * * *
Dendrogram using Average Linkage (Within Group)
                                         Rescaled Distance Cluster Combine
```



```
        C A S E              0         5        10        15        20        25
  Label                      Num  +---------+---------+---------+---------+---------+

  FS-MSL-9997-B ball         41
  FS-MSL-9987-C ball         47
  FS-MSL-9997-A ball         40
  FS-MSL-9803 ball           43
  FS-OMS-846 ball            53
  FS-OMS-877 ball            55
  WC-TR-172 anomalous        23
  FS-MSL-9660-A ball         44
  FS-MSL-9660-B ball         45
  FS-MSL-9798 ball           56
  FS-OMS-1251 ball           37
  FS-OMS-2357 ball           38
  FV-SS-8062 bar lead         9
  FS-MSL-9987-A ball         42
  FV-OP14-15277A ball        20
  FV-SS-39525A ball          32
  FV-ITS-121428B fragment    26
  WC-TR-320 ball              1
  FV-OP14-78970B shot        28
  FV-SS-39525C ball          34
  FV-ITS-121624B fragment     4
  FV-ITS-121624A fragment     7
  FV-SS-39525D ball          33
  FS-MSL-9987-B ball         46
  FS-OMS-915 ball            52
  FS-OMS-765 ball            54
  FS-OMS-906 ball            39
  FV-ITS-121428A fragment    25
  WC-TR-325 tabular piece    36
  WC-TR-327 fragment         35
  WC-TR-318A fragment        27
  FV-SS2996-168A shot        10
  FV-OP14-15277D shot        17
  WC-TR-321 maxi ball         2
  FV-OP14-15277B shot        19
  FV-ITSp-119384 shot        31
  FV-ITS-121765 fragment      5
  FV-SS-39525B ball          29
  FV-SS-8061 bale seal        8
  FV-OP14-15277F shot        16
  FV-SS2996-168D shot        13
  RMH-A4 ball                48
  FV-SS2996-168B shot        14
  FV-SS2996-168E shot        11
  FV-OP14-78973 ball         24
  RMH-A5 shot                49
  WC-TR-318B maxi ball        3
  FV-OP14-15277C shot        18
  FV-OP14-78970A shot        22
  FV-SS2996-168C shot        12
  FV-ITSp-119523 shot        30
  FV-OP14-15277E shot        15
  FV-OP14-15250 bale seal    21
  FV-ITS-121624C fragment     6
  RMH-A8 shot                50
  Fort Clatsop ball          51
```

Appendix E – Lead isotope data cluster diagram (ball, bale seal, bar lead, and shot)

```
* * * * * * H I E R A R C H I C A L   C L U S T E R   A N A L Y S I S * * * * * *
Dendrogram using Average Linkage (Within Group)
                                            Rescaled Distance Cluster Combine
```