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LEAD ANALYSIS OF HUMAN SKELETONS FROM THE 19TH CENTURY SEAFORT BURIAL SITE, ALBERTA

BY

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The undersigned certify that they have read, and recommended to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled LEAD ANALYSIS OF HUMAN SKELETONS FROM THE 19TH CENTURY SEAFORT BURIAL SITE, ALBERTA submitted by ARNE KELLY CARLSON in partial fulfillment of the requirements for the degree of MASTER OF ARTS.

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ABSTRACT

The analysis and interpretation of skeletal lead has become common in anthropological research employing chemical analyses of human tissues. This thesis presents the results, analysis, and interpretation of trace lead in eight unidentified skeletons from the Seafort Burial Site, associated with 19th century fur trade posts at Rocky Mountain House, Alberta. Two types of skeletal lead data were collected using mass spectrometry.

The first type of data collected was the isotopic composition of the lead in the individuals. Such data provides information about the source(s) of lead to which individuals were exposed. The radiogenic origins of three of the four stable isotopes of lead give lead from any given geologic deposit (source) a characteristic isotopic "signature". As lead does not fractionate measurably in biological systems, including human metabolism, the isotopic composition of skeletal lead reflects the source(s) of lead to which individuals were exposed. It is assumed that different cultural groups will be exposed to different sources of lead through both natural processes and cultural practices. Given this assumption, lead isotope analysis of the Seafort individuals was undertaken in order to investigate these individuals' cultural affinities. A number of lead artifacts, and artifacts containing lead which represent anthropogenic sources of lead, and a number of faunal bones which represent natural sources of lead were analyzed for lead as well. The primary sources of lead in the Seafort individuals were identified. This identification allowed the individuals to be associated with the mid 19th century Rocky Mountain House (1835-1861). Moreover, the isotopic composition of the skeletal lead allowed the individuals to be grouped into at least two and possibly three groups. Using historical, archaeological, osteological, and ethnographic information, in conjunction with the lead isotope data, these groups were assigned cultural identities. Individuals 2a and 2b, are suggested to have been Plains Indians. Individuals 1, 3, 7, 11, and 12 are suggested to have been Hudson's Bay Company employees and/or people closely associated with fur trade society. Individual 4 is also suggested to have been associated with fur trade society. However, this individual appears to have been less closely affiliated than the others. A number of potentially valuable further applications of lead isotope analysis of skeletal remains and artifacts are presented.

The second type of data collected was the level of lead in the skeletal remains. Such data provides information about the amount of lead to which individuals were exposed over their lives. It was determined that people associated with fur trade society in the mid 19th century were exposed to greater amounts of lead than people are exposed to today. This finding is consistent with other studies on historical changes in lead exposure. Additionally, as lead accumulates in the skeleton over an individual's life, variation from a linear model of accumulation vs age for a population suggests individualized lead exposure for the individuals of the population. A relatively high degree of individualized exposure is apparent for the Seafort individuals. However, some evidence suggests that lead exposure in the fur trade was relatively consistent and equal between individuals, and that the variations in the skeletal lead levels of the Seafort individuals is a consequence of exposure to lead outside the fur trade. The health effects of lead exposure were examined. While the data suggest that one individual (2b) may have experienced lead poisoning, it does not appear that lead was a significant health risk to people of the fur trade.

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INTRODUCTION

This thesis is a contribution to the anthropological investigation of past peoples through chemical analyses of ancient human tissues. It reports on the analysis and interpretation of bone lead (Pb) in eight unidentified human skeletons from the Seafort burial site associated with the 19th century fur trade at Rocky Mountain House in what is now Alberta (Skinner 1972). Anthropologists have contributed to the body of knowledge surrounding the dynamics and health effects of lead in people and continue to investigate lead from their own unique perspective (Aufderheide et al. 1988). To anthropologists, skeletal lead is not only studied in order to examine its epidemiology and effects on people, but is also studied to provide information about people. Two broad objectives guided the planning and implementation of this research.

The first objective was to explore the use of lead isotopic composition to characterize skeletal remains and to address questions of cultural affinity. To date, skeletal lead has not been used for this purpose. The basic question in bio-anthropological investigation of group affinity is one of determination if all members of a skeletal population are of the same cultural group. Alternatively, it is whether apparently anomalous individuals within a skeletal population -- anomalous in terms of morphology or context -- are "locals or foreigners" (Verano and DeNiro 1993:361-362). Can the Seafort individuals be grouped and assigned socio-cultural identities based on the isotopic composition of lead in their skeletons? Interpretation of the apparent variations in the isotopic composition of the lead in the Seafort individuals is undertaken in reference to the history and society of the 19th century fur trade in Rupert's Land.

The second objective was to address a number of questions concerning the lead environment at 19th century fur trade posts as reflected by skeletal lead levels. What is the typical skeletal burden of lead in inhabitants of Western Canada during the 19th century fur trade, and how does this relate to world-wide and regional historical changes in lead exposure and contamination? Can adverse health effects caused by lead be postulated for the fur trade? What are the social correlates of observed variations in the skeletal lead content of the Seafort individuals? Such questions have been considered in other anthropological research on skeletal lead in past peoples and form the conventional approach to lead analysis (Aufderheide et al. 1988).

This thesis consists of five chapters including this introductory one. Chapter two provides a summary of background information derived from the literature concerning lead and its isotopes in the environment, biological systems, and bone. Chapter three presents the results and interpretation of the isotopic composition of lead in the Seafort individuals. Chapter four examines the levels of lead in the Seafort individuals as it reflects the lead environment of the fur trade and at Rocky Mountain House in the mid 1800's. Chapter five presents a brief summary of the results of this study. The format of this thesis requires that a number of conventions be followed. The chapters are essentially independent of each other, have their own references and unique sub-sections, and can be read without reference to each other. Discussions of materials, methods, and concerns of the studies presented in chapters three and four are given within those chapters. Tables and figures for each chapter are numbered independently, starting with number one in each chapter.

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CHAPTER 2

LEAD AND HUMANITY: INTRODUCTION AND BACKGROUND

CHAPTER 2

LEAD AND HUMANITY:
INTRODUCTION AND BACKGROUND

BACKGROUND ON LEAD RESEARCH

Lead has long been an extremely useful metal, and its toxicity to humans has long been known (Nriagu 1983). In the last 30 years, primarily as a consequence of increasing pollution and mounting concern about low level lead toxicity, extensive and significant research from a large variety of disciplines has been conducted to define the specific dynamics and effects of lead in the environment and biological systems. This research provides us, today, with a large body of knowledge about lead, its characteristics, its cycling in the environment, and its effects upon people. Reviews of lead in the environment and its health effects include: Ewers and Schlipkoter (1991); Goyer and Falk (1974); Griffin and Knelson (1975); Harrison and Laxen (1981); Hepple (1972); Hotz (1986a); Hutchinson and Neema (1987); Ibels and Pollock (1986); Jaques (1985); NRCC (1973); Nriagu (1978a); Ratcliffe (1981); Stokes (1986); Thornton and Culbard (1987); Waldron (1980); Waldron and Stofen (1974).

Lead Chemistry and Geochemistry

The properties and chemistry of lead are summarized by Nriagu (1978b), and Sahl et al. (1974). Metallic lead (Pb) is a malleable, inelastic, dense metal. It has a low melting point and readily alloys with other metals (Blaskett and Boxall 1990). Atomic lead has two oxidation states, 2+ (PbII) and 4+ (PbIV), but the PbII form dominates in natural systems. Lead is usually found in compounds, with the most common mineral form being the sulphide Galena, PbS (Sahl et al. 1974:82-A). Many other lead minerals exist and many minerals contain intrusive lead in which lead ions have replaced monovalent or divalent metals in the mineral lattice (see Sahl et al. 1974:82-A & D). It is also an ubiquitous trace metal in virtually all sulphide metal ores (Blaskett and Boxall 1990). Lead oxides and numerous halogenide and carbonate salts are frequent inorganic lead compounds. More than 1,000 organic lead compounds (primarily PbIV) are known, the most common of these being tetraethyl and tetramethyl lead used in automobile gasoline (Rickard and Nriagu 1978:248-254). Lead also forms strong complexes with organic compounds (Rickard and Nriagu 1978:254-260) which provides the chemical basis of chelation therapy for lead poisoning (Bulman 1990).

The lead of the earth is a mixture of lead originally present at the formation of the earth (primordial lead) and lead that has been created since then through radioactive decay of uranium (U) and thorium (Th) (Faure 1986:284-287; Gulson 1986:13-15; Parkes 1986:40). Through this decay, involving a number of intermediate daughter products, ^{238}U gives ^{206}Pb, ^{235}U gives ^{207}Pb, and ^{232}Th gives ^{208}Pb. This process of radioactive decay and the genesis of lead has been used as the basis of age models for dating geologic deposits. Knowledge of the half lives of U and Th, measurement of the relative proportions of the isotopes of Pb in the deposit, and an assumption of the original quantities of lead present at the formation of the earth (based on the composition of meteoritic lead) can be used to calculate time since geologic emplacement of the deposit (Faure 1986:309-340; Gulson 1986:15-23; Sahl et al. 1974:82-B).

The radiogenic origins of three of the isotopes of lead result in crustal deposits having specific isotopic compositions. The relative amounts of each of the four lead isotopes in any given deposit are dependent upon time of geological emplacement, and the original quantities and relative proportions of Pb, U, and Th in the parent material (Faure 1986; Gulson 1986). As these proportions vary geographically and through time (the younger the deposit the greater the relative proportions of the radiogenic isotopes) lead from any given deposit will have a unique lead isotope "signature", expressed as isotope ratios (e.g. Cumming et al. 1990). Such characteristic signatures can allow determination of the origin (point source) of mined lead and trace lead in other materials (Kowal et al. 1991; Faure 1986:309-340; Rabinowitz 1987). These principles form the basis of archaeometric provenance studies using lead (Gale 1989; Parkes 1986).

Lead isotope ratios are not affected by low-temperature chemical processes such as in biological systems (Gulson 1986:14-15; Rabinowitz and Wetherill 1972:705). That is, all four isotopes behave similarly in chemical reactions and do not fractionate measurably like many lighter elements such as carbon and sulphur. The relatively small differences in atomic weight between the isotopes of lead are not chemically significant, whereas the weight differences between the isotopes of lighter elements are chemically significant. As a result, lead from a given source will maintain its original isotopic ratio in any low-temperature chemical system unless mixed with lead from another source. Given two-component mixing, the mixed isotopic composition will fall between the original ones (a linear relationship) depending on the proportion of lead each source contributed (Gulson 1986:22-23; Faure 1986). Mixing can occur naturally in geological and biological systems, or through human activities such as mining and smelting.

Lead in the Environment

Lead is and has been ubiquitous in the environment. It is found in trace quantities (<0.01%) throughout the world in rock, soil, water, air, and biological systems. Nriagu (1978b) provides a useful model of the global lead cycle. This model is based in biogeochemistry, "the study of the interactions between biological life forms and their surroundings" (1978b:8). In this model, lead flows through a number of pools or reservoirs by various processes. There are four main lead reservoirs, each with various sub-reservoirs. These include: 1) the atmosphere; 2) the lithosphere, with sub-reservoirs of soils, and sediments; 3) the hydrosphere, with sub-reservoirs of oceans, pore water in sediments, lakes and rivers, glaciers, and groundwater; and 4) the biosphere with sub-reservoirs of living and dead land biota, and living and dead marine and freshwater biota. The estimated total lead in each of these pools, and the flow of lead between them, are outlined and illustrated by Nriagu (1978b:10-11). Of these pools, the lithosphere acts as the primary sink for lead. Two categories of processes move lead into the active system. These are: natural processes including such things as volcanic emissions and weathering of geologic deposits; and anthropogenic processes -- the mining and use of lead by people.

The influx of lead into living land biota is primarily by the established pathways of metabolic intake. Four levels of inter-relationships between flora and fauna and their abiotic environment are recognized in the model. These are: 1) the internal environment of the body; 2) the fetch (immediate) environment providing the air, water, nutrients and/or food for the individual; 3) the regional or mosaic of fetch environments; and 4) the general environment of the earth as a whole (Nriagu 1978b:8).

Human exploitation of lead beginning approximately 5000 years ago has increased the amount of lead in the global cycle to well above pre-industrial levels. Of the total amount of lead exploited by humanity since it first began to be used (estimated to be 261 million tonnes, or approximately 50% of the known lead resources), approximately 62% of this has been used since A.D. 1900 (Nriagu 1986). This has caused an increase in levels of lead in the biosphere. Researchers have attempted to assess the degree of magnitude of this increase.

Patterson (1965) estimated the natural level of lead in humans based on relationships between the relative abundances of crustal metals as found in the biosphere. "Natural" levels are defined as "those which prevailed during the creation and evolution of our physiological responses to lead" (1965:344). These are levels that do not include contaminant lead derived from human exploitation of the metal. This is the same lead level defined by Drasch (1982) as the "physiological zero point... the lead burden of a population, which did not use lead at all and which had access to this element only through uptake as a trace component in diet" (1982:204). Values derived for this natural level of lead are on the order of approximately 0.5-2.0 μg/gm. Variability in natural levels comes from regionally variable Pb levels via geochemical and geological processes.

Patterson (1965) makes the distinction between "natural" lead levels (as above) and "typical" lead levels which reflect levels in a population that used lead. The typical level of lead of a given population is a function of the relative degree the culture uses lead and the particular uses to which lead is put. As such, typical levels are often highly variable regionally, temporally, across cultures, and across subsections of culture. An individual with a body burden above natural levels has been contaminated. The body burden of lead is simply the total amount of lead stored in the body (Schroeder and Tipton 1968).

Some researchers, however, specifically Jaworowski (1990; see also Jaworowski et al. 1985a, 1985b), de-emphasize the distinction between "natural" and "typical" levels of lead in human tissues. Variable geochemical patterns, subsistence habits, and cultural and industrial practices over time and space will result in a variable "natural" body burden of lead both within and between populations, whether the populations in question are prehistoric or industrial. Jaworowski regards it as a "futile exercise" to estimate theoretically the natural levels of lead as Patterson (1965) has done on a global basis.

These differences in definition come down to implicit differences in the definitions of the fetch environment of the individual, or level 2 of the inter-relationships of individuals and their environment in Nriagu's (1978b) model of the global lead cycle. In the model, the fetch environment is a given. It is the total environment in which an individual lives including all natural and cultural factors affecting the environment. Therefore, the natural level of lead in an individual is that level which reflects this lead environment, as in Jaworowski's (1990) view. Factoring out the cultural contribution of lead in the fetch environment creates a hypothetical "natural" level of lead. In contrast, however, if one wants to assess the relative degree to which people of a given region and time period have contaminated their environment and themselves, it is useful to take Patterson's (1965) position and differentiate between naturally occurring lead (e.g. from geologic processes) and culturally introduced lead (e.g. from peoples' exploitation of the metal).

It has been estimated that lead levels circulating in the global cycle have increased approximately 1000 to 100000 times above original "natural" levels (Patterson et al. 1987). Moreover, it has been stated that the levels of lead in people have increased 500 fold above uncontaminated levels (Ericson et al. 1979; Patterson 1965). This, however, has not been demonstrated through empirically based historical studies. Jaworowski (1990:181-186) presents a review of various historical studies examining lead burden in people over time. The manner in which researchers have tried to estimate uncontaminated lead levels in people, in terms of Patterson's (1965) definition, is through analysis of bones from ancient skeletal populations which did not use lead, and which should therefore represent uncontaminated levels (Drasch 1982; Ericson et al. 1979; Grandjean and Holma 1973; Grandjean et al. 1979; Neilsen et al. 1986; Shapiro et al. 1975, 1980). Following determination of such levels, comparison of these populations with modern or other populations will reflect the degree of increase in the body burden of lead due to the use of lead.

Jaworowski (1990) criticizes this method mostly in terms of its comparative nature. For example, lead levels of ancient Peruvians from 2000 years ago (Ericson et al. 1979) cannot meaningfully be compared to lead levels of people living in Canada today or at any other time. Jaworowski (1990) summarizes the data obtained through such historical studies and finds that the main trend in lead burden over time is that anthropogenic lead has perhaps increased the upper end of the range of lead levels observed in human tissues on a world wide scale. However, lead levels in the past were probably just as variable as they are now. Many modern populations have bone lead levels comparable to those in populations of the past. Moreover, while the exploitation of lead has increased dramatically over the last 100 years, typical body burdens of lead within people have been generally decreasing over the last 200 years. Jaworowski's (1990:185) best estimate of a natural range for lead levels in human bone, regardless of time or place, is <0.2 μg/g to 22 μg/g, dry weight.

In general, then, the amount of lead introduced to the global lead cycle through human agencies is substantial, particularly in the last 100 years. However, most of this lead has been returned to the lithosphere which acts as the primary sink for anthropogenic lead. The world-wide average lead burden in people has probably increased somewhat, but the degree of this increase is unquantifiable, and essentially meaningless when extrapolated to any particular part of the world. The inherent, worldwide variability in lead absorption by people due to varying geochemical and cultural factors makes assessment of the relative degree of lead contamination something researchers should pursue on a regional basis, and on a defined temporal scale. Such an orientation will allow conclusions to be drawn about the historical changes in the lead environment of the region under consideration. These can then be compared to other regions for a broader or global perspective.

Sources of Lead in Humans -- History of Lead Production and Use

Lead enters people's bodies from numerous sources which can be classified into two broad categories: environmental/natural sources, and anthropogenic sources (Mahaffey 1978). Environmental sources are such things as "uncontaminated" air, water, soil, and native unprocessed animal and plant food products. All of these items contain a trace amount of "natural" lead (assuming they are not contaminated with anthropogenic lead). Anthropogenic sources are all those human manufactured and processed products which contain lead, as well as lead released to the environment through mining, smelting and manufacturing.

A number of reviews have been written concerning the history of lead production and use including Gillfillan (1965), Grandjean (1975), McCord (1953a,b, 1954a,b,c), Nriagu (1983), Waldron (1973), Wedeen (1984). Nriagu's (1983) book is a good account of the history of lead use in ancient times, while Wedeen (1984) presents an interesting history of lead poisoning. The physical properties of lead, particularly its malleability, low melting point and capacity to alloy easily with other metals resulted in its early use by humans (Nriagu 1983). The oldest known piece of lead from a human context dates to 6500 B.C. at Çatal Huyuk, Turkey (Nriagu 1983:67). In general, the spread of lead technology follows that of the spread of metallurgy, particularly silver exploitation. Cupellation, the means by which silver is extracted from lead ore, was developed by 4000 B.C. in Persia (Nriagu 1983:92-98; Waldron 1973:392). By 1000-500 B.C. lead-silver technology had spread throughout most parts of the Old World (Nriagu 1983:69). From these earliest times, lead production in the Old World increased steadily up to and through the Roman Empire Period, after which time a relative decrease in lead production occurred.

It has been suggested that the fall of Rome is partly due to lead poisoning considering the large lead industry of the time (comparable to current per capita production) and the uses to which it was put (Gillfillan 1965; Nriagu 1983). However, a number of authors criticize this idea citing lack of evidence for elevated lead levels in Roman skeletons and pointing out the model's basically simplistic explanation of a complex event (Eisinger 1984; Jaworowski 1990:184; Waldron 1973:396).

After the Roman Period, lead production did not begin increasing again until between A.D. 700 and 1000. In the middle 1700's, with the beginning of the industrial revolution, world lead production rapidly and steadily increased to its maximum as seen today. The extent of lead production in Pre-Columbian America did not approach the magnitude of that in the Classic Old World. However, evidence demonstrates that civilizations in Central and South America were exploiting lead to a limited degree (Nriagu 1983:184-188). In North America, the Late Archaic and Woodland period cultures were using native Galena (Farquhar and Fletcher 1980, 1984), and Late Period prehistoric Pueblo potters were producing lead glazed wares (Jarcho 1964).

Over the ages, lead has been used in the manufacture of numerous products. During the Egyptian Pharonic period lead was used for ornaments, solder, anchors, net sinkers, and for construction purposes (Nriagu 1978b:1). Lead was used prior to 3000 B.C. in China (Nriagu 1978b:1). It was used as construction material in Roman plumbing systems and boat building (Eisinger 1984; Nriagu 1978b:4; Waldron 1973:393). Lead was often alloyed with many other metals, including tin for solder, to be used in plumbing and later in canning technology, and to line cooking and storage vessels. Lead was alloyed with copper and bronze for sculpture and coinage.

Mining, smelting, manufacturing and using lead and products containing lead have resulted in a wide variety of sources, over the years, which have been demonstrated to, or could potentially expose people to lead. In Rome, lead acetate, also called sapa or sugar of lead, was added to wines and foods for sweetening and preventing spoilage (Nriagu 1978b:4; Waldron 1973:393). Lead in wine and other beverages contributed to lead poisoning well into the 18th and 19th centuries (Wedeen 1984). Numerous medicines consisting of lead compounds have been used over the ages. Such medicines included plasters, soaps, and solutions to be taken orally and thought to cure various ills (Wedeen 1984:50-61). Other uses of lead include its addition to glass, and as a glaze for ceramic ware (McCord 1954b; Taylor and Bull 1986). As well, lead was used in cosmetics. In Greek and Roman times white lead was used to whiten the complexion. Often a natural dye such as beet juice was added to white lead and the mixture used as rouge (McCord 1954b:76). In England after about 1600, cosmetics began to increase in popularity, soon spreading to the colonies. Pewter, predominantly tin with varying quantities of lead, copper, and antimony, was a commonly found lead alloy in England and the early american colonies (McCord 1953b). Many household utensils were made from pewter including spoons, mugs, plates, tankards, jars, lamps, candlesticks, and storage vessels, all of which items contributed to lead exposure in the household. Pewter stills have been blamed for the contamination of alcohol and the poisoning of people in colonial america (McCord 1954a; Wedeen 1984).

In modern society, the sources of lead are numerous. Many articles present lists and discussions of various current sources of lead (e.g. Grandjean 1975; Hotz 1986a; Patterson 1965; Rabinowitz 1987; Ratcliffe 1981; Yaffe et al. 1983). The major source media of lead are air, food, water, dust, soil and paint. Lead is released into the atmosphere through many industrial activities, automobile exhaust, and various other means. In the last decade, however, with the growing awareness of the harmful effects of lead, the contribution of lead in the atmosphere from automobile exhaust has become smaller with the introduction of non-leaded gasolines. Water contains lead from the atmosphere, pipes, and processing plants (e.g. Gallacher et al. 1983). Canned goods can contain relatively high concentrations of lead derived from solder used to manufacture the cans. The mechanical components of much industrial food processing equipment can contribute to lead in food (Kolbye et al. 1974; Mitchell and Aldous 1974). Vegetable foods all contain lead which the plants have taken up from ground water, soil, and air, and up until recently pesticides such as lead arsenate were commonly used. Household dust often contains lead derived from lead based house paint.

Lead Metabolism

The overwhelming consensus is that lead is a toxic trace element as opposed to an essential trace element (Aufderheide 1989). It enters the metabolic system through dietary ingestion, inhalation, and direct absorption through the skin. Upon entering the blood stream it is quickly transported throughout the body. Chemically, the body deals with lead in much the same way as it does with calcium (Aufderheide 1989). Thus, it is expected that lead is found in areas of high calcium deposition such as the skeleton, and is involved in metabolic reactions normally involving calcium. In a person not exposed to excessive amounts of lead, the body, in general, maintains an equilibrium between input and output, such that most soft tissue maintains a lead balance with the environment mediated through the blood (Barry 1978:98; Kehoe 1961:96). The skeleton, however, slowly accumulates lead over an individual's life (Wittmers et al. 1988).

In adults, 5-15% of lead that is ingested is absorbed into the blood stream, while in children the amount is on the order of 25-50% (Aufderheide 1989; Grandjean 1975:30; Kehoe 1961:95; Rabinowitz et al. 1973:726, 1974:147, 1975:361, 1976:206; Waldron and Stofen 1974:44). Thus, lead in food, water, and other matter, which follows the digestive tract, enters the body via this route. General nutrition and the intake of various vitamins, minerals, fats and proteins effect the rate at which lead is absorbed (Barlthrop and Khoo 1975:373; Grandjean 1975:30; Rabinowitz et al. 1975; Reichlmayer-Lais and Kirchgessner 1984:373-374; Waldron and Stofen 1974:45-46;), as does the solubility of the particular lead compounds reaching the stomach (Reichlmayr-Lais and Kirchgessner 1984:368-369). Ingestion provides the greatest contribution of lead to an individual (Barry 1978:98; Reichlmayr-Lais and Kirchgessner 1984:368; Smith and Hursch 1977:477). Lead that is not absorbed in the intestinal tract is excreted in the faeces.

Lead absorbed through the lungs comes from particulate or vapour lead compounds in the air that are deposited in the respiratory tract through normal breathing. 30-50% of inhaled lead is deposited in the lungs and enters the blood stream (Aufderheide 1989; Grandjean 1975:30; Harrison and Laxen 1981:141-143; Smith and Hursch 1977:477; Waldron and Stofen 1974:40). In our current urban society (until recently with the reduction in use of leaded gasoline) it has been estimated that approximately 25-50% of the total lead absorbed into the body comes from air (Rabinowitz et al. 1973:726, 1974:149, 1975:391). The rate and amount of absorption via this route is largely dependent upon concentration, particle size, and solubility of the compounds.

Lead in substances applied to the skin may be absorbed into the blood stream (Aufderheide 1989). However, in general this is a minimal route by which lead enters the body (Grandjean 1975:31; Waldron and Stofen 1974:46). Certain lipophilic compounds and organic compounds such as tetra-ethyl lead are more readily absorbed than others. As well, in areas of broken skin lead is more easily absorbed.

Once in the blood stream, lead quickly attaches itself to red blood cells. More than 90% of blood lead is found on the erythrocytes, presumably bound to haemoglobin, with the remaining 10% located in the plasma (Reichlmayr-Lais and Kirchgessner 1984:371; Smith and Hursch 1977:477; Waldron and Stofen 1974:47). From the blood, lead is quickly transported throughout the body and enters various tissue pools within a few minutes. In a balance situation, 90% of absorbed lead is filtered from the blood by the kidneys and then excreted in urine. Most of the remainder is excreted in faeces, and a small fraction excreted through sweat, hair, nails and other excretions (Aufderheide 1989:249). There is no placental-fetal barrier to the transport of lead from mother's blood to fetus (Goyer 1990; Lauwerys et al. 1978).

Kinetic models describing the systemics of transport, distribution, storage, and excretion of lead throughout the body have been developed. Such models address lead in terms of how long lead is in various pools in the body, where the lead comes from, and where it may go (Rabinowitz 1991:33). They do not address levels of lead in tissues or the effects of lead. The most common kinetic models outlined involve three basic lead pools or compartments in the body (e.g. Batschelet et al. 1979; Rabinowitz et al. 1973, 1974, 1975, 1976; Smith and Hursch 1977). Compartment 1 consists of blood and tissues in rapid equilibrium with blood and has a mean half-life of lead of approximately 15-70 days. Compartment 2 consists of soft tissues and has a mean half-life of lead on the order of 35-650 days. Compartment 3 is the skeleton with a half-life on the order of 10-60 years.

A number of researchers have made refinements to the basic three pool model, most of which introduce additional compartments (e.g. Batschelet et al. 1979; Marcus 1985a, 1985b; Rabinowitz 1991; Steenhout 1982). Rabinowitz (1991), however, provides a simplified summary model of the toxicokinetics of bone lead. In this model, two basic lead pools are recognized. Compartment 1 is lead in blood and lead in tissues essentially in equilibrium with blood. Compartment 2 is lead in bone. The mean half-life or residence time of lead in the blood pool is approximately 1 month, and the mean half-life of lead in the bone pool ranges from approximately 10-30 years. However, the bone pool itself appears to be comprised of two or more pools (Batschelet et al. 1979; Marcus 1979, 1985a, 1985b; Rabinowitz 1991; Rabinowitz et al. 1974, 1976; Steenhout 1982) with each deeper pool having a greater mean life for lead, the sum result being the observed range in the mean half-life for the bone pool as a whole.

The body burden of lead is the total amount of lead in the body. A number of studies have been conducted to determine the typical amount of lead in the human body and its various tissues (Barry 1975, 1978; Barry and Mossman 1970; Gross et al. 1975; Schroeder and Tipton 1968). In general there are two types of tissues in the body: those which accumulate lead over time, primarily hard tissues; and those which do not, primarily soft tissues (Barry 1978:98). Over 90% of the body burden of lead in adults is in the skeleton, with approximately 70% of this in cortical bone (Barry 1978). In children approximately 70% of the body burden of lead is in the skeleton (Nordberg et al. 1991). Adults have generally higher concentrations of lead in their tissues than children, and male adults generally have higher concentrations than female adults. The typical estimated body burden in adults of today ranges between 80-200 mg/70kg standard weight (Barry 1978:132). However, Rabinowitz (1991:34) reports a range of values for the mass of lead in the skeleton from 25-750 mg.

The readily observable symptoms of lead intoxication follow the general progression of colic, to palsy and gout (Wedeen 1984:1). Other symptoms can include appetite loss, nausea, and vomiting. The nervous system is affected with relatively higher levels of lead as it blocks or slows electrical conductivity across synapses resulting in such things as weak grip, wrist and ankle drop, and palsy. Moreover, the brain will ultimately begin to be affected causing nervous convulsions which, in severe cases, can lead to coma and death (Handler et al. 1986:407). Numerous insidious effects of lead intoxication, other than the easily observable ones outlined above, occur as well (see Wedeen 1984; Handler et al. 1986:407; Ratcliffe 1981; Lucier and Hook 1991; Hotz 1986a). The generally agreed upon value for "safe" blood lead levels has progressively decreased over the years from c. 80 μg/dl to 40 μg/dl for adults, to 25 μg/dl for children and other special groups such as pregnant and lactating women (Ewers and Schlipkoter 1991; Hotz 1986b:1-5; Wedeen 1984:7). The earlier higher values were determined based upon apparently safe levels of occupational exposure in lead workers. Mounting realization that lead has toxic chronic effects, particularly in children, which do not manifest themselves in clinical symptoms of plumbism, as well as the fact that blood lead is not a good measure of the body burden of lead, particularly the amount stored in the skeleton, brought about these progressive decreases in acceptable "safe" blood lead levels (Hotz 1986b).

Lead in Bone

Since the skeleton is the largest lead reservoir in the body, numerous studies have been conducted examining the chemistry, metabolism and kinetics of lead in bone (e.g. Christoffersson et al. 1984, 1986; Drasch et al. 1987; Flood et al. 1988; Heard and

Chamberlain 1984; Lindh 1980; Lucier and Hook 1990, 1991; Marcus 1979, 1985b; Norimatsu and Talmage 1979; Schutz et al. 1987; Silbergeld et al. 1988; Smith and Hursch 1977; Stack 1990; Steenhout 1982; Strehlow and Kneip 1969; Westerman et al. 1965; Wittmers et al. 1988). Lead in bone is primarily fixed to, and incorporated into, the mineral lattice of hydroxyapatite crystals making up the inorganic mineral fraction of bone. Lead is described as a bone seeking element by Smith and Hursch (1977). Skeletal uptake and release of lead can be considered initially as a surface chemistry phenomenon. The surfaces are comprised primarily of the surfaces of trabeculae, the walls of the lacunae, canaliculi (single greatest surface in total), and Haversian and Volkmann's canals. These surfaces are ultimately surfaces of bone hydroxyapatite crystal, or amorphous forms of calcium phosphate which may represent intermediate stages in the formation of hydroxyapatite (Sandford 1992:82). Lead ions are first bound to the hydration shell, or chemically active zone, of the crystal.

Marcus (1985a) describes the above process as a cylindrical diffusion process with the cylinder being primarily the "canalicular territory" (1985a:443). Up to this point chemical equilibrium is maintained between the solution and the crystal with the above processes being readily reversible. However, lead ions eventually replace crystal lattice ions, particularly calcium, in the interior structure of the crystal, and are only readily released through osteoclastic activity or through slow diffusion processes. These processes are more rapid in trabecular bone than in cortical bone. As such, lead is turned over faster in areas of the most active bone growth and remodelling (Smith and Hursch 1977:479) such as in the trabecular, metaphysis regions of long bones.

The turnover rate or residence time of lead in bone is estimated as its biological half time of roughly 10-30 years (Rabinowitz 1991:34). The rate varies depending on age, sex, specific bone, and nutritional status of the individual. For instance, compact bone has a half-life for lead of 10-30 years, while trabecular bone appears to have a half-life for lead of approximately 5 years (Nordberg et al. 1991). Compact and trabecular bone may represent, on a gross morphological scale, slower (compact) and faster (trabecular) kinetic pools of lead in bone. However, Rabinowitz (1991:35) states that while "it is tempting to relate slow and slower bone pools... with specific gross anatomical locations such as long bone or trabecular or ivory bone. I suspect any cubic centimetre of skeleton will contain some of each kind of bone [pool] in varying amounts." These factors may be related to the presence in varying amounts of amorphous (non-crystalline) forms of calcium phosphate which may act as a more labile bone pool (Ortner and Putschar 1985:25; Sandford 1992:82).

Wittmers et al. (1988; see also Barry 1978:98-112; Stack 1990) provide a summary of the trends in the distribution of lead in the skeleton. There is bilateral symmetry in lead concentrations in bones of a single individual. Variability exists in lead concentrations within any single bone (Jaworowski 1990:179-181). As such, relatively larger samples of bone should be used in analysis, if possible, to homogenize and factor out this effect (Jaworowski 1990:181; Sandford 1992:93). Intra-individual and intra-bone variability in lead levels may be related to irregular, as opposed to constant or even, exposure (Grandjean 1975:35). The lead content of all bones increases with age up till about the 7th decade of life. After this time, concentrations continue to increase in compact bone, while in trabecular bone they either plateau or decrease. Up until bone growth ceases around 20 years of age, trabecular bone generally contains more lead than compact bone. After about 35 years of age, compact bone generally contains greater amounts of lead than trabecular bone. The rate of accumulation is dependent upon degree of exposure. The typical rate for cortical bone is about 0.5 ppm/year, but as much as 1.0 ppm/year or greater when industrial exposure is significant (Stack 1990:202).

Adult males generally have a higher lead content in their bones than adult females (Wittmers et al. 1988). This has been related to different levels of exposure due to differences in occupational and social behaviours between the sexes (Barry 1978:109). However, the generally lower skeletal lead levels in women than in men more likely reflects differences in the remobilization of lead as it occurs in women during pregnancy and lactation. During these periods a higher demand for calcium is in effect. Lead, which behaves like calcium, would be mobilized and removed from the skeleton thereby lowering the overall lead concentration (Silbergeld 1991). This remobilization of lead in pregnant and lactating women, and in cases of osteoporosis, can pose a health risk if the amount of lead remobilized is significant (Silbergeld et al. 1988). In addition, over a woman's lifetime menstrual blood may serve a significant role in the excretion of lead from the body.

Lead and Anthropology

Most skeletal lead analysis by anthropologists has focused on measuring total lead content in prehistoric and historic human bone as it reflects the ante-mortem body burden of lead in the individual. Because of the long biological half-life of lead in bone, the skeletal burden of lead is seen as a reflection of the total lifetime exposure of an individual to lead (Aufderheide et al. 1988:931-932). Based on this, inferences concerning a past population's society, lifestyle, economy, and health can be made upon determination and interpretation of patterning in lead levels in archaeological skeletons.

Aufderheide et al. (1988; see also Aufderheide 1989) present a review of anthropological applications of skeletal lead analysis. The most common type of application is the "Assessment of the Extent of Lead Technology in a Cultural Group" (Aufderheide et al. 1988:932). Within this category, interpretations are based on the premise that the higher the total lead content measured in skeletal material, the greater the utilization of lead technology (greater exposure) by the population in question. This information is generally used in reference to tracing historical changes in lead exposure through time. Studies conducted from this perspective include Drasch (1982), Ericson et al. (1979), Grandjean (1975), Grandjean et al. (1979), Grandjean and Holma (1973), Jarcho (1964), Jaworowski (1968), Jaworowski et al. (1985a, 1985b), Kosugi et al. (1988), Mackie et al. (1975), Nielsen et al. (1986), Patterson et al. (1987), Rogers and Waldron (1985), Reinhard and Ghazi (1992), Shapiro et al. (1980), Waldron et al. (1976), Wittaker and Stack (1984).

The next type of application is the "Separation of Two Socioeconomic Subgroups Within a Studied Population" (Aufderheide et al. 1988:932). Interpretations of skeletal lead content within this category are based on the idea that different social or occupational situations of individuals within a community could result in different exposure to lead and therefore different skeletal levels of lead. Studies conducted with this orientation include, Aufderheide (1991), Aufderheide et al. (1981, 1985), Corruccini et al. (1987), Lalich and Aufderheide (1991). Similar to this is the third type of application which strives for "Identification of a Unique Social or Occupational Role of Specific Individuals Within a Population" (Aufderheide et al. 1988:932-935). Interpretations under this category are based on the premise that variation in values of lead content between individuals of a subgroup, potentially reflect individuals' unique social or occupational situations.

The fourth type is "Prediction of Health Effects" (Aufderheide et al. 1988:34). Interpretations under this category are based on the premise that extremely high lead levels in skeletal material potentially represent toxic blood levels of lead. An empirically derived formula for estimating blood lead levels from bone lead levels is commonly used in such assessment (see Corruccini et al. 1987:238). Studies under this category include, Beattie (1985), Corruccini et al. (1987), Gillfillan (1965), Handler et al. (1986), Kowal et al. (1989).

Both the final two categories of applications that Aufderheide et al. (1988) outline have forensic implications. These categories are "Assistance in Separation of Mixed Skeletal Material" (1988:934), and "Identification of Human Remains as Ancient or Modern" (1988:935). The first of these is based on the assumption that different individuals will have different skeletal lead levels. Analysis of the amount of lead in mixed skeletal elements would allow different individuals' bones to be separated from one another. The ancient-modern category is based on the premise that pre-industrial populations would have significantly less skeletal lead than modern or industrial populations. Bones with low lead content would presumably be pre-industrial. This premise is, however, questionable (see above). Only two known studies, both reported in Aufderheide et al. (1988), fall within these last two categories of applications.

A relatively recent emphasis within anthropological studies employing lead analysis deals with identifying the source(s) of the lead in the skeleton using stable isotope ratios. Following the lead of medical researchers (e.g. Manton 1977; Rabinowitz 1987; Rabinowitz and Wetherill 1972; Rabinowitz et al. 1973), lead isotope ratios have been used to determine the source of lead in archaeological skeletal material (Kowal et al. 1990, 1991; Molleson et al. 1986; Reinhard and Ghazi 1992). Geochemists and archaeometrists have utilized lead isotopes to categorize geologic deposits and "source" artifacts for some time (e.g. Cumming 1990; Faure 1986; Gale 1989; Gulson 1986).

Diagenesis

To interpret lead data in archaeological bone in terms of the once living persons and their culture, the researcher must be confident that the lead represents metabolically derived lead and not diagenetic lead. Diagenesis is defined in anthropological trace element studies as "postmortem alterations in the chemical constituents of bone following deposition in soil" (Sandford 1992:86). Its importance to trace element studies is reflected by the amount written on it (e.g. Edward and Benfer 1993; Grupe 1988; Grupe and Pipenbrink 1988; Hancock et al. 1987; Klepinger et al. 1986; Kyle 1986; Lambert et al. 1989, 1990; Pate and Hutton 1988; Patterson et al. 1987:169-174; Price 1989; Price et al. 1992; Reinhard and Ghazi 1992:188-189; Sandford 1993; Sillen 1989; Waldron 1981, 1983; Weber 1992; Williams 1988). Lead may be taken up by bone from soil, or leeched from bone, although there is some question as to which takes primacy (see Jaworowski 1990:176-181; Patterson et al. 1987:169-170).

Anthropological trace element studies of bone and studies of diagenesis in bone have provided a number of guidelines and specific analytical procedures to detect and control for diagenesis. It is a general rule that the longer bones have been buried the greater the potential for significant diagenetic change (Sandford 1992:88). This general trend, however, can be highly variable temporally and spatially. Compact bone, being denser and generally thicker than trabecular bone, is less easily affected by diagenesis than trabecular bone (Grupe 1988). As such, compact bone samples are preferred over trabecular bone samples for trace element analysis. As well, since the endosteal and periosteal surfaces of bone undergo the greatest degree of diagenetic change in buried bone (Lambert et al. 1989), these surfaces should not be included in bone samples. The general condition and colour of bone can be used as an indicator of the degree to which diagenesis has occurred (Edward and Benfer 1993:191-192). The more the bone colour approximates the colour of fresh bone -- light, pale yellow to ivory -- the less likely diagenesis has occurred. In order to reduce the potential effects of diagenesis chemical cleaning of the samples in such reagents as acetic acid can be undertaken (e.g. Price et al. 1992; Weber 1992). Analysis of soil samples from the burial environment for the element(s) under consideration has been usefully employed in assessing the possibility of significant diagenetic effects on bone (e.g. Pate and Hutton 1988).

CONCLUSION

The global lead cycle outlined by Nriagu (1978b) provides a useful model describing the cycling of lead in the world environment. The inter-relationships between an individual and its abiotic environment encompass all processes, both natural and cultural, affecting and cycling lead. For anthropologists studying lead in past populations, the immediate, or fetch, environment(s) of the population under study must be considered the single most important factor in the cycle; it provides the immediate sources of lead. In this study the term lead environment is adopted for this concept, and is defined as all those natural and cultural particulars and processes in a given area and time which result in peoples' exposure to and uptake of lead. As such, it is what skeletal lead data reflects and ultimately, the thing about which the anthropologist makes cultural inferences. It provides the interpretive baseline for analysis. That is, skeletal lead reflects the portions of an individual's environment, and all the processes involved, both cultural and natural, that relate to lead sources in that environment. Moreover, skeletal lead reflects the lifetime exposure of that individual to lead (Aufderheide et al. 1988). For interpretation of lead data, one must first assume that lead in a particular skeleton is metabolic lead, and has not been derived or significantly altered by post-mortem diagenetic processes. Given this, one can then begin to relate skeletal lead data back to the cultural and natural processes which resulted in the observed lead burden of the individual. This should be done through articulation of the skeletal lead data with information derived from other sources such as geology, archaeology, and history. Such a process allows interpretation that is broader and more complete than that derived from only one of these realms of information.

Skeletal lead data, then, allows interpretation of past peoples in four broad ways. First, one may interpret it through comparisons over time and space, allowing historical trends in lead exposure to be outlined. Second, one may interpret the data in terms of the effects of lead on the population, for example what health effects may have been prevalent. Third, one can interpret the data in terms of cultural and social processes which were in operation, and which contributed to the observed skeletal lead. Were there social or occupational differences between individuals or groups of individuals that led to observed variations and patterning in skeletal lead data? The fourth way one may interpret results is in terms of characterization. The unique lead fetch environment of a population or individual, as defined above, indexes that population or individual to that environment. This has the potential to allow assignment of an unknown individual to a know lead environment based on the attributes of the lead burden of the individual. Of course a well defined comparative data base, both in terms of known populations and environments is necessary for such to be accomplished. These four analytical directions form the interpretive potential of lead analysis of ancient human tissues.

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CHAPTER 3

A QUESTION OF GROUP AFFINITY: CHARACTERIZATION OF THE 19TH CENTURY SEAFORT BURIALS USING STABLE LEAD ISOTOPES

A QUESTION OF GROUP AFFINITY: CHARACTERIZATION OF THE 19TH CENTURY SEAFORT FUR TRADE BURIALS USING STABLE LEAD ISOTOPES

INTRODUCTION

The analysis of trace lead in human skeletal remains is useful for addressing a variety of anthropological questions (see Aufderheide et al. 1988). Most such research examines the level of lead in bone, a reflection of an individual's lifetime exposure to lead (Aufderheide et al. 1988:931-932). Recently, analysis of stable lead isotopes has allowed investigation of the particular source(s) of the lead in skeletal remains (Kowal et al. 1990, 1991; Molleson et al. 1986; Reinhard and Ghazi 1992). Such studies were developed from research using lead isotope data to ascertain the source(s) of lead as an environmental pollutant (Ault et al. 1970; Chow et al. 1974) and as the cause of lead poisoning (Manton 1977; Rabinowitz 1987; Rabinowitz and Wetherill 1972; Yaffe et al. 1983).

This paper presents an application of lead isotope analysis of skeletal remains to address problems of characterization and group affinity. The basic question in bio-anthropological investigation of group affinity asks whether all members of a skeletal population are of the same cultural group. Alternatively, are apparently anomalous individuals of a skeletal population -- anomalous in terms of morphology or context -- "locals or foreigners" (Verano and DeNiro 1993:361-362). Traditionally, biometric and morphological analyses have formed the methodological approaches to such investigation. However, with recent developments in chemical analyses of human bone, a number of studies addressing group affinity have been conducted using stable isotopes of carbon, nitrogen and other elements (see Verano and Deniro 1993; also Katzenburg 1992:116; Katzenburg and Krouse 1987, 1989). The underlying premise in such studies is that "the isotopic composition of human tissues, minerals and fluids closely reflects the isotopic composition of the sources" (Katzenburg and Krouse 1987:156). Furthermore, the isotopic composition of some chemical elements is inherently variable both in the environment and within the human body. This variability stems from a wide range of factors including geochemical processes, geogrpahic variation in the chemical composition of crustal deposits and the biosphere, trophic levels and isotopic mass fractionation, and cultural practices. It follows that individuals of different cultural groups, if exposed to different sources of the element(s) under consideration, should be distinguishable on the basis of the isotopic composition of the chemical elements within their skeletons.

It is somewhat surprising that lead has not been employed in such research. Lead is an ubiquitous trace element in human skeletal material (Stack 1990). It is taken into the body via ingestion and inhalation and incorporated into bone through normal metabolic processes where it accumulates over time (Wittmers et al. 1988). Moreover, the radiogenic origin of three of the four stable lead isotopes results in lead having variable proportions of these isotopes based on time of formation (Faure 1986). Thus lead is characterized by its isotopic composition or "signature". Lead's inherent isotopic variability has allowed geologists and archaeometrists to use it to characterize ore bodies and artifacts (e.g. Cumming et al. 1990; Faure 1986; Gale 1989; Gulson 1986). For source tracer studies, these same characterizing principles can be applied to lead in skeletal remains.

This study presents the results of lead isotope analysis of eight individuals from the Seafort Burial Site (Skinner 1971, 1972) and a number of contemporaneous artifacts and faunal specimens which represent possible lead sources. The Seafort cemetery is associated with 19th century Hudson's Bay Company fur trade posts at Rocky Mountain House in what is now Alberta (Stenson 1985). Within this group of individuals were two isolated crania, without mandibles, buried together in a small wooden box as secondary burials. This unique context suggested that these individuals may have had a different cultural affiliation than other individuals buried at the site. However, because of the condition of the crania (the facial portions of the skulls were missing in one case, and shattered and incomplete in the other) few craniometric measurements could be taken, nor could complete morphological information be gathered. As such, traditional biometric and morphological techniques for investigating group affinity could not be effectively employed. It was the purpose of this study to inquire into the cultural affiliation of these and the other Seafort individuals using skeletal lead data. Through this application, it became apparent that analysis of the isotopic composition of skeletal lead is useful for characterizing human skeletal material and has additional potential for providing insight into aspects of individuals' life histories.

USING LEAD TO EXAMINE GROUP AFFINITY

Before introduction of the particular study undertaken on the Seafort burials, it is necessary to introduce a number of principles surrounding lead and its isotopes, and to formulate a framework with which to interpret skeletal lead isotope data in terms of characterization and group affinity.

Principles of Lead Isotope Characterization

The inherent variable nature of the isotopic composition of lead, explained by the processes of its formation, allows an isotopic "signature" of trace lead in bone, artifacts, and other items to be determined. The lead of the Earth is a mixture of lead originally present at the formation of the Earth (primordial lead) and lead that has been created since then through radioactive decay of uranium and thorium (Faure 1986:284-287; Gulson 1986:13-15; Parkes 1986:40). Through this decay, involving a number of intermediate daughter products, ^{238}U gives ^{206}Pb, ^{235}U gives ^{207}Pb, and ^{232}Th gives ^{208}Pb. This process of lead genesis has been used as the basis of age models for geologic dating. Knowledge of the half lives of U and Th, measurement of the relative proportions of the isotopes of Pb, and an assumption of the original quantities of lead present at the formation of the earth (based on the composition of meteoritic lead) is used to calculate time since geologic emplacement of the deposit (Faure 1986:309-340; Gulson 1986:15-23; Sahl et al. 1974:82-B). In general, the younger the deposit the greater the relative proportions of the radiogenic Pb isotopes. As such, lead from any given deposit will have a unique lead isotope "signature" expressed as isotope ratios (e.g. Cumming et al. 1990). Such characteristic signatures can allow investigation of the origin (source) of mined lead and trace amounts of lead in other materials (e.g. Kowal et al. 1991; Rabinowitz 1987), and form the basis of archaeometric provenance studies using lead (Gale 1989; Parkes 1986).

An important property of lead in terms of characterization of bone, is that in biological systems all four isotopes behave similarly in chemical reactions and do not fractionate measurably as do lighter elements such as carbon and sulphur (Gulson 1986:14-15; Rabinowitz and Wetherill 1972:705). The relatively small differences in atomic weight between the isotopes of lead are not chemically significant, whereas the weight differences between the isotopes of lighter elements are. As a result, lead from a given source will maintain its original isotopic ratio in chemical systems (such as human metabolism or metallurgical smelting) unless mixed with lead from another source. Since lead accumulates in the skeleton, mixing of lead from different sources occurs through normal metabolism. Both within and between cultural groups, and over time, there is likely more than one source of lead to which individuals are exposed. As a consequence, the isotopic composition of bone lead is a mixed composition.

Given mixing of two types of lead, the mixed isotopic composition will fall between the original ones (a linear relationship) depending on the proportion of lead each source contributed (Faure 1986; Gulson 1986:22-23). This process holds for metabolic accumulation of lead in the skeleton, as lead is quickly distributed throughout the body (Rabinowitz 1991). Exposure to a new source will ultimately be reflected in skeletal lead composition by a shift from the original composition towards that of the new source, ultimately resulting in a new overall composition. If exposure to the original source stops, the composition of the new source will eventually mask that of the old. The length of time such a process takes is poorly understood at present (Rabinowitz 1991). It is dependent upon the original amounts of lead in the skeleton, the magnitude of exposure, and the metabolic kinetics of lead in the body. Relatively sudden and great exposure to a new source would result in the original composition being effectively masked, particularly if there were originally small amounts of lead in the skeleton. The measured composition of skeletal lead can be considered to reflect a proportionately weighted average composition of all sources of lead to which an individual was exposed over their lifetime. The weighting is a function of time, dose over time, (pre)-existing levels, and accumulation and remobilization rates. Since trabecular bone has a faster turnover-rate than compact bone (Nordberg et al. 1991; Vaughn 1975), the above mixing processes occur at a faster rate in trabecular bone than in compact bone.

The composition of lead is generally reported as isotopic ratios. Geologists usually measure and report the ratios 206/204, 207/204, and 208/204. These ratios, all in terms of ^{204}Pb (non-radiogenic), quantify the time dependent growth curves of the radiogenic isotopes, which reflect the relative age of the lead (Faure 1986). The more recently an ore deposit formed, the higher the value of these ratios. Plotting these ratios against each other defines age dependent isotopic growth curves.

In archaeometric provenance studies, which use lead isotopic composition to characterize deposits and to "source" artifacts, the ratios 207/206 and 208/206 are frequently used (Gale 1989). These ratios offer good discriminating power, and can be measured with higher precision as they are not measured in relation to the least abundant isotope, ^{204}Pb. Plotting these ratios against each other allows definition of characteristic isotope fields for lead deposits or other metal deposits with trace amounts of lead. To define an isotope field, a line is drawn at 2 sigma around the plotted samples which represent a single metal ore deposit or lead source (e.g. Gale 1989:492). If the composition of trace lead measured in an artifact of bronze, for instance, falls within the defined field, then the proposition that the deposit characterized by the field is the source of the metal of the artifact is supported. The "exclusion principle", however, is generally the stronger interpretive tool (Gale and Stos-Gale 1992:313). This states that if the isotopic composition of a lead artifact falls outside a defined isotope field, then the proposition that the ore body defined by the field is not the source of the ore is strongly supported. Uncertainty in determination of the source of metal in artifacts comes from the possibility of having mixed ore sources. Also, there is the possibility that two different ore deposits may have formed at the same time or with different or variable parent materials, and thus, by chance, have the same lead composition. Gale (1989) provides a good review of principles and concerns of archaeometric provenance studies using lead isotopes (see also Sayre et al. 1992, and replies beginning with Gale and Stos-Gale 1992)

The Lead Environment

Lead in the human skeleton reflects an individual's lifetime exposure to it (Aufderheide et al. 1988). This is primarily a consequence of lead's slow turnover rate in the skeleton (c. 10-30 years) and its accumulation in skeletal tissues over time (Nordberg et al. 1991; Wittmers et al. 1988). Lead environment is defined here as all those natural and cultural particulars and processes in a given area and time which result in peoples' exposure to and uptake of lead. Exposure implies and subsumes a variety of cultural and natural conditions and processes which range from those determining the availability of lead to those which result in people absorbing it. The conditions are primarily the availability of lead, while the processes are those factors (cultural situation and behaviour) that result in exposure and absorption. Human groups experiencing different conditions and/or processes of lead exposure inhabit different lead environments, regardless of spatial proximity between the two groups; people who are exposed to lead under the same conditions and processes inhabit the same lead environment.

The significance that the concept of lead environment has for questions of group affinity is that individuals are indexed to the lead environment in which they live by the level and the composition of lead in their skeletons. The ability to differentiate cultural/social groups within a skeletal population through examination of lead in bone becomes possible because of both inter-group variability in available lead sources (probably having variable isotopic compositions), and inter-group variability in cultural behaviours and practices surrounding the use of lead and items containing lead (resulting in variable exposure and uptake). Ethnic differences in behaviours surrounding the consumption of goods have been demonstrated in the fur trade (Pyszczyk 1989). The level of skeletal lead is a measure of the relative magnitude of exposure to lead, while the isotopic composition of skeletal lead reflects the particular sources of lead to which an individual was exposed. By analyzing the lead in skeletal remains, it can be determined if individuals inhabited the same or different lead environments, and by extension, it can be inferred whether they belonged to the same or different cultural or social groups. Data presented by Kowal <u>et al.</u> (1991:199) illustrate differences in skeletal lead composition of three groups, 19th century Franklin expedition sailors, 19th century Inuit, and modern Canadians from Vancouver, that would be expected given that all three of these groups inhabited significantly different lead environments. Definition of the particular identities of groups within a skeletal population comes through interpretation of the historical and archaeological context of the remains.

It has been demonstrated that the <u>levels</u> of lead in skeletal remains can be effective for discriminating between the skeletal remains of individuals who inhabited different lead environments (Aufderheide <u>et al.</u> 1981). Colonial American slaves and plantation owners were differentiated based on the lead levels observed in the skeletons of the individuals. The two groups experienced different degrees of exposure to lead -- different lead environments -- and their skeletal lead levels reflected this difference. The plantation owners had generally high levels of lead, while the slaves had generally low levels of lead. The primary reason for these differences was suggested to be that the wealthy plantation owners consumed a significant amount of expensive food and beverages stored in lead lined containers, while the slaves did not.

At a finer level of interpretation, variation in the levels of skeletal lead in individuals <u>within</u> a defined group (apparent variation from the group's typical lead levels) have been explained in terms of individualized exposure within the group (e.g. Lalich and Aufderheide 1991:258). Such variation may be a result of unique social or occupational roles of individuals (Aufderheide <u>et al.</u> 1988). Alternatively, given that skeletal lead represents a mixture of all lead to which an individual was exposed, variation in the level and/or composition of an individual's skeletal lead from the group's typical level and composition may reflect the residual effects of the individual having lived, sometime in their past, in a different lead environment than the one with which they have subsequently been associated. Historical and archaeological information provide contextual information with which to interpret such a situation in terms of an individual's life-history.

To date, no studies investigating the isotopic composition of lead in skeletal remains specifically in terms of group affinity have been undertaken. However, comparison of the isotopic composition of lead in human tissues with the composition of lead in potential sources has allowed identification of the sources of the lead (e.g. Kowal et al. 1991; Rabinowitz 1987). Applying this analytical capability to questions of group affinity in skeletal populations is a simple step. If two groups are exposed to different sources of lead, then the isotopic composition of the lead in their skeletons should be different. Moreover, the respective sources of lead to which the groups were exposed can possibly be identified through analysis of potential lead sources that were available to the individuals. Such sources are represented by artifacts and other remains coming from the same historical and cultural context as the skeletal remains. Furthermore, if different sources contributed to a group's skeletal burden of lead, and if these sources are identified and the isotopic composition suitably well defined, the relative significance of each source can be estimated. Prior to analysis of a given population, historical and archaeological information can allow identification of the possible cultural groups of origin and identification of the potential sources and modes of lead exposure experienced by the groups.

Two broad categories of lead sources can be delimited from the outset. The first of these are natural sources such as the soil, water, and local unprocessed wild food products of an area. The ubiquitous distribution of lead in the biosphere and lithosphere result in virtually all living things having trace amounts of lead within their systems (Nriagu 1978a; Stack 1990). Natural sources are often represented in the archaeological record by faunal bones, the physical remains of locally available foods. Depending on cultural-historical context, natural sources may represent the only sources of lead for some populations. The second type of sources are anthropogenic sources resulting from the manufacture and use of lead products and items containing lead. These sources are represented in the archaeological record by lead artifacts and other artifacts containing trace lead. In cultural groups possessing lead technology, anthropogenic sources contribute the most significant fraction of lead to individuals.

THE SEAFORT BURIAL SITE, ROCKY MOUNTAIN HOUSE, AND FUR TRADE SOCIETY

Before the lead analysis is presented, the cultural/historical context of the Seafort burials is outlined. It is this context that provides information with which to interpret the lead isotope data. Possible cultural groups to which the Seafort individuals belonged can be suggested, and potential sources and modes of lead exposure can be identified.

Dempsey (1973), Smyth (1976), and Stenson (1985) provide histories of the fur trade at Rocky Mountain House. Five forts were operated between 1799-1875, four of which have been located (Fig. 1). These sites are now protected within the boundaries of Rocky Mountain House National Historic Park established in 1979. A number of archaeological investigations have been conducted at these sites.

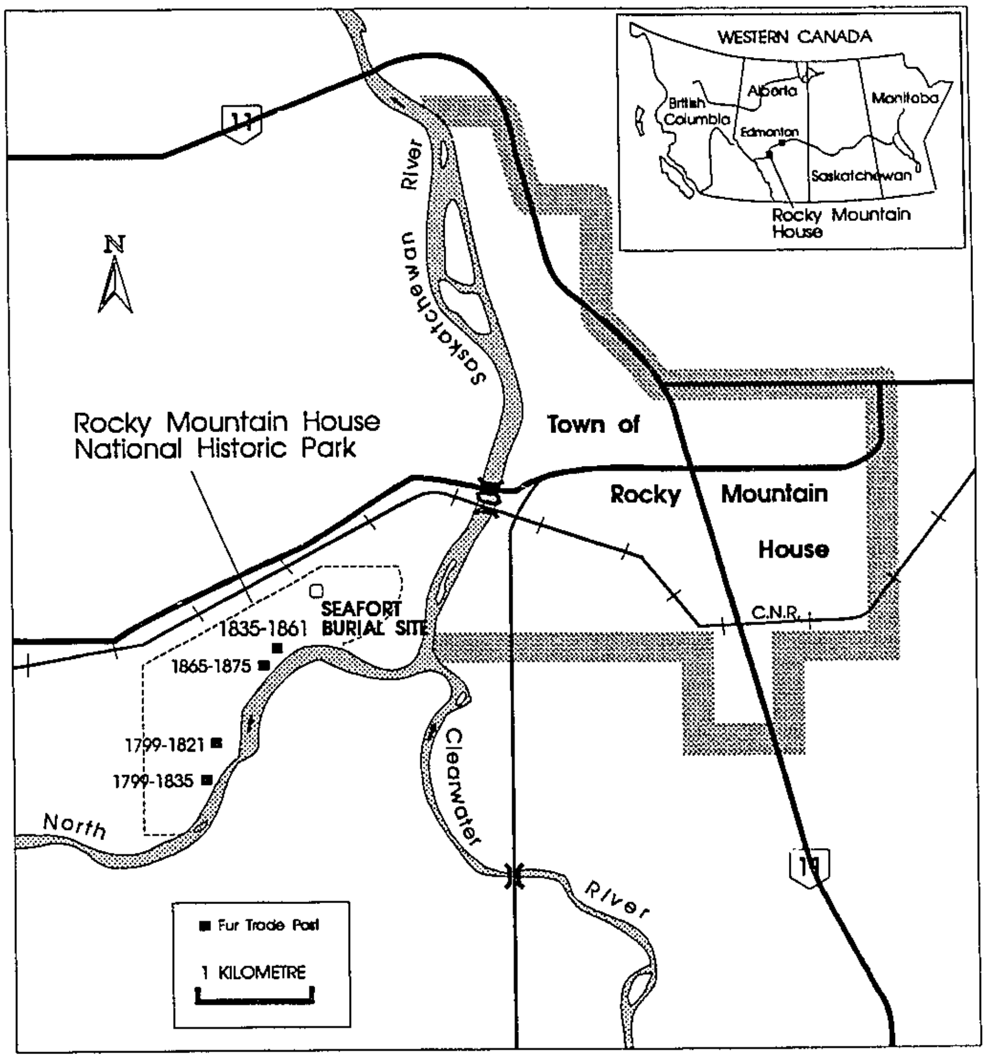

Figure 1: Location of the Seafort cemetery and Rocky Mountain House forts.

Prior to establishment of the National Park, Noble (1973) excavated the 1799-1835 fort site (FcPr-1/13R), and Vaucher (1968) excavated the 1865-1875 fort (FcPr-2/1R). In 1975 a program of survey and excavation was initiated to document the Rocky Mountain House remains within the proposed Historic Park (Steer 1975, 1976), at which time two other fort sites were identified and excavated: FcPr-3/15R the Hudson's Bay Company 1835-1861 fort (Steer et al. 1978; 1979); and FcPr-4/16R the site of the original Northwest Company 1799-1821 fort (Steer and Rogers 1976a, 1976b, 1978).

The Seafort Burial Site (FcPr-7/17R, previously FcPr-100) was found in 1969 when disturbed by construction activities of Seafort Petroleum Limited. It is located approximately 750 metres north of the 1835-1861 fort site (Fig. 1). Skinner (1971, 1972) located and excavated 12 graves (nos. 1-12), which contained the remains of 14 unidentified individuals (six neonates, three subadults, and five adults). In 1979, during further construction activities, 12 additional burials (nos. 13-24) were exposed (Steer and Lutick 1979). This second group was quickly reinterred following limited analysis and interpretation. Based on artifactual and historical evidence, Skinner associated burials 1-12 with the Hudson's Bay Company 1835-61 post (Skinner 1971, 1972). Most of the individuals of burials 13-24 were associated with this mid-century fort as well. A few are possibly associated with earlier forts (Steer and Lutick 1979:63).

Before it was disturbed in 1969, the cemetery had been forgotten, and its surface ploughed and farmed (Skinner 1971; Steer and Lutick 1980). However, its context, the nature of the artifactual remains interred with the burials, and its location, all indicated that it was a cemetery used during the 19th century fur trade. The people buried there were individuals who lived and died in the 19th century during their association, to whatever degree, with the fur trade at Rocky Mountain House. What were their respective cultural and social positions within the larger, mixed cultural community, and what was the degree and nature of association that these people had with the fur trade? To what cultural groups did they belong? Few journals or historical documents originating from the posts at Rocky Mountain House exist (Smyth 1978:2). As such, investigation into the identities of the Seafort individuals must be conducted primarily through general history, archaeology and osteology.

Fur trade society in the mid-19th century was centred around the formal hierarchy of the Hudson's Bay Company (Brown 1980; Hamilton 1985; Van Kirk 1980). The structure was pyramidal with the governor and London committee at the top, the chief factors below this, followed by other officers and clerks, then tradesmen, skilled labourers, and common labourers (Hamilton 1985:223). The officers were mostly European and/or Euro-Canadian men of English or Scottish descent, while the labourers could be European (often Orkneymen and Lowland Scots), Mixed-Blood, French Canadian, or Indian (Brown 1980:21-50). In this paper, the term Mixed-Blood refers to people of mixed biological ancestry. Other terms for this have included Country-Born, Half-Breed, and Métis; Mixed-Blood is used here as it is familiar, does not connote racial bias, or imply any specific cultural affiliation (as does Métis), particularly for unidentified skeletal remains. Young men, from as early an age as fourteen, would typically sign five year contracts of employment as labourers with the Hudson's Bay Company (Brown 1980:25). William Gladstone, a labourer and boat builder who worked intermittently at Rocky Mountain House between 1848 and 1861 mentioned that in 1848 about 20 Scottish "greenhorns" were to be sent up to Rocky Mountain House for the winter (Gladstone 1985:18). The number of employees at Rocky Mountain House usually ranged between 12-18 men (Smyth 1978:2). At the expiry of their term, the men had the option of renewing their contract. This renewal process could go on for essentially as long as the person wished. In the 19th century fur trade, it was not uncommon for men to serve for the long term in the company's employ. Hamilton (1985:126) argues for the economic security that this gave country skilled men during a time when settlements in Rupert's Land were still in their infancy.

Crosscutting hierarchical social divisions to varying degrees, but not part of the formal structure, were the wives and families of the men (Van Kirk 1980). Wives and families could swell the population of a post considerably, and often travelled with the men in the yearly trading cycle. Gladstone (1985:33) stated that in 1851 "...there was plenty of company at Edmonton, 80 men lived at the fort and most of these were married and had families." The typical ratio of men to women at Rocky Mountain House is estimated to have been approximately three men to one woman (Smyth 1978:2). Women provided valuable, yet generally unrecognized, services to the operation of fur trade posts (Van Kirk 1980). In the mid 19th century, most fur trade wives were Mixed-Blood women, the daughters of earlier unions between traders and Indian women (Brown 1980; Van Kirk 1980).

Many Indians would visit to trade at the posts. The northwest plains groups such as the Peigan, Sarsi, Blackfoot, and Blood Indians of the Blackfoot Alliance traded at Rocky Mountain House (see Dempsey 1988, 1972:27; Stenson 1985:53-64). In addition, a few hunters, often Indians, would live at or near the posts, employed by the Hudson's Bay Company (Dickason 1992:138; Ray 1974:85; Van Kirk 1980:15-17). There were usually two or three hunters attached to Rocky Mountain House, who were usually Cree or Stoney Indians, Mixed-Bloods, or occasionally Iroquois (Smyth 1978:17). In the later part of the 19th century some Indians began to hire on as part-time labourers with the Hudson's Bay Company (Dickason 1992:298).

The make-up of fur trade society suggests that any individual -- Indian, officer, labourer, wife, or child -- of the various social groups, who died at Rocky Mountain House, could have been buried at the fort cemetery. However, it is unlikely that officers who died would not have been mentioned in records and journals. As there is no known reference to any officers having died at Rocky Mountain House (Skinner 1971; Steer and Lutick 1980), it is concluded that none of the Seafort skeletons are Hudson's Bay Company officers. Individual labourers working at the posts were infrequently mentioned in records whether living or having died. However, at least one employee is known to have died of "distemper" at Rocky Mountain House in the winter 1855-56 (Smyth 1975:n.p.). As Hudson's Bay Company policy discouraged traders from having families at posts, it was a relatively rare event for wives or children to be mentioned (Van Kirk 1980:33). For instance, Gladstone notes that he got married, but does not identify his wife further (1985:47).

Children are reported to have been born at Rocky Mountain House, including a child of David Thompson's in 1802 (Schierholtz 1962:7).

Historical records and accounts provide little information as to the specific identity of individuals buried at the Seafort Cemetery (Skinner 1971; Steer and Lutick 1980:8). Only three references to the cemetery are currently known to exist. The first of these was made by Reverend Robert Rundle who visited Rocky Mountain House in October 1841. This reference provides the best possibility for a personal identification of one of the Seafort individuals (Dempsey 1977:89-90). Three days after Rundle baptized who he estimated to be a 7 year old girl, the daughter of John Rowand Jr. and Ke-ne-nu-wis-man, the girl, Isabelle, died and was given a Christian burial by Rundle at the fort cemetery. Only one of the 26 Seafort individuals is approximately this age, and appears to be female based on artifactual evidence (burial 3, see below). As such, it is likely that burial 3 is this individual.

The second reference to the cemetery was made by Reverend Thomas Woolsey in 1857 during a visit to Rocky Mountain House:

> Visited one of the cities of the dead in the afternoon. It is certainly the largest burial ground I ever saw, being uninclosed, and consequently may be regarded as occupying a vast tract of country. Some few of the graves have rudely-constructed pickets around them; but, with one exception -- that of a Highlander -- there is no intimation as to whose mortal remains are there (from Steer and Lutick 1980:8).

Skinner (1971:142) speculated that individual 7 was in fact this Scotsman that Woolsey mentions. He reports that Burial 7 was the only one excavated that had any evidence of a grave marker (as it turned out this observation includes the additional 12 burials located in 1979, see Steer and Lutick 1980). As well, cranio-metric and morphological analyses suggested (to Skinner), not only that individual 7 was Caucasian, but possibly Scottish. He pointed out that this specific identification was questionable.

The other reference to the cemetery was by William Gladstone (1985). He tells the story of a Blackfoot man killed by Cree Indians during the winter of 1858 and the body cut into small pieces. A few days later Father Lacombe arrived at the fort and chastised the men for not burying the body. Gladstone states: "Of course we would not let him [Father Lacombe] go alone, so we brought the remains to the fort and buried it [sic] just outside the graveyard" (Gladstone 1985:60). No such dismembered body was found at the Seafort Burial site.

Archaeological context and content provide some information as to the identities of the individuals. The evidence for European clothing on most of the individuals and crucifixes on two of the individuals (4 and 20) suggest that these people were living the European way of life as represented in the fur trade of Rupert's Land (Skinner 1971; Steer and Lutick 1980). That at least some of the individuals were probably Canadians or Métis is suggested by a wool tam from Burial 15 (Steer and Lutick 1980:83). It is very similar to Métis/Voyageur headgear illustrated in Brown (1980:Pls. 14 & 16). The mode of burial (primary inhumation in constructed coffins) of all the remains except Burial 2, supports a Euro-Canadian cultural affiliation as well. In contrast, the plains Indians did not bury their dead immediately after death. Rather, they placed bodies on scaffolds, hills, cliffs, in trees, or abandoned tipis (Brink 1988:109; Kidd 1986:61; Wissler 1911:31). Later, the surviving bones could be recovered and buried. It is possible that the crania of Burial 2 indicate some connection to this aboriginal practice. However, Full-Blood Indians who had adopted western religion, or who had signed on as labourers or hunters could have been buried in the graveyard. For instance a notable Cree was buried at Fort Edmonton (Pyszczyk pers. comm.).

Recent osteological investigation of three of the Seafort burials (4, 11, and 12) has provided strong evidence of the social identity of these three individuals. Activity induced stress markers on the skeletons, which probably developed from habitual labour tasks of the fur trade (carrying and lifting heavy loads, and paddling or rowing) suggested to Lai and Lovell (1992:230) that these three individuals were Métis labourers in the employ of the Hudson's Bay Company.

Based on the above brief review of the evidence, it seems likely that burials 4, 7, 11, and 12 are the remains of Hudson's Bay Company labourers. Moreover, 4, 11, and 12 were most likely Mixed-Bloods who had been working for the company for the better part of their adult lives. Individual 7, probably caucasian, and perhaps European, seems to have been relatively new to fur-trade service, given his young age at death (23) and the lack of obvious skeletal markers of occupational stress (Lai 1989; Lai and Lovell 1992). Individuals 2a and 2b are unique. The burial context suggests that they may have been culturally Indian, with an unknown degree of connection with the fur trade posts. The subadult individuals 1 and 3, and the six neonates were probably children of the men and women who lived at the fort. In particular, individual 3 may have been Isabelle, the daughter of John Rowan Jr. That these individuals were children of the people of the fort is based, at minimum, on circumstantial historical evidence that the children of Hudson's Bay Company labourers were born and lived at the fur trade forts, and that the Seafort neonatal and child remains were given European style burials.

Lead Sources

The historical context of the fur trade at Rocky Mountain House outlined above identifies, at minimum, two possible cultural groups (Indians and Euro-Canadians) to which the Seafort individuals may have belonged. Further separation of the Euro-Canadian group into European (e.g. British) and Canadian (e.g. Métis) can be suggested as well. Outlining expected sources and modes of lead exposure experienced by individuals of these groups aids in discrimination of the groups based on skeletal lead.

All three groups would have been exposed to natural sources of lead. Such lead is found in trace quantities in water, air, soil, and wild animal and plant food products. Probably the single most significant source of natural lead would have been that derived from eating wild game. The staple game foods at Rocky Mountain House were bison, moose, and elk, with other animals such as deer, rabbit, fish, and fowl contributing some food (Smyth 1978:21). Such food would contain trace amounts of lead derived from the animals' local diet. Pemmican, dried pounded bison meat, mixed with berries and fat, was an extremely effective method of preserving bison meat (The Beaver 1964, Summer Outfit 295:53-55; Dickason 1992:199). Developed by the plains Indians, it became the protein staple for fur traders across Rupert's Land. In the 19th century, the Saskatchewan District's greatest importance to the fur trade was in supplying pemmican to the rest of Rupert's Land (Smyth 1978:14). The lead found within animal tissues would be expected to have a composition reflecting the available range of lead in the animals' respective natural habitats. Although high quantities of lead were not found in bison and elk skeletal tissues from Rocky Mountain House (Chapter 4 this volume:93), and the amount of lead in animal meat is generally low (Ewers and Schlipkoter 1991:985), the sheer volume of these products consumed (five or more pounds per person per day of fresh meat or pemmican [Smyth 1978:24]) would contribute a measurable amount of lead to these individuals. Eating organ meat, particularly the kidney and liver, which contains higher levels of lead than muscle meat (Ewers and Schlipkoter 1991:985), would contribute somewhat greater amounts of lead to an individual than eating muscle meat. A reliance on primarily natural foods of the plains, processed and prepared for consumption without technology that could contribute lead to it, would result in an individual having a relatively low skeletal lead level, with a composition similar to or the same as that of the foods. Samples available for lead analysis, that represent these natural sources include the faunal remains recovered during archaeological excavations at the fur trade forts.

Pure lead items and numerous products containing lead were used during the fur trade. The relative significance of many of them, in terms of lead exposure, is difficult to ascertain, but, in general, the listing below proceeds from those sources most likely to have contributed lead to those least likely to have contributed. Additionally, it is not implied that any or all of these sources could or would have caused plumbism. That the items listed below are potential sources, is outlined in numerous articles (e.g. Grandjean 1975; Mahaffey 1978; Moore 1986), and most of them are reported in lists of goods available at Rocky Mountain House (e.g. Dempsey 1973:36-48) and in the men's account lists from other fur trade posts (e.g. H.B.C.A. B60/d/1). Of the lead sources, those that introduced lead to food and beverages would be the most significant. Such sources are the most wide spread and affect the greatest number of people. Moreover, ingestion is the primary route by which lead enters the body.

Cooking vessels, particularly copper kettles, which were ubiquitous fur trade items (Dickason 1992:104) represent a potentially significant lead source. Copper itself contains trace amounts of lead (Dennis 1963:140; West 1982:58). Moreover, until the late 19th century lead was added to copper during smelting to increase its malleability (Dennis 1963:132), and possibly to increase its weight so that it fetched a higher price (Granjean 1975:15). Lead in the soldered seams and within the copper itself could be mobilized during cooking, particularly if the water were salted as lead forms relatively strong compounds with the halogenides such as chlorine (Sahl et al. 1974). As well, the preparation of tea, of which copious quantities were consumed by fur traders and Indians (e.g. Gladstone 1985:43), results in an acidic environment which may be conducive to lead mobilization through attack of the lead by tannic acid. Lead reacts fairly readily with other organic acids such as acetic, citric and tartric acids (Nriagu 1978:5). However, tea leaves have been shown to absorb lead from the water in which they are steeped (Ratcliffe 1981:142). A replication study of tea preparation in fur trade copper kettles could prove enlightening. Leaded ceramic glazes and glassware from which lead could be leached (Moore 1986:173-175; Taylor and Bull 1986) were used at Rocky Mountain House (Steer et al. 1979). Lead may also have been present in, and possibly leached from the japanned surface of cups and pots (japanning is a high gloss, usually dark coloured decorative and protective surface treatment for metals, Ross 1988:173) that were very common items used by the men of the fur trade (e.g. H.B.C.A. B60/d/1). Tobacco smoking contributes lead to an individual, and in modern society, smokers have generally higher blood lead levels than non-smokers (Mahaffey 1978:15; Moore 1986:173). The men and women of the fur trade era smoked considerably (Ray 1974:142-144). Individual 7 from the Seafort cemetery demonstrates tooth wear consistent with habitual clenching of a pipe between his teeth (Skinner 1971:83-84). Lead shot, used in hunting fowl and small game, if lodged in the meat could have been ingested or have contaminated the food. In our current society, lead shot is a relatively serious lead source in the poisoning of wild birds (Forbes and Sanderson 1978:243-266). Distilled alcohol has relatively high levels of lead derived from distillery hardware particularly from illegal stills (Wedeen 1984; McCord 1954). Rum and brandy were common commodities at fur trade posts. Wine, as well, often contained added lead as a preservative and sweetener (Grandjean 1975:12; Wedeen 1984:178). This practice continued well into the 19th century, notwithstanding the contemporary knowledge of lead's harmful effects (Wedeen 1984). Lead foil used as packaging for tea, chocolate, and tobacco up until 1913 could also have contaminated these products (Granjean 1975:20). Food preserved in lead soldered cans has been shown to become contaminated with lead (Sherlock 1987; Kowal et al. 1991; Mitchell and Aldous 1974). The use of luxury items such as pewterware have also been suggested to have contaminated food (Grandjean 1975:14; McCord 1953). It is noted, however, that there is no archaeological evidence of canned food or pewter at Rocky Mountain House (Steer et al. 1979), nor were canned goods shipped into Rupert's land. While some food supplies such as flour, salt, cheese, and sugar were imported, country foods such as pemmican were the primary food staples of the fur trade (Smyth 1978).

Occupational exposure to lead in the fur trade could have been significant in particular cases. Generally, however, it would have affected only a small number of people. Casting lead balls and shot and working with lead in other ways such as soldering could have resulted in inhalation of airborne lead (Moore 1986:175). As well, coal contains lead, and when burned, lead is released to the air (Grandjean 1975). One practice by buffalo hunters which could be considered potential occupational exposure is the practice of holding gun balls in the mouth for ease of reloading while on the hunt (Carpenter 1977:32).

An interesting, potentially significant, source of lead for Indians in the fur trade era is described by Carpenter (1977) writing of his Métis grandmother's life in the 19th century. He tells of how she described:

> When the Hudson's Bay Company shipped tea to the outposts it came in large packages that were greatly prized by Indians fortunate enough to have muzzle loaders. The packages contained lead which the Indians saved, melted, and poured out in long strips on a smooth flat rock. When it had cooled, a sharp knife was used to cut it into small pieces and calling all his children together, the father would have them chew the pieces into shot. The women and men also chewed, firming the pieces into fine balls. Running around the Indian camps as her parents were trading, Marie Rose often stopped to watch a circle of intent children, jaws and tongues moving as if in rhythm, turning the small lead lumps around in their mouths (1977:36).

The potential this practice would have for introducing a significant amount of lead to an individual can be considered quite high given the possibility that pieces of lead could actually be swallowed. It could have been a relatively serious form of chronic and perhaps acute exposure for individual Indians. It is unlikely that Europeans or employees of the Hudson's Bay Company would have used this method of manufacturing ammunition. As no other references to this practice have been found other than the one presented above, its prevalence cannot be estimated.

THE STUDY

The statements put forth above concerning the socio-cultural identities of the Seafort individuals form the hypotheses tested below with lead isotope analysis of the skeletal remains of the individuals. In particular, does the lead isotope data support the proposition that individuals 2a and 2b are Indians, that Individual 7 is European, and that the rest are relatively long-term members of fur trade society? Investigation proceeds through two levels of analysis and interpretation. First, outlining patterns in the isotopic composition of the lead measured in bone samples from the Seafort individuals and in artifact and other samples representing potential lead sources (as outlined above) allows primary sources of lead at Rocky Mountain House to be delimited. Following this, comparison of the composition of lead characterizing the skeletal remains with the composition of lead from different sources allows evaluation of the relative significance of contributing sources and evaluation of the groups' cultural identities based on assumptions of differing exposure to different sources, experienced by particular groups.

The Sample

The Seafort individuals examined are eight of the twelve recovered by Skinner (1971, 1972). The remains are conserved at the Department of Anthropology, University of Alberta. The five neonate skeletons were not included, although bone samples were removed from these for later analysis. It was decided to exclude the neonates in the first round of analyses because neonatal remains have a greater possibility of being affected by diagenetic processes as they are composed of a relatively large proportion of trabecular bone (see below). Furthermore, the lead in the neonatal skeletons would be better interpreted secondarily with reference to lead data derived from the adult section of the population.

Table 1 summarizes the osteological and archaeological information on the eight individuals analyzed. A number of osteological studies have been conducted on the Seafort remains, with Skinner (1971) providing the first comprehensive assessment. Prompted by new osteological techniques developed in the intervening years, Lai (1989; see also Lai n.d.; Halgrimsson n.d.) conducted further analyses. Lai and Lovell (1992) examined the remains of the three adult male Indian or Mixed-Blood skeletons (Burials 4, 11, and 12) in terms of occupational stress markers on the skeleton. Recently, the skeletons have undergone detailed osteological description and analysis (Lovell pers. comm. 1993) in response to a call for the compilation of baseline data on human skeletal collections as set forth by the Palaeopathology Association Skeletal Database Committee (Rose et al. 1991). It is from this most recent assessment that the estimates of age and sex used in this study are taken (Table 1).

From these eight individuals, a total of 22 bone samples were analyzed. Six samples were of trabecular bone (spongiosa) from the proximal, metaphysis region of the tibia, while the remainder were compact bone from either the tibia diaphysis or temporal squama. Table 2 summarizes the particular skeletal samples removed and analyzed.

Four faunal bone samples (three bison and one elk) were also analyzed for lead (Tables 3 and 4). The specimens from which the bone samples were taken were recovered during excavations of the fort sites and form part of the archaeological collections from Rocky Mountain House. The lead in these faunal specimens represents natural sources of lead in the 19th century northwest plains.

Seven artifacts were analyzed for lead composition (Table 5). They consist of three copper kettle fragments, three lead gun shot/balls, and a sample of carbonized residue recovered from a pipe bowl fragment. Two each of the copper and lead artifacts, and the pipe bowl were recovered from excavations at the mid-century (1831-1865) Hudson's Bay Company fort to which the Seafort Cemetery has been associated (Skinner 1972; Steer and Lutick 1980). The other copper kettle fragment was recovered from the 1865-1875 Hudson's Bay Company Fort, and the other lead ball was recovered from the Northwest Company 1799-1821 fort. These artifacts represent potential anthropogenic lead sources at Rocky Mountain House.

A single soil sample was analyzed (Tables 3 & 4). It was collected by Skinner (1971) from directly above the coffin of Burial 11 and was analyzed to determine the amount and isotopic composition of readily soluble and exchangeable lead in the soil of the Seafort Burial Site. It is valuable to analyze the lead in soil directly associated with buried human skeletal remains as this information assists in the assessment of potential post-mortem diagenetic exchange of lead between bones and soil (see below).

TABLE 1: Summary of Seafort Burials Analyzed (Data from: Skinner 1971; Lai and Lovell 1992; Seafort Skeletons Data File, Department of Anthropology, University of Alberta 1993)

BURIAL	CONDITION	SEX	AGE*	ANCESTRY	ARTIFACTS/COMMENTS
1	Good preservation, some bones broken.	F?	12-16 (14)	Mixed?/ Indian?	Split log spruce coffin, beads possibly from moccasins and beaded garment.
2a	Cranium only. Good bone preservation.	M?	40-65 (50)	Indian?	Secondary burial of two crania, no mandibles. Empty fly pupae casings. Square spruce coffin nailed together, crania apparently wrapped in a beaded cloth.
2b	Cranium only. Good bone preservation.	F?	15-20 (18)	Mixed?/ Indian?	
3	Complete skeleton, good preservation.	F?	4-6 (5)	Mixed?/ Indian?	Split log spruce coffin, beads probably from a necklace.
4	Good, some damage to lower limbs. Good preservation.	M	30-40 (35)	Mixed?	Spruce coffin nailed together, crucifix pendant, shell shirt buttons, long hair.
7	Complete. Good preservation.	M	22-25 (23)	Caucasian?	Spruce coffin nailed together, base of grave marker and two posts, shredded bark pillow, wool blanket, bone and shell trouser and shirt buttons, silk scarf.
11	Essentially complete Good preservation.	M	40-60 (45)	Mixed?	Spruce coffin nailed together, shredded bark pillow, wool blanket frag., knit wool material, hair.
12	Complete. Good preservation.	M	30-40 (35)	Mixed?	Wooden coffin.

* Number in brackets indicates a single, median age estimate.

TABLE 2: Human Bone Samples Analyzed

Sample/ Burial	Sample Site	Bone Type	Dry Weight (gms.)	Ash Weight (gms.)
S1/1	R. Tibia, diaphysis	Compact	0.1143	0.0809
S2/1	R. Tibia, prox.	Trabecular	0.0748	0.0434
S4/2b	R. Temporal, squama	Compact	0.0254	0.0129
S5/2a	R. Temporal, squama	Compact	0.0570	0.0406
S6/3	R. Tibia, diaphysis	Compact	0.0553	0.0377
S7/3	R. Tibia, prox.	Trabecular	0.0635	0.0330
S9/4	R. Tibia, diaphysis	Compact	0.1148	0.0808
S10/4	R. Tibia, prox.	Trabecular	0.0746	0.0372
S11/4	R. Temporal, squama	Compact	0.0237	0.0140
S15/7	R. Tibia, diaphysis	Compact	0.1509	0.1075
S16/7	R. Tibia, prox.	Trabecular	0.1809	0.1105
S17/7	R. Temporal, squama	Compact	0.0583	0.0359
S21/11	R. Tibia, diaphysis	Compact	0.0481	0.0374
S22/11	R. Tibia, prox.	Trabecular	0.0839	0.0435
S23/11	R. Temporal, squama	Compact	0.0871	0.0615
S24/12	R. Tibia, diaphysis	Compact	0.1331	0.0937
S25/12	R. Tibia, prox.	Trabecular	0.2291	0.1196
S26/12	R. Temporal, squama	Compact	0.1038	0.0751
S27/7	R. Tibia, diaphysis	Compact	0.1284	0.0921
S28/4	R. Tibia, diaphysis	Compact	0.1399	0.1001
S29/2a	R. Temporal, squama	Compact	0.1416	0.1019
S30/2b	R. Temporal, squama	Compact	0.1174	0.0827

TABLE 3: Summary of Faunal and Soil Specimens Analyzed

Sample	Cat. No.	Specimen	Context
E7	FcPr 100/11/228	Soil, grey brown silt loam	From directly above coffin, burial Number 11
E9	16R4E4	Elk, (*Cervus elaphus*), left radius, distal 1/3, young adult	From the N.W. Co. 1799-1821 fort site.
E10	15R23G7	Bison (*Bison bison*), left femur, distal 1/2, immature	From the H.B.C. 1835-1861 fort site, early period, pit feature no. 113
E11	15R23G6	Bison (*Bison bison*), left radius and ulna, distal 1/4, adult	From the H.B.C. 1835-1861 fort site, early period, pit feature no. 113
E12	15R14V6	Bison (*Bison bison*), left humerus, distal fragment, adult	From the H.B.C. 1835-61 fort site, late period, cellar, structure 1, feature no. 26

TABLE 4: Environmental Samples Analyzed

Sample	Specimen	Dry Weight (gms.)	Ash Weight (gms.)
E7	Soil	300 (total)	n/a
E9	Elk Bone	0.8326	0.6138
E10	Bison Bone	0.7906	0.5938
E11	Bison Bone	0.5866	0.4213
E12	Bison Bone	0.9507	0.7510

TABLE 5: Artifact Samples Analyzed

Sample	Specimen	Cat. No.	Context	Weight (Clean & Dry, gms.)
A1	Rolled Copper Sheet	15R/14V6-32	1831-1865 H.B.Co. Fort	0.8407
A2	Copper Kettle Handle Lug	15R/15H1-4	1831-1865 H.B.Co. Fort	0.3877
A3	Pipe Bowl Residue	15R/15V2-38	1831-1865 H.B.Co. Fort	0.0259
A4	Lead Gun Ball	15R/15V2-38	1831-1865 H.B.Co. Fort	0.0104
A5	Lead Gun Shot	15R/2451-10	1831-1865 H.B.Co. Fort	0.0058
A7	Copper Kettle Handle Lug	1R/FcPr-2:1871	1865-1875 H.B.Co. Fort	0.7656
A8	Lead Gun Shot	16R10M3	1799-1821 N.W.Co. Fort	0.0104

Methods

Determination of lead isotopic composition was accomplished using a VG Micromass 30 mass spectrometer, at the University of Alberta. Repeat analyses of analytical standard lead (NBS SRM 981) allowed correction of isotopic ratios for mass fractionation, and gave a minimum analytical error in ratios of approximately 0.1%. This error was sometimes exceeded in individual samples due to relatively poor precision in individual sample measurements. Individual measurement error was added to overall analytical error in reporting. The ratios measured were 206/204, 207/204, and 208/204. From these, 207/206 and 208/206 were calculated. The levels of lead in a number of samples (see chapter 4 this volume), and in analytical blanks was determined using Isotope Dilution Mass Spectrometry (IDMS). IDMS is considered a definitive method to obtain precise isotopic ratio measurements from which the quantity of lead in a sample can be calculated (Barnes et al. 1973, 1982; Gramlich et al. 1977; Machlan et al. 1979).

Steps for collection and preparation of samples prior to mass spectrometry include: 1) sample recovery; 2) sample digestion; and, 3) extraction and purification of lead. Sample recovery requires removal of an appropriate amount of bone from the skeleton. Human bone samples weighed between 25-150 milligrams (dry) (Table 2). Faunal bone samples weighed between 500-1000 milligrams (dry) (Table 4). Table 6 outlines the steps involved in sample recovery. Table 7 outlines sample digestion procedures, and Table 8 outlines lead extraction and purification procedures.

TABLE 6: Bone Sample Recovery Procedures

Compact Bone
1) Remove and discard c. 0.5 mm of periosteal surface of sample site using electric Dremel drill with stainless steel burr bit (removes potentially diagenetically altered surficial bone)
2) Collect sample (bone dust) in vial using hand drill with 1/4" titanium plated steel twist drill, avoid drilling all the way through to endosteal surface if possible
3) Examine sample under microscope and remove any foreign particles or discoloured bone fragments
Trabecular Bone
1) Abrade and discard thin compact bone over sample site with electric Dremel drill with stainless steel burr bit
2) Collect sample by mechanically removing trabeculae from aperture using stainless steel tweezers
3) Examine sample under microscope and remove any foreign particles
4) Rinse sample in distilled deionized water
5) Chemically wash sample in 1.5 N Acetic acid for 24 hrs.
6) Rinse sample in distilled deionized water

TABLE 7: Bone Sample Preparation Procedures

1) Dry bone samples at 110 °C for 24 hours in weighed platinum dish
2) Equilibrate to room temperature and weigh
3) Ash sample at 450 °C in muffle furnace for minimum 48 hours or until grey-white
4) Equilibrate to room temperature and weigh
5) Digest sample with 6-8 ml 1:1 HNO_3 in weighed teflon beaker
6) Let stand closed on hot plate at 80 °C for 12 hours
7) Equilibrate to room temperature and weigh
8) Split sample if lead level measurement required, circa 1/4 of sample (2.5-2 ml) becomes ID (Isotope Dilution) aliquot, remainder forms IR (Isotope Ratio) aliquot
9) Weigh ID aliquot into teflon beaker
10) Spike ID aliquot with appropriate amount of 206 Pb (Note: splitting and spiking of samples was necessary for only those samples upon which lead levels were determined)

TABLE 8: Lead Purification Procedures

1) Evaporate sample aliquot in teflon beaker to conc. HNO_3
2) Cool and pour solution into silica centrifuge tube containing two drops of saturated lead free $Ba(NO_3)_2$ solution
3) Agitate with teflon stirring rod to precipitate $(Ba,Pb)(NO_3)_2$
4) Centrifuge and discard supernatant solution
5) Dissolve precipitate in minimum amount of H_2O
6) Repeat steps 2, 3, and 4 for second purification
7) Dissolve dried precipitate in circa 1 ml 1.5N HCl, forms $(PbCl_4)^{-2}$
8) Purify Pb:Chloride in anion exchange column, wash with 4 X 1 ml, 1.5N HCl, strip Pb with 3 X 2 ml H_2O
9) Collect in teflon beaker and add 1 drop lead free H_3PO_4
10) Evaporate down to single drop phosphoric acid containing Pb
11) Load drop for mass spectrometry onto refined rhenium filament with lead free silica gel

The copper and lead artifact samples were cleaned in dilute HNO_3, rinsed in distilled water, dried, weighed, and then digested in 10 ml 1:1 HNO_3 in a teflon beaker. The pipe bowl residue was ashed, weighed and digested in eight ml of HNO_3. The solubilized artifact samples were taken through the same purification procedures as the bone samples (Table 8).

The soil sample was prepared in order to determine the amount and composition of readily exchangeable soil lead. Guided by procedures outlined by Pate and Hutton (1988), a 300 gram sample of soil was saturated with distilled, deionized water. This paste was covered and left to stand for 24 hours, and then an additional 400 ml of water were added to it. The sample was again left to stand for eight hours. The water was filtered under vacuum from the soil. Recovery was slightly greater than 400 ml of water. The solution was evaporated to dryness in a teflon jar. The residue was taken up in 5 ml of concentrated nitric acid and 20 ml of water and again evaporated to dryness in a platinum dish. It was then ashed at 450 °C for 48 hours. The ashed residue was digested in nitric acid and taken through the same preparation and purification procedures as the other samples. Soil pH was determined by adding 40 ml of water to 20 grams of soil. The paste was left to stand for 1/2 hour, stirred and left to stand for an additional hour. The pH of the paste/standing water was measured using a pH meter.

Sampling and chemical procedures were undertaken in a manner so as to avoid contamination of the samples with modern lead and cross contamination between samples. Tools were thoroughly cleaned between extraction of different samples. Following collection, and between each step, samples were stored in either closed air-tight containers, or a sealed desiccator. Chemical procedures were carried out in a "clean lab" with filtered air. Acid reagents were purified by vapour distillation. Vessels were of either platinum, teflon or silica, and were cleaned by boiling in nitric acid, and rinsing with deionized distilled water. Four reagent blanks, samples consisting of only analytical reagents, were carried through all chemical procedures along with the analytical samples. Blank samples allow determination of the amount and composition of contaminant lead introduced during chemical procedures.

Diagenesis

To interpret lead data in archaeological bone in terms of living persons and their culture, one must be confident that the lead represents metabolically derived lead and not diagenetic lead. Diagenesis is defined in anthropological trace element studies as "postmortem alterations in the chemical constituents of bone following deposition in soil" (Sandford 1992:86). Its importance to trace element studies is reflected by the amount written on it (e.g. Edward and Benfer 1993; Grupe 1988; Grupe and Pipenbrink 1988; Hancock et al. 1987; Klepinger et al. 1986; Kyle 1986; Lambert et al. 1985, 1989, 1990; Pate and Hutton 1988; Patterson et al. 1987:169-174; Price 1989; Price et al. 1992; Reinhard and Ghazi 1992:188-189; Sandford 1993; Sillen 1989; Waldron 1981, 1983; Waldron et al. 1979; Weber 1992; Williams 1988). Lead may be taken up by bone from soil, or leeched from bone, although there is some question as to which takes primacy (see Jaworowski 1990:176-181; Patterson et al. 1987:169-170).

A number of considerations were made and specific procedures followed to minimize and to detect the effects of diagenesis in the Seafort sample. These considerations apply to the faunal bone samples as well. The artifacts were thoroughly cleaned in nitric acid and distilled water prior to digestion. Moreover, the large quantity of lead in the artifacts would mask the effects of any introduced contaminant soil lead. It is a general rule that the longer bones have been buried the greater the potential for significant diagenetic change (Sandford 1992:88). As the Seafort skeletons were, at most, buried for 135 years, diagenesis was probably not significant. It should be noted, however, this general trend can be highly variable temporally and spatially. Second, although a number of trabecular bone samples were analyzed, compact bone samples were given primacy during interpretation. Compact bone, being denser and generally thicker than trabecular bone, is less easily affected by diagenesis than trabecular bone (Grupe 1988). Third, since the endosteal and periosteal surfaces of bone undergo the greatest degree of diagenetic change in buried bone

(Lambert et al. 1989), these surfaces were not included in the compact bone samples. Fourth, the general condition and colour of bone can be used as an indicator of the degree to which diagenesis has occurred (Edward and Benfer 1993:191-192). The more the bone colour approximates the colour of fresh bone -- light, pale yellow to ivory -- the less likely diagenesis has occurred. The overall condition of the Seafort skeletal remains is very good, and the colour of the bone samples (except the periosteal and endosteal surfaces) ranged from yellow to ivory coloured. Dark coloured bone particles found within the compact bone samples were removed. Finally, in order to reduce the potential effects of diagenesis on the surfaces of the trabecular bone samples (surfaces which could not be removed through any practical procedures), these samples were cleaned in acetic acid, which has been shown to reduce diagenetic effects (Price et al. 1992; Weber 1992).

To investigate diagenesis further, a soil sample from directly above the coffin of burial 11 was analyzed for lead in order to examine the potential of the burial environment for exchange of lead between the bones and soil. Although only a single sample, it is assumed to be representative of the soil over the entire site, as the cemetery was located in a discrete area of a single uniform river terrace, and Burial 11 was situated centrally amongst all the burials (Skinner 1972). Pate and Hutton (1988) argue that the amount of readily soluble ions of an element in soil better reflects the availability of these ions for chemical exchange with bone than does the total amount of the element in the soil. Large proportions of the total amount of many soil elements, lead included, are insoluble in soil solutions because they are firmly bound into soil mineral crystal structures, or are in relatively insoluble compounds (Davies 1990). Following this reasoning, the amount of readily exchangeable lead in the soil was analyzed and determined to be 0.012 μg/g (Chapter 4 this volume:93). This is considerably less than the amount of lead measured in any of the samples including the faunal bones. Furthermore, lead is more readily mobile in acidic soils than in basic soils (Davies 1990:190; Zimdahl and Skogerboe 1977). The pH of 7.9 determined for the soil sample is not conducive to lead mobility. As such, it is concluded that the soil environment of the Seafort cemetery was not such that diagenetic exchange of lead between bones and soil was significant.

The best evidence against diagenesis in the Seafort samples, is that the isotopic composition of the exchangeable soil lead is significantly different than the lead in any of the skeletal samples (see below, Figure 2). If diagenesis had been extensive, it would be expected that the composition of lead in the bones would closely match that in the soil. This procedure provides a test of whether exchange of lead between bones and soil has occurred. It is recommended that in future studies of skeletal lead, comparison of the isotopic composition of soil lead with that of skeletal lead be done routinely as a test for diagenesis. Given the above considerations, it is concluded that the lead measured in the Seafort skeletal samples is metabolic lead.

Results

Tables 9, 10, and 11 present the isotope ratio values measured for the lead in the Seafort skeletal samples, in the soil and faunal samples, and in the artifacts respectively. Measurement error is reported at 1 sigma. Reagent blank lead composition (204:206:207:208) was measured to be 1:18.39:15.47:37.81, with an average level (n=3) of 15 ng. Correction of the isotope ratios for blank lead had no effect within error. Appendix 1 presents the measured raw data.

TABLE 9: Pb Composition of Seafort Human Skeletal Samples

Burial/ Sample/Bone*	206/204 ± S.E.	207/204 ± S.E.	208/204 ± S.E.	207/206 ± S.E.	208/206 ± S.E.
1/S1/C	18.50 ±0.02	15.63 ±0.02	38.51 ±0.04	0.845 ±0.001	2.082 ±0.002
1/S2/T	18.50 ±0.02	15.62 ±0.02	38.49 ±0.05	0.845 ±0.002	2.081 ±0.003
2a/S5/C	19.01 ±0.04	15.65 ±0.04	38.94 ±0.09	0.821 ±0.003	2.036 ±0.007
2a/S29/C	19.21 ±0.03	15.72 ±0.02	39.13 ±0.05	0.818 ±0.001	2.037 ±0.003
2b/S4/C	18.59 ±0.03	15.65 ±0.03	38.64 ±0.07	0.842 ±0.002	2.078 ±0.005
2b/S30/C	18.56 ±0.02	15.62 ±0.02	38.56 ±0.04	0.842 ±0.001	2.078 ±0.002
3/S6/C	18.52 ±0.05	15.66 ±0.03	38.51 ±0.06	0.846 ±0.003	2.080 ±0.007
3/S7/T	18.60 ±0.02	15.66 ±0.02	38.61 ±0.05	0.842 ±0.001	2.076 ±0.003
4/S9/C	18.60 ±0.03	15.60 ±0.03	38.55 ±0.06	0.839 ±0.002	2.072 ±0.005
4/S11/C	18.66 ±0.02	15.66 ±0.04	38.68 ±0.05	0.839 ±0.001	2.073 ±0.003
4/S28/C	18.64 ±0.05	15.64 ±0.05	38.64 ±0.11	0.839 ±0.004	2.073 ±0.009
4/S10/T	18.91 ±0.02	15.67 ±0.02	38.81 ±0.04	0.829 ±0.001	2.052 ±0.002
7/S15/C	18.45 ±0.02	15.63 ±0.02	38.47 ±0.07	0.847 ±0.001	2.085 ±0.004
7/S17/C	18.43 ±0.03	15.61 ±0.02	38.43 ±0.05	0.847 ±0.002	2.085 ±0.004
7/S27/C	18.44 ±0.03	15.61 ±0.02	38.45 ±0.04	0.847 ±0.002	2.086 ±0.004
7/S16/T	18.48 ±0.03	15.64 ±0.02	38.56 ±0.06	0.846 ±0.001	2.086 ±0.004
11/S21/C	18.42 ±0.03	15.61 ±0.02	38.37 ±0.06	0.848 ±0.001	2.083 ±0.004
11/S23/C	18.44 ±0.02	15.61 ±0.02	38.42 ±0.05	0.847 ±0.001	2.084 ±0.003
11/S22/T	18.42 ±0.02	15.62 ±0.02	38.43 ±0.05	0.848 ±0.001	2.086 ±0.003
12/S24/C	18.46 ±0.02	15.63 ±0.02	38.49 ±0.04	0.846 ±0.001	2.085 ±0.003
12/S26/C	18.52 ±0.02	15.64 ±0.02	38.56 ±0.04	0.845 ±0.001	2.082 ±0.002
12/S25/T	17.42 ±0.02	15.56 ±0.03	37.33 ±0.06	0.893 ±0.002	2.143 ±0.004

* Refers to Bone Type: C=Compact Bone; T=Trabecular Bone

TABLE 10: Pb Composition of Rocky Mountain House Artifact Samples

Sample	Material	206/204 ±S.E.	207/204 ±S.E.	208/204 ±S.E.	207/206 ±S.E.	208/206 ±S.E.
A1	Copper	18.38 ±0.02	15.62 ±0.02	38.41 ±0.05	0.850 ±0.001	2.090 ±0.003
A2	Copper	18.50 ±0.02	15.69 ±0.02	38.69 ±0.05	0.848 ±0.001	2.091 ±0.003
A3	Pipe Bowl Residue	18.47 ±0.02	15.67 ±0.02	38.60 ±0.04	0.848 ±0.001	2.090 ±0.002
A4	Lead Ball	18.47 ±0.02	15.71 ±0.02	38.70 ±0.05	0.850 ±0.001	2.095 ±0.003
A5	Lead Shot	18.67 ±0.02	15.73 ±0.02	39.08 ±0.05	0.843 ±0.001	2.093 ±0.003
A7	Copper	18.21 ±0.03	15.64 ±0.02	38.39 ±0.05	0.859 ±0.001	2.108 ±0.003
A8	Lead shot	18.59 ±0.03	15.89 ±0.02	39.31 ±0.06	0.855 ±0.002	2.114 ±0.004

TABLE 11: Pb Composition of Environmental Samples

Sample	Material	206/204 ±S.E.	207/204 ±S.E.	208/204 ±S.E.	207/206 ± S.E.	208/206 ± S.E.
E7	Soil	18.09 ±0.02	15.61 ±0.02	37.88 ±0.04	0.863 ±0.001	2.094 ±0.003
E9	Elk Bone	18.84 ±0.07	15.58 ±0.05	38.56 ±0.14	0.827 ±0.005	2.047 ±0.015
E10	Bison Bone	19.03 ±0.04	15.70 ±0.03	38.84 ±0.07	0.825 ±0.002	2.041 ±0.006
E11	Bison Bone	18.80 ±0.04	15.65 ±0.03	38.65 ±0.08	0.832 ±0.002	2.056 ±0.005
E12	Bison Bone	18.89 ±0.05	15.66 ±0.05	38.76 ±0.08	0.829 ±0.004	2.052 ±0.008

Figure 2 illustrates 208/204 plotted against 206/204 for all the samples. Error bars are drawn at two sigma (95%). Samples S25 and A3 are not included in this plot and further analyses. In the case of S25, a trabecular bone sample, the composition of the lead is extremely different from any other sample, representing significantly older lead. As this sample was highly stained, and prior to cleaning had numerous small soil particles adhering to its surfaces, it was probably contaminated by non-anthropogenic lead from soil minerals. It is excluded from further consideration. Sample A3, the pipe bowl residue, while on initial consideration appears to be acceptable, is suspect for two reasons. First, its composition is virtually exactly the same as copper samples for which chance is the only explanation. Second, the output of the results of the mass spectrometric analysis for this sample returned from the lab without a sample number. Given these factors it is excluded from consideration.

It is apparent in Figure 2 and from Table 9 that the skeletal lead in all the Seafort individuals, except 2a and the trabecular bone sample from individual 4, is of similar composition within error (95%). Some spread in the cluster is apparent, with the extreme samples having no overlap at 2 sigma. The composition of the lead in artifacts from the mid-nineteenth century post (1835-1861) is of essentially the same composition. Moreover, it is very similar to the lead in most of the skeletal remains. The lead composition of the two artifact samples from other forts is significantly different than that of the skeletal samples and the 1835-1861 artifacts. The composition of the lead in all the faunal samples is the same within error. Some slight overlap with the skeletal samples is apparent. It is pointed out that the spread in the isotopic composition of the human skeletal samples is between the composition of the 1835-1861 artifacts and the faunal samples, and that the lead in the soil sample is significantly different than the lead in all other samples.

In order to discriminate the patterns suggested above more clearly, the ratios 207/206 and 208/206 were calculated and plotted against each other (Figs. 3, 4, and 5). Isotope fields for the human skeletal samples and the mid-century artifact samples are defined at 95% (2 S.E.) in these plots (Figs. 3 and 4). Only compact bone samples were used, and the values for each individual were averaged (Fig. 3). The pattern of spread in the human samples

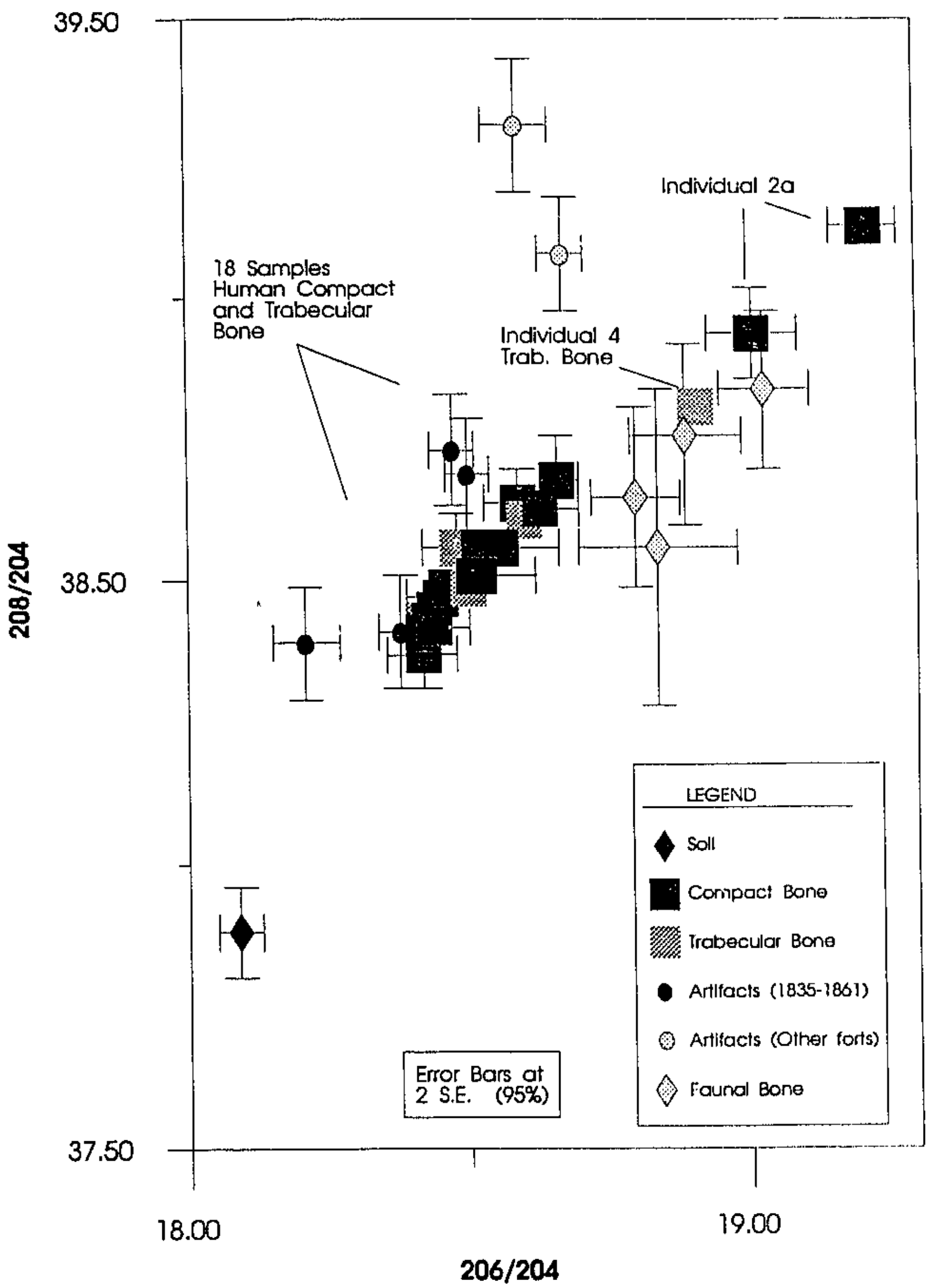

Figure 2 : Pb composition in the Seafort skeletons and artifacts from Rocky Mountain House (208/204 against 206/204).

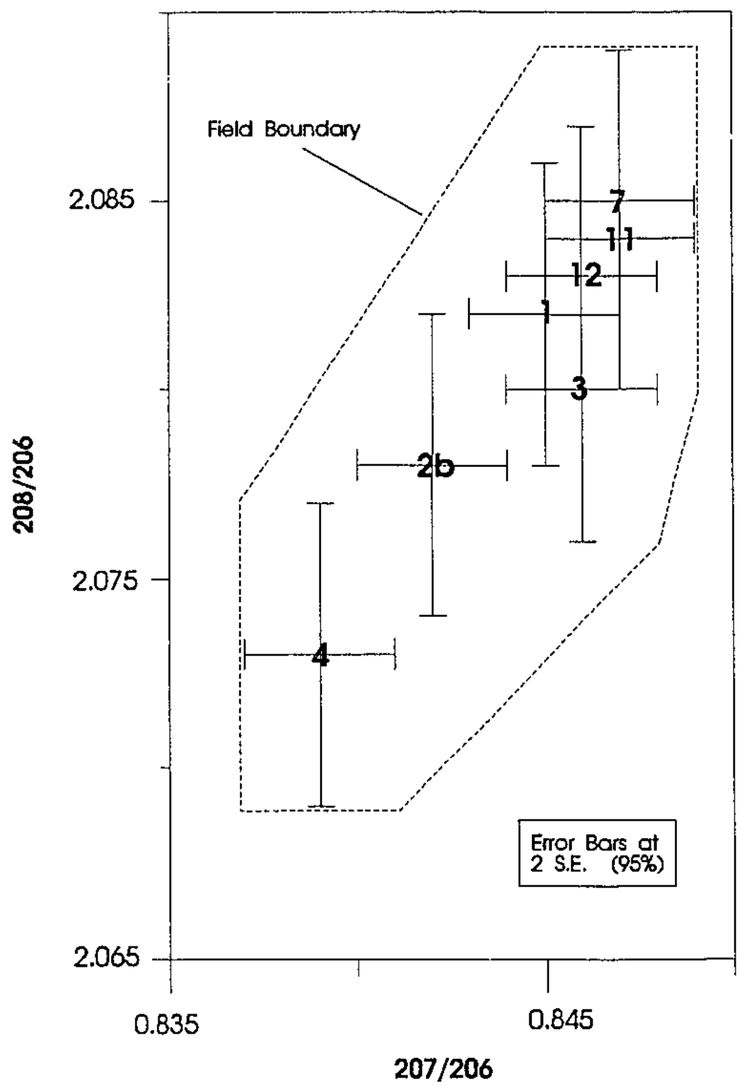

Figure 3: Lead isotope field (208/206 against 207/206) for Seafort human skeletal samples (compact bone only) from individuals with a significant proportion of anthropogenic lead (excludes individual 2a).

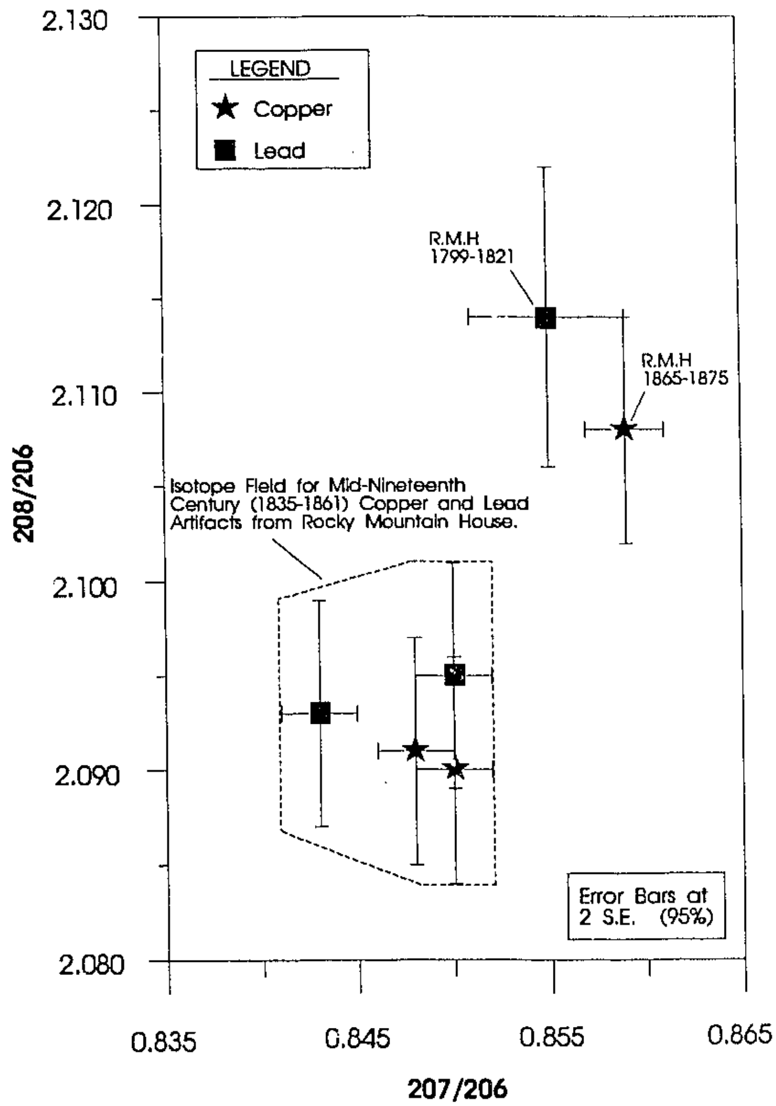

Figure 4: Lead isotope field (208/206 against 207/206) for mid 19th century copper and lead artifacts from Rocky Mountain House (1835-1861) compared to similar artifacts from earlier and later forts.

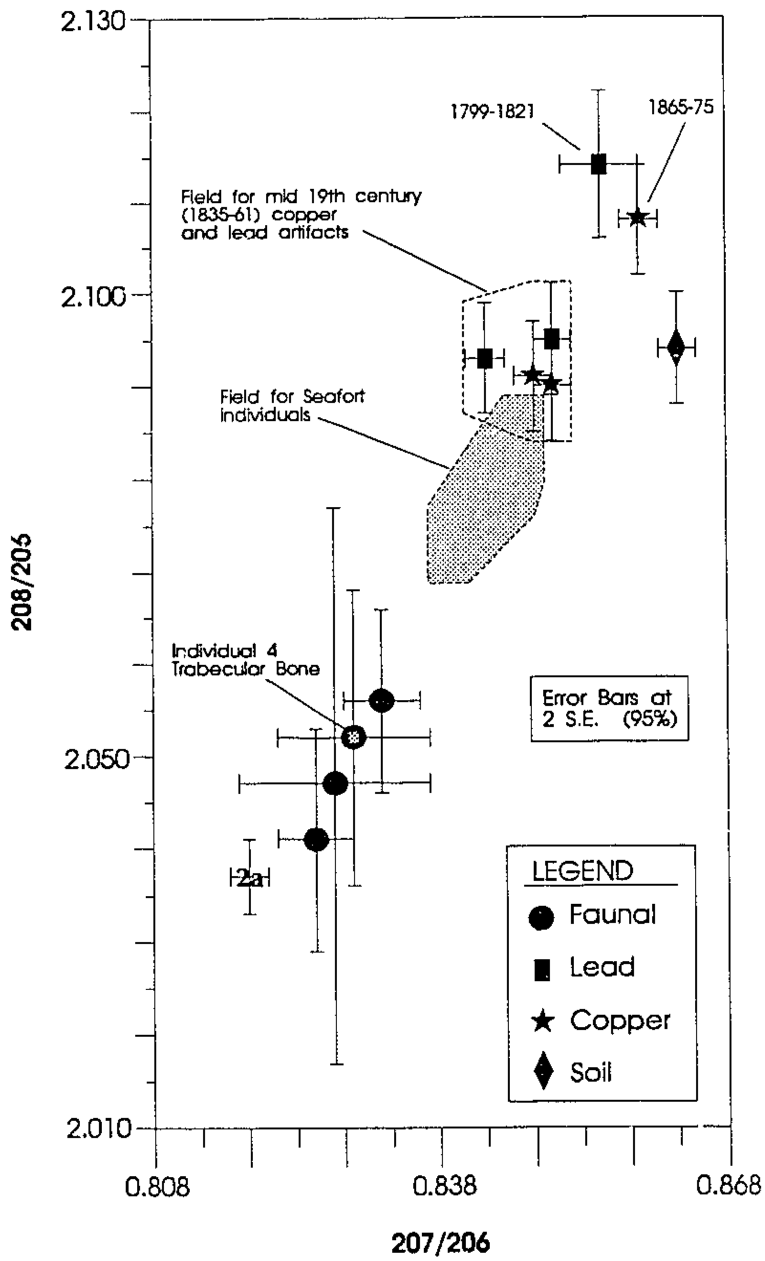

Figure 5: Composition of lead in Seafort individuals, Rocky Mountain House artifacts, and faunal samples (208/206 against 207/206).

is clarified. For individuals 1, 3, 7, 11, 12 the isotopic composition is essentially the same within error (Fig. 3). The isotopic composition in individual 4 overlaps with only that of individual 2b, while 2b overlaps slightly with individuals 1, and 3. For all the human samples, except individual 2a, there is no overlap with the faunal samples. However, there is significant overlap with the artifact cluster (Fig. 5); within two sigma (measurement error of 95%) the isotopic values of individuals 1, 3, 7, 11, and 12 overlap with the artifact cluster. The direction of spread is clearly between the mid-century artifacts and the faunal samples. Individual 2a falls within the faunal cluster, as does the trabecular bone sample from individual 4. The lead in the trabecular bone samples from all the other individuals is essentially the same within error as the lead in the individuals' respective compact bone samples.

DISCUSSION

The following discussion begins with an examination of the apparent sources of lead found in the Seafort individuals as indicated by the lead data from the artifact and faunal samples. Subsequently, the cultural affinities of the Seafort individuals are examined in reference to the lead sources and in conjunction with the historical information outlined above.

Lead Sources in the Fur Trade as Found at Rocky Mountain House

From the outset, two general sources of lead -- natural and anthropogenic -- were identified above as potentially contributing lead to the Seafort individuals. The isotope ratio values of the samples representing these two general sources are significantly different allowing discrete isotope fields to be defined for the faunal remains and for the lead and copper artifacts from the 1835-1861 fort at Rocky Mountain House (Fig 5). That these two source fields actually represent the two primary sources of lead for the Seafort individuals is suggested by the isotope ratio values determined for the human skeletal samples; the lead in the human skeletal samples overlaps with or falls between the two source fields. It is recognized that these two general sources do not represent all the sources that contributed lead to the individuals. Other unidentified specific sources likely contributed lead to these individuals over their lives. However, the consistency of the pattern, with the human skeletal samples falling between the two source fields suggests that these were the primary sources for the Seafort individuals. Furthermore, both the faunal and artifact lead isotope fields were defined using specimens representing sources of lead that were actually available at Rocky Mountain House between 1835-1861. As the fields for these sources are based on few samples, they must be taken as approximations of the "true" isotope fields defining anthropogenic and natural sources of lead during the mid-19th century at Rocky Mountain House.

The four faunal specimens analyzed represent two of the primary species of animals upon which fur traders subsisted -- bison and elk (Smyth 1978). Bison in particular had a wide range, roaming over virtually the entire northwestern plains in the summer and migrating to the parkland in the winter (Moodie and Ray 1976).

They would have been taking in trace amounts of lead through their diet from over this entire region. This natural, preindustrial habitat was almost certainly variable in lead composition. As such, the lead in bison bone must be considered to be a mixed composition reflecting the lead composition of the northwestern plains as a whole. Based on this inference, it can be hypothesized, that given a large enough sample size, the lead in 19th century bison bones would define an isotope field characterizing the natural lead available from animal meat from the northwestern plains. The three bison bone specimens analyzed here, while a very small sample, at minimum fall into this isotope field and define a portion of it. Analyzing additional specimens would more confidently define the field, and probably expand its boundaries. However, an approximation of its definition is gained by the specimens analyzed here. As bison meat was a fur trade staple food, and given the above considerations, the faunal samples analyzed are considered to define an isotope field approximating the composition of naturally available lead to Rupert's Land fur traders and Plains Indians.

The copper and lead samples from the 1835-1861 fort do not represent the full range of specific anthropogenic lead sources to fur trade people of Rocky Mountain House and the fur trade. However, as in the case of the faunal specimens, it is proposed that the isotope field these few artifacts define, can be considered an approximation of the composition of lead in all significant anthropogenic sources available to people of Rupert's Land fur trade society in the mid-19th century. In the mid-19th century, until Canadian confederation, virtually all European goods entering Rupert's Land came via the Hudson's Bay Company. Moreover, those goods representing potential lead sources such as copper kettles and lead ammunition were supplied by a limited number of British companies (Lafleche 1979), and most of the specific items were manufactured in Britain from copper and lead smelted in Wales (see below). It can be proposed that the most significant anthropogenic sources of lead to 19th century Rupert's Land fur traders were British in origin, and the isotope field defining such "19th Century British Lead" would likely be relatively homogenous and finite.

Up until the last quarter of the 19th century, Britain smelted and supplied most of the world's copper and lead (Aitchison 1960:521; Dennis 1963:127). Non-ferrous metal industries in Canada and the United States began to be developed in the 19th century (Wayman 1989; Wilson 1913;). However, until quite late in the 1800's most ore and partially smelted ores (mattes) from North America were exported, particularly to Britain (Dutrizac and Sunstrum 1989; Kossatz and Mackey 1989). The Swansea Valley of South Wales in the 1800's, has been called the "metallurgical centre of the world" (Mackey 1989). At this time, ores or metal mattes were being imported from around the world including South America, North America, and Australia (Dennis 1963:138; Mackey 1989). Ores and mattes with different assays (different percentages of the metal being extracted) would be mixed during initial smelting procedures to provide a uniform assay (Dennis 1963:130). As such, it would be impossible to determine the specific ore body or source of the copper in a copper kettle, for example, using lead isotope analysis because the isotopic signature of the trace lead in such copper is a mixed signature and does not represent ore from any one deposit. However, this mixing of ores during smelting of lead and copper would result in homogenization. The isotopic composition of the lead in finished products would tend to be less variable than the isotopic composition of the lead in all the various ores. As a consequence, a relatively discrete isotope field should be able to be defined for smelted copper and lead represented by manufactured products coming out of England. It is pointed out that the isotope field for the mid-19th century artifacts defined here based on smelted lead and copper (Fig. 6) is quite large compared to fields defined for specific ore deposits. Compare the isotope fields for ore deposits illustrated in Gale (1989) and Cumming et al. (1990) with the isotope field defined in Figure 6 for finished copper and lead products. It would be expected that fields defining specific ore bodies would be narrower than fields defining mixed ores and manufactured objects. However, the field representing mixed ores, would be narrower than a hypothetical field drawn around all the individual ores which contributed to the mixed field.

Although requiring further evidence, this scenario for a generalized lead isotope field categorizing, at least, mid-19th century British anthropogenic lead sources in the fur trade, is supported by the analysis of artifacts from Rocky Mountain House. Both lead and copper artifacts from the 1835-1861 fort at Rocky Mountain House are of very similar isotopic compositions, yet the metals themselves were likely smelted by different smelters, and the finished products manufactured by different producers. Moreover, lead solder from cans from the Franklin expedition of 1845 (Kowal et al. 1991) is of virtually the same isotopic composition as the Hudson's Bay Company goods from the 1835-1861 Rocky Mountain House (Fig. 6). While chance is a possibility for this congruence, a commonality in some stage of smelting and/or manufacture presents itself as a likely explanation.

An additional possibility worth pointing out, although, clearly requiring further testing and a much larger data base, is that over time the generalized isotope field proposed for British manufactured lead items and items containing lead appears to change. This has potentially valuable implications for using lead isotope analysis of historic lead and copper artifacts (trade goods) from Britain as a dating tool. Note that both lead and copper artifacts from earlier and later forts at Rocky Mountain House are significantly different than those from the mid-century fort. As well, lead solder in canned goods from Britain in 1880 (Kowal et al. 1991) is significantly different from the 1835-1861 Rocky Mountain House artifacts (Fig. 6). This pattern, and the basis for use of lead isotope analysis as a temporal indicator could be explained by changing relative volumes of ores imported to Britain from different places over the 19th century. With colonial expansion, and increasing industrialization of the countries supplying ores to Britain, over time volumes of ores imported from specific places would change, stop altogether, or new ones be exploited. As such, the generalized isotope field representing mixed ores and finished products, would be expected to shift and change also. Testing of such an hypothesized temporal trend, in terms of the fur trade, would require a comparative data base to be constructed using well dated copper and lead artifacts used by the Hudson's Bay Company in the 18th and 19th centuries.

In regard to lead exposure experienced by the Seafort individuals during their lives, the patterns apparent in the plots (Figs. 2-5) of the isotope values for the lead in the skeletal

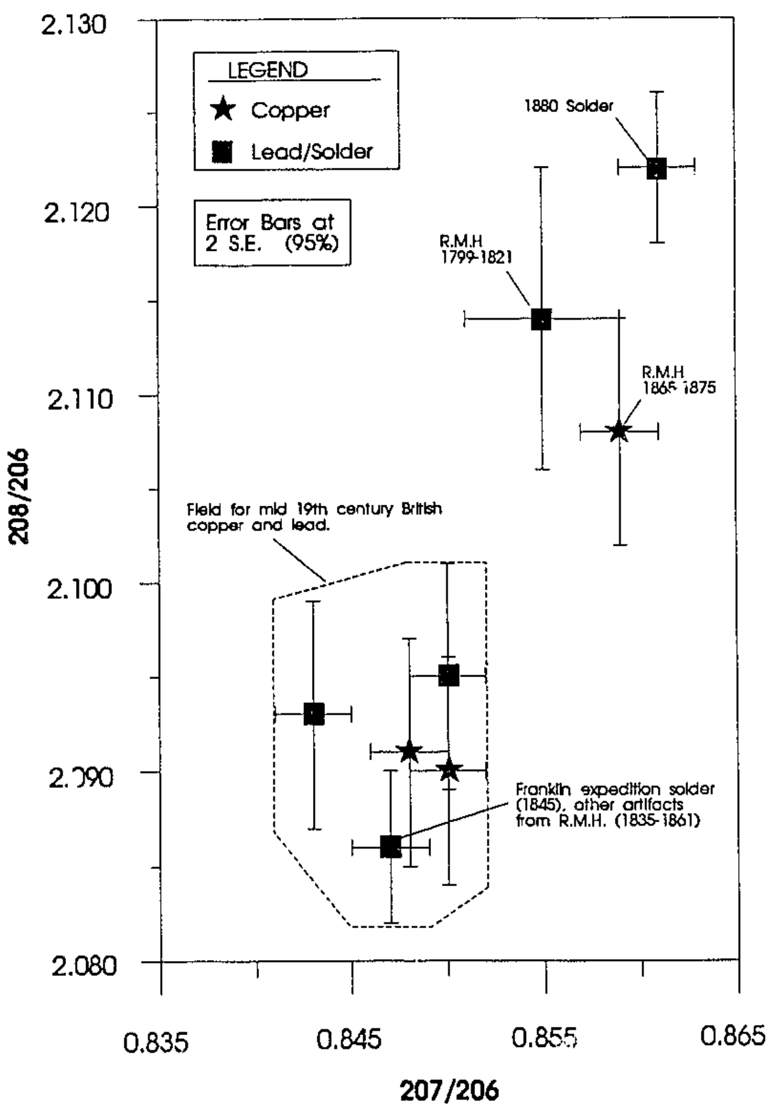

Figure 6: Lead isotope composition (208/206 against 207/206) of nineteenth century copper and lead artifacts.

remains, faunal samples, and artifacts suggest that both natural sources and anthropogenic sources contributed to the skeletal lead observed in the Seafort individuals. The isotopic composition of the lead in individuals 1, 3, 7, 11, and 12 overlaps at two sigma with the isotope field defined for the artifacts from the mid-century fort (Figs. 5 & 7). This pattern supports the proposition that the primary source of lead in these individuals was anthropogenic and likely absorbed during their association with the fur trade. Moreover, it is only the artifacts from the 1835-1861 fort that have lead of similar composition as that in the human skeletal remains. This supports the conclusions drawn through historical and archaeological interpretation that the Seafort cemetery was the burying ground for the 1835-1861 fort. In the case of individual 2a, natural lead sources appear to have been the most significant, as this individual falls directly within the isotope field defined for the faunal samples. Little or no contact with anthropogenic sources of the fur trade is apparent for this individual.

As for individuals 2b and 4, while the composition of the lead in these individuals does not overlap with that of the anthropogenic sources or the natural sources, it does overlap with the composition of the lead in the other Seafort individuals (Figs. 3 and 7). This suggests that anthropogenic sources contributed to the lead in these individuals, but was not the only source. The isotope ratio values for individuals 2b and 4, between the two primary lead sources, can be viewed as illustrating the relative degree of mixing of the two sources for these individuals; the location of any given individual along the line between these two primary sources approximates the proportional total contribution of lead from each of the sources. For example, since individual 4 falls approximately half-way between the two sources, it is suggested that over this individual's life approximately half of the lead in the skeleton at death was contributed from natural sources while the other half was contributed by anthropogenic sources. In contrast, natural sources apparently contributed little or no lead to individual 7, while for individual 2a, the situation is the opposite. It is recognized that given uncertainties in the boundaries of the source fields identified, and the possibility of other unknown sources having contributed lead to the Seafort individuals, the proposed relative proportion of lead contributed by these sources is merely an approximation at best.

While the trabecular bone samples for individuals 1, 3, 11, and 12 are all the same as these individuals' respective compact bone samples, the trabecular and compact bone samples from individual 4 are significantly different. Moreover, the composition of the lead in the trabecular bone sample from individual 4 is the same as that in the faunal samples. This difference is explained by the faster turnover rate for trabecular bone than for compact bone. Lead in trabecular bone has a half-life of approximately 5 years, while lead in compact bone has a half-life of approximately 10-30 years (Nordberg et al. 1991). As well, bone lead consists of a mixed composition. Given these factors, if exposure to a new source begins, or if exposure to a source stops, trabecular bone will reflect the different composition more quickly; the mixing process is faster. Given such a situation of changing sources, it would not be unexpected for compact bone and trabecular bone to have different

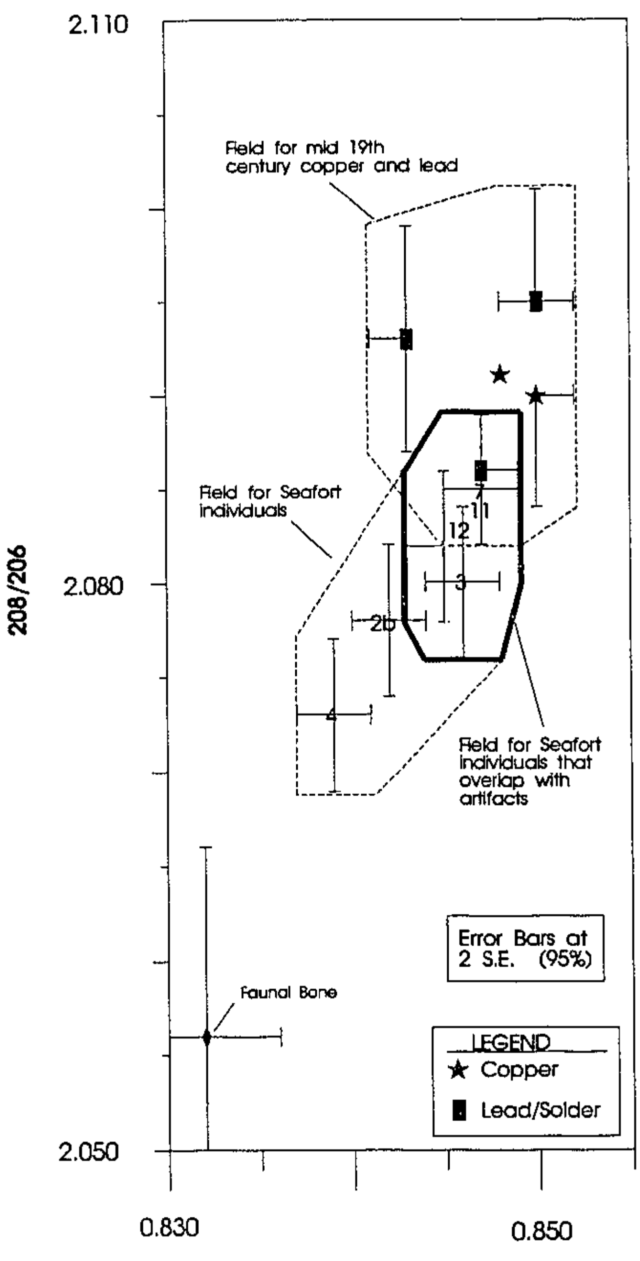

Figure 7: Comparison of lead isotope fields of Seafort skeletal samples and mid 19th century copper and lead artifacts.

isotopic compositions. As a consequence, comparison of the isotopic composition of the two bone types from a single individual provides an indication of the relative stability or consistency of exposure to sources of lead. The trabecular and compact bone lead isotopic values from individual 4 suggest that this individual had more variable exposure to different sources, over time, than the other individuals. Moreover, it can be proposed that since the trabecular bone sample from individual 4 has the same lead composition as the faunal samples, perhaps this individual had little exposure to anthropogenic sources over the later part of his life. However, this proposition must remain speculative. The difference in the isotopic composition of the lead in the two samples from individual 2a, may reflect such processes as well. Although it remains unknown, perhaps one of the two samples contained a relatively greater fraction of trabecular bone than the other.

Cultural Affinities of the Seafort Individuals

The lead isotope data from the Seafort skeletons suggests that these individuals are the remains of people belonging to at least two, and possibly three cultural groups. The human skeletal samples can be grouped into two discrete clusters, the first represented clearly by Individual 2a and obliquely by individual 2b, and the second represented by all the others. Individual 4 can be separated from this second group as the composition of the lead within this individual does not overlap with that in the artifacts from the 1835-1861 Rocky Mountain House. It is expected that the neonates (currently not analyzed) could fall into either of these two groups. As there is no placental barrier to lead (Goyer 1990), neonatal skeletal lead composition would be the same as the mother's. As well, men and women could potentially have experienced differential exposure to lead as a consequence of different activities and occupations. However, the gender profile of the Seafort sample is not suitable for examining such possibilities. Table 12 summarizes the proposed cultural affiliations for the Seafort individuals suggested by the lead isotope data.

Table 12: Suggested Cultural Affiliations of the Seafort Individuals

Individual	Affiliation/Social Position
1	Hudson's Bay Company Child
2a	Plains Indian
2b	Plains Indian?
3	Hudson's Bay Company Child (Isabelle Rowan?)
4	Mixed-Blood/Indian? Hudson's Bay Company -- part-time labourer or hunter?
7	European Hudson's Bay Company Labourer
11	Mixed-Blood Hudson's Bay Company Labourer
12	Mixed-Blood Hudson's Bay Company Labourer

Individual 2a appears to have been a Plains Indian. That this individual was apparently exposed primarily to natural sources of lead supports this determination, which in turn, supports the hypothesized group affiliation for this individual based on historical and archaeological information. Indians (or people living in a similar manner as Indians) would be the only cultural group of the region that potentially could not have been exposed to anthropogenic sources of lead. Natural sources of lead from country food such as bison would have been the primary sources for Plains Indians. While Plains Indians would likely have been exposed to anthropogenic lead from articles such as kettles and ammunition obtained through trade, their strong traditional culture and subsistence, and the relatively great socio-cultural autonomy (from Europeans) that the Plains Indian groups maintained until very late in the 19th century (Dempsey 1976, 1988), diminishes the potential magnitude of lead exposure from European goods. That individual 2a was quite old at death (approx. 50) and apparently exposed to little or no anthropogenic lead suggests the possibility that he had limited lifetime contact with Europeans or European goods containing lead. The establishment of fur trade posts on the North Saskatchewan River occurred very late in the 18th century -- the approximate time this individual would have been born. Additionally, the level of lead in individual 2a was low (Chapter 4 this volume:102), indicating a low level of lifetime exposure to lead. If this individual were exposed to anthropogenic lead sources over his lifetime it was of a sufficiently low magnitude as to have had little total effect in terms of the amount of lead accumulated in the skeleton and to have had little effect in shifting the isotopic composition of the lead away from the natural signature and towards the anthropogenic signature.

Individual 2b has been assigned cultural affiliation with Plains Indians as well. While the isotopic composition of the lead in this individual does not directly support this assignment, the context of the burial (buried with 2a) allows this assignment to be considered seriously. Moreover, the level of lead in this individual, approximately 192 ppm (ash wt.), two to five times greater than the other individuals, indicates a body burden of lead which was probably toxic and a mode of exposure that was not typical (Chapter 4 this volume:p). As well, given the individual's young age at death (c. 18) it is likely that individual 2b received a relatively massive dose of lead over a relatively short period of time. To bring about such a situation, the only available lead that could provide an appropriate quantity would be anthropogenic lead. The necessary magnitude of such a dose would result in the skeletal lead composition extant prior to the dose being effectively masked. The isotope data supports this scenario in that the composition of the lead in this individual just touches the lead isotope field proposed for mid 19th century British lead sources at two sigma (Fig. 7). That it does not overlap to a greater degree, suggests the residual effect of pre-existing lead in the skeleton prior to the hypothesized large dose of anthropogenic lead.

The adult individuals 7, 11, and 12, and the sub-adults 1 and 3 all have virtually the same skeletal lead composition as the anthropogenic sources, although there is some shift towards the faunal lead (Fig. 7). Based on this pattern, these individuals are all assigned a cultural affiliation with Hudson's Bay Company society. That is, the adult males were likely full-time labourers in the employ of the Hudson's Bay Company and fully ensconced in life and society of fur trade posts. The sub-adults, were probably the children of people living and working in the fur trade, and had been born and raised in that social context. This is consistent with the proposed personal identification of individual 3 as Isabelle Rowan, who, being the daughter of John Rowan Jr., would probably have been living in fur trade posts, in close association with the accompanying lead sources. In general, the patterns in the lead isotope data support the hypothesized cultural affiliations for these individuals as determined through historical, archaeological, and osteological interpretations.

Individual 4 presents an interesting case. Although archaeological and historical context suggest the same Hudson's Bay Company affiliation for this individual as for the other individuals, the skeletal lead composition of individual 4 does not overlap with the others', indicating the possibility of a different cultural affiliation. It was suggested above that approximately 50% of the lead in the skeleton of this individual came from anthropogenic sources while 50% came from natural sources. That the composition of the lead in the trabecular bone sample from individual 4 is the same as that of the faunal bones, suggests a proportionately high contribution of lead from natural sources as well. This suggestion is, as stated above, only a crude approximation. However, accepting it tentatively allows speculating about the cultural affinity of this individual. One explanation that would account for the value of the skeletal lead isotope ratio observed for individual 4 would be that he was a temporary or part-time Hudson's Bay Company Employee. An Indian or Mixed-Blood hunter or labourer, working part time for the Hudson's Bay Company, not living regularly at fur trade posts, and living primarily off bison and other natural foods could conceivably have a skeletal lead composition as observed for individual 4. However, while this scenario is possible, it must remain speculative.

CONCLUSION

The results of the present investigation using lead isotope analysis of human skeletal remains to address questions of group affinity indicate that it has great potential for such a task. The lead isotope data gathered from the Seafort individuals and contemporaneous specimens representing potential sources of lead to these individuals define relatively clear patterns interpreted to represent differing degrees of exposure to anthropogenic and natural lead sources. In the case presented here, it is assumed that Plains Indians would not generally have been exposed to significant amounts of anthropogenic lead, while people living and working at fur trade posts would be. The lead isotope data from the Seafort skeletons allows the individuals to be grouped into two such groups -- those individuals with skeletal lead of the same composition as faunal remains (individual 2a) and those individuals with skeletal lead of the same composition as the lead and copper artifacts (individuals 1, 3, 7, 11, 12). Individuals 2b, and 4 do not fall clearly into either of these two groups. However, the composition of their skeletal lead indicates that the same two general sources of lead contributed to these two individuals. Interpreting the skeletal lead in these two individuals points out the value of having other information than skeletal lead composition such as archaeological and historical context to assist in interpretation.

The value of contextual information concerning the skeletal population under investigation cannot be dismissed. However, analysis of skeletal lead composition in and of itself is capable of discriminating individuals exposed to different sources of lead over their lives. This capability is independent of the level of knowledge (on the part of the researcher) of the historical/archaeological context of the skeletal remains being examined. Lead isotope data will allow groups within a population to be defined, if in fact more than one group existed and were exposed to different sources of lead than each other. Without archaeological/historical context, however, explaining apparent groupings in a skeletal population based on the isotopic composition of skeletal lead would be difficult. In such a case, the lead isotope data becomes merely descriptive.

Additionally, the capability of lead isotope analysis to discriminate groups is independent of whether or not groups actually possessed lead technology. In a situation where it is suspected that two different prehistoric cultural groups are represented in a skeletal population, if the respective cultures inhabited different geographic regions, the isotopic composition of the naturally available lead in their respective environments may be different. As such the groups should be distinguishable. Such geographical patterning in skeletal lead composition may exist in our current world based on variable anthropogenic lead sources. If so, given a well defined comparative data base, skeletal lead data may be useful for addressing questions of place of residence in forensic investigation of unidentified human remains. Moreover, and again given an appropriate comparative data base, assignment of unidentified historic and prehistoric human remains to a cultural group, time or place may be possible. Clearly, further research is required for these potentialities to be realized.

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CHAPTER 4

LEAD LEVELS IN THE 19TH CENTURY FUR TRADE SEAFORT BURIALS FROM ROCKY MOUNTAIN HOUSE, ALBERTA

<u>LEAD LEVELS IN THE 19TH CENTURY FUR TRADE SEAFORT BURIALS FROM ROCKY MOUNTAIN HOUSE, ALBERTA</u>

<u>INTRODUCTION</u>

The analysis of lead levels in archaeological human skeletal remains has been demonstrated to be a fruitful area of research (e.g. Aufderheide 1991; Aufderheide <u>et al.</u> 1981, 1985, 1988; Beattie 1985; Corruccini <u>et al.</u> 1987; Handler <u>et al.</u> 1986; Kosugi <u>et al.</u> 1988; Kowal <u>et al.</u> 1989, 1990, 1991; Lalich and Aufderheide 1991; Reinhard and Ghazi 1992; Rogers and Waldron 1985; Shapiro <u>et al.</u> 1980, 1975; Whittaker and Stack 1984). Most such research is based on the assumption that skeletal lead reflects an individual's lifetime exposure to it (Aufderheide <u>et al.</u> 1988:931-932, 1981). Interpretation and explanation of observed patterning and variations of bone lead levels in a skeletal group is usually accomplished in reference to archaeological and historical knowledge of the group in question. Aufderheide <u>et al.</u> (1988) summarize applications of skeletal lead analysis including assessment of the extent of lead technology in a cultural group, separation of two socioeconomic subgroups within a population, identification of unique social or occupational roles of individuals within a population, prediction of health effects, separation of mixed skeletal remains, and identification of human remains as modern or ancient.

This paper reports on the detection and interpretation of lead levels in the remains of eight unidentified skeletons from the Seafort Burial Site, a cemetery associated with 19th century fur trade posts at Rocky Mountain House in what is now Alberta (Dempsey 1973; Skinner 1972; Smyth 1976; Stenson 1985). These individuals were members of the various cultural groups of the 19th century fur trade in Rupert's Land. In detecting and interpreting the levels of lead in these skeletons, a number of questions concerning the lead environment of 19th century fur trade posts were addressed. The most general of these was: What is the typical skeletal burden of lead in the inhabitants of pre-confederation Western Canada during the 19th century fur-trade? Through comparison of the lead levels observed for the people of Rocky Mountain House with similar data derived from other populations, insight into the trends and history of lead contamination is gained. On a smaller scale, what are the apparent trends in lead exposure experienced by the Rocky Mountain House inhabitants, and how do these relate to cultural or social factors of the fur trade? While the skeletal lead data reflects the lifetime exposure of the Seafort individuals to lead, it also reflects to some degree the lead environment of fur trade society.

The degree to which it does, is dependent upon the length of time each individual was living in fur trade society. As such, the nature and degree of exposure to lead that individuals living in fur trade society experienced is examined using the skeletal lead data derived from the Seafort individuals.

The potential health effects caused by lead exposure and the degree to which lead may have been detrimental to life in the fur trade is also examined using lead data gathered from the Seafort remains. Lead poisoning was relatively common in 19th century Europe, notwithstanding the contemporary knowledge of its toxicity, primarily as a consequence of relatively poor hygienic standards in terms of lead and its uses (Wedeen 1984). While European society and culture was distant from colonial Hudson's Bay Company society, the use of lead and products containing lead occurred in both. As such, adverse health effects from lead exposure for fur traders, their families, Indians and other people influenced by fur trade society is a possibility.

ROCKY MOUNTAIN HOUSE -- HISTORICAL BACKGROUND

Before the lead analysis is presented, it is appropriate to outline briefly the cultural/historical context of the Seafort burials. Dempsey (1973), Smyth (1976), and Stenson (1985) provide histories of the fur trade at Rocky Mountain House. Five forts were sporadically operated between 1799-1875. The first fort was established in 1799 by the Northwest Company. The original purpose of the post was to attract the trade of the Kootenay Indians. However, this never came to fruition, and the post served the plains trade for most of its existence (Stenson 1985). The Hudson's Bay Company, upon learning of the Northwest Company's plans, built their own post in 1799, Acton House. These two forts operated side-by-side from 1799 until 1821, at which time the companies amalgamated. The Northwest Company's Rocky Mountain House was abandoned and the operation taken to Acton House, which lost its original name and became Rocky Mountain House (Stenson 1985). This fort remained open until 1832. In 1835, the third fort was constructed, staying open as a winter post until 1861. The last fort was finished, following occupation of a temporary post, in 1868-69 and finally abandoned in 1875. Archaeological investigations at Rocky Mountain House between 1963 and 1979 have resulted in identification and excavation of four of the posts (Fig.1) (Noble 1973; Steer 1975, 1976; Steer et al. 1979; Steer and Rogers 1976a, 1976b, 1978; Vaucher 1968). These sites are now protected within Rocky Mountain House National Historic Park established in 1979.

The Seafort Burial Site (FcPr-7/17R, previously FcPr-100) was found in 1969 when disturbed by construction activities of Seafort Petroleum Limited. It is located approximately 750 metres north of the 1835-1861 fort (Fig. 1). Before it was disturbed in 1969, the cemetery had been forgotten, and its surface ploughed and farmed (Skinner 1971; Steer and Lutick 1980). Skinner (1971, 1972) located and excavated 12 graves (nos. 1-12), which contained the remains of 14 unidentified individuals (six neonates, three subadults, and five adults). In 1979, during further construction activities, 12 additional burials (nos. 13-24) were exposed (Steer and Lutick 1979). This second group was quickly reinterred following limited analysis and interpretation.

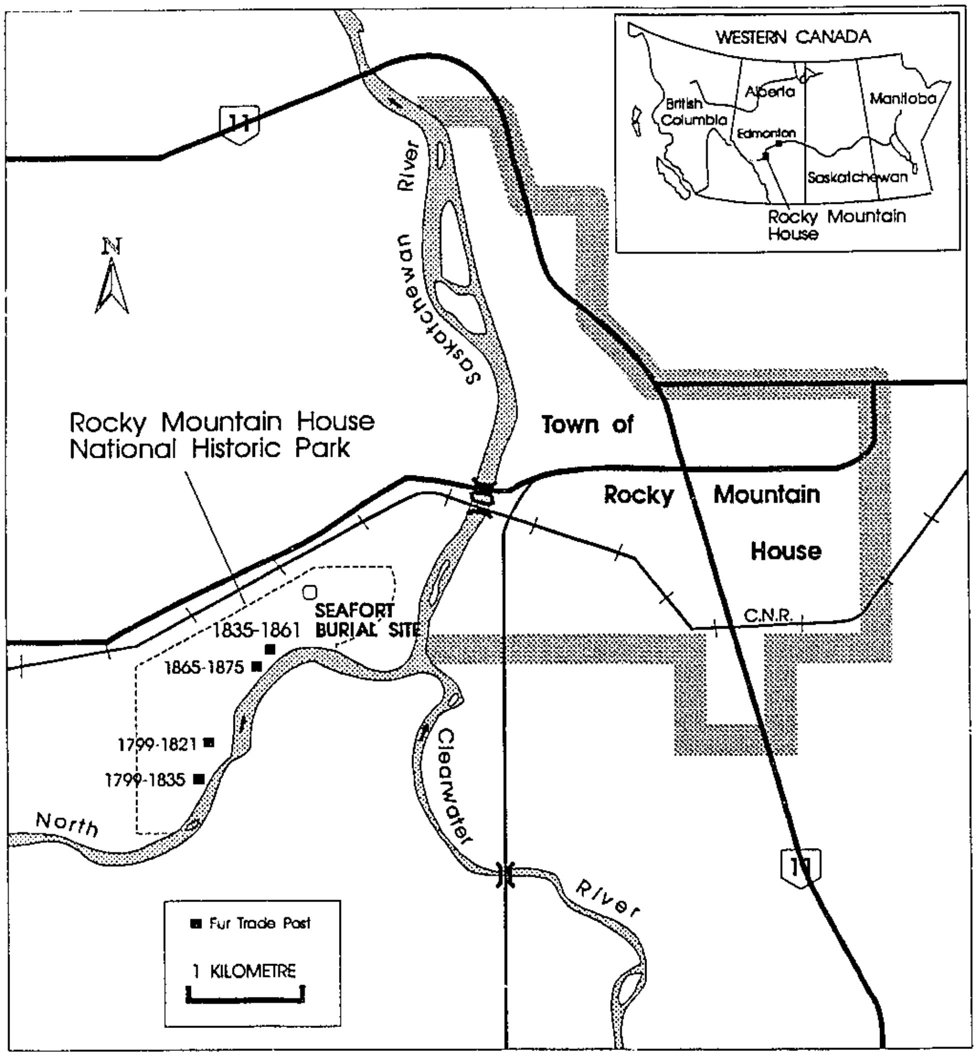

Figure 1: Location of the Seafort cemetery and Rocky Mountain House forts.

The location of the cemetery, its context, and the nature of the artifactual remains interred with the burials, all clearly indicated that it was a cemetery used during the fur trade at Rocky Mountain House in the 19th century. Based on artifactual and historical, and lead isotopic evidence, burials 1-12 have been associated with the Hudson's Bay Company 1835-61 post (Skinner 1971, 1972; Chapter 3 this volume). Most of the individuals of burials 13-24 have been associated with the mid-century fort as well, while some are possibly associated with earlier forts (Steer and Lutick 1979:63). Few journals or historical documents originating from the posts at Rocky Mountain House exist (Smyth 1978:2). As such, investigation into the identities of the Seafort individuals has been conducted through other means such as general history, archaeology and osteology. Chapter 3 (this volume) presents a study on the cultural identities of the Seafort Burials using lead isotope analysis.

Fur trade society in the mid 19th century centred around the formal hierarchy of the Hudson's Bay Company, although in practice it was somewhat more flexible than the formal structure may indicate (Brown 1980; Hamilton 1985; Van Kirk 1980). The structure was pyramidal with the governor and London committee at the top, the chief factors below this, followed by other officers, clerks, tradesmen, skilled labourers, and common labourers (Hamilton 1985:223). The officers were mostly European and/or Euro-Canadian men of English or Scottish descent. The labourers could be European (often Orkneymen or Lowland Scots), French Canadian, Mixed-Blood, or Indian men (Brown 1980:21-50). In this paper, the term Mixed-Blood refers to people of mixed biological ancestry. Other terms for this have included Country-Born, Half-Breed, and Métis; Mixed-Blood is used here as it is familiar, does not connote racial bias, or imply any specific ethnic affiliation (as does Métis). Young men, from as early an age as fourteen, would typically sign five year contracts of employment as labourers with the Hudson's Bay Company (Brown 1980:25). At the expiry of their term, the men had the option of renewing their contract. This renewal process could go on for essentially as long as the person wished. In 19th century Rupert's Land it was not uncommon for men to serve for the long term in the company's employ. Hamilton (1985:126) argues for the security that this gave country skilled men of whatever descent, during a time when settlements in Rupert's Land were still in their infancy.

Hudson's Bay Company men were not the only people in fur trade society. The wives and families of the men, while not part of the formal structure of the Hudson's Bay Company could swell the population of a post considerably, and often travelled with their husbands in the yearly trading cycle (Brown 1980; Van Kirk 1980). Gladstone (1985:33) stated that in 1851 "...there was plenty of company at Edmonton, 80 men lived at the fort and most of these were married and had families." In the mid 19th century, most wives were Mixed-Blood women, the daughters of earlier unions between fur traders and Indian women. Indians that traded at Rocky Mountain House were primarily, though not exclusively, from the plains groups of the northwestern plains, such as the Peigan, Sarsi, Blackfoot, and Blood Indians of the Blackfoot Alliance (see Dempsey 1976:27, 1988; Stenson 1985:53-64). In addition, Indians, often Cree, would live at or near the posts in the company's employ as hunters (Brown 1980; Dickason 1992:138; Ray 1974:85; Van Kirk 1980:15-17). In the later 19th century some Indians began to hire on as part-time labourers (Dickason 1992:298).

THE SAMPLE

The skeletal remains examined in this study are eight of the twelve individuals (five adults and three subadults) recovered by Skinner (1971, 1972). Five neonatal skeletons were not included, although bone samples were removed from these for later analysis. It was chosen to exclude the neonates in the first round of analyses, as neonatal remains would more likely be affected by diagenetic processes as such bones contain a relatively large proportion of trabecular bone (see below). Furthermore, the lead in the neonatal skeletons would be better interpreted secondarily with reference to lead data derived from the adult section of the population. Table 1 summarizes the osteological and archaeological information on the eight individuals analyzed. These remains are conserved at the Department of Anthropology, University of Alberta.

TABLE 1: Summary of Seafort Burials Analyzed (Data from: Skinner 1971; Lai and Lovell 1992; Seafort Skeletons Data File, Department of Anthropology, University of Alberta 1993)

BURIAL	CONDITION	SEX	AGE*	ANCESTRY	ARTIFACTS/COMMENTS
1	Good preservation, some bones broken.	F?	12-16 (14)	Mixed?/ Indian?	Split log spruce coffin, beads possibly from moccasins and beaded garment.
2a	Cranium only. Good bone preservation.	M?	40-65 (50)	Indian?	Secondary burial of two crania, no mandibles. Empty fly pupae casings. Square spruce coffin nailed together, crania apparently wrapped in a beaded cloth.
2b	Cranium only. Good bone preservation.	F?	15-20 (18)	Mixed?/ Indian?	
3	Complete skeleton, good preservation.	F?	4-6 (5)	Mixed?/ Indian?	Split log spruce coffin, beads probably from a necklace.
4	Good, damage to lower limbs. Good preservation	M	30-40 (35)	Mixed?	Spruce coffin nailed together, crucifix pendant, shell shirt buttons, long hair.
7	Complete. Good preservation.	M	22-25 (23)	Caucasian?	Spruce coffin nailed together, base of grave marker and two posts, shredded bark pillow, wool blanket, bone and shell trouser and shirt buttons, silk scarf.
11	Essentially complete Good preservation.	M	40-60 (45)	Mixed?	Spruce coffin nailed together, shredded bark pillow, wool blanket frag., knit wool material, hair.
12	Complete. Good preservation.	M	30-40 (35)	Mixed?	Wooden coffin.

* Number in brackets indicates a single, median age estimate.

A number of osteological studies have been conducted on the Seafort remains, with Skinner (1971) providing the first comprehensive assessment. Prompted by new osteological techniques developed in the intervening years, Lai (1989; see also Halgrimsson n.d.; Lai n.d.) conducted further analyses. Lai and Lovell (1992) examined the remains of Burials 4, 11, and 12 in terms of occupational stress markers on the skeleton. Recently, the skeletons have undergone detailed osteological analysis (Lovell pers. comm. 1993) in response to a call for the compilation of baseline data on human skeletal collections as set forth by the Palaeopathology Association (Rose et al. 1991). It is from this most recent assessment that the estimates of age and sex used in this study are taken. Unfortunately, the information collected on the second group of burials discovered in 1979, before they were reinterred, was limited. The analysis consisted of a reporting of observed burial context, and estimations of age, sex, and ancestry. However, neither the osteological data nor the collection and interpretive methods were reported.

Chapter 3 (this volume) presents the results of a study done in conjunction with the present one using lead isotope analysis of the skeletal remains to investigate the social and cultural affinities of the Seafort individuals. At least two, and possibly three socio-cultural groups were found to be represented by the Seafort burials (Chapter 3 this volume). The first group consists of those individuals who appear to have been members of Hudson's Bay Company society; people who lived and worked full time in association with the fur trade. Burials 1, 3, 7, 11, and 12 belong to this group. Of these, individuals 1 and 3 are considered to have been fur trade children (as are the neonatal remains not analyzed) while individual 7 appears to have been a European, who was likely relatively new to fur trade service. Individuals 11 and 12 were likely long term, Mixed-Blood Hudson's Bay company employees. The second group is represented by individuals 2a and 2b who appear to have been Indians with an unknown degree of connection with Rocky Mountain House and the fur trade. The burial context of burial 2 suggests this assignment, as does the isotopic composition of the lead in individual 2a (Chapter 3:66-67, this volume). Individual 4 represents the possible third cultural group. Archaeological and osteological evidence from previous studies (e.g. Lai and Lovell 1992) suggested that this individual was a Mixed-Blood labourer like Individuals 11, and 12. However, the lead isotope data indicated the possibility that this individual did not have as close an association with fur trade society as the other individuals (Chapter 3 this volume). While the data is inconclusive, it was suggested that this individual may have been an Indian or Mixed-Blood hunter, part time labourer, or new to fur trade service. For the purposes of this study, however, individual 4 is included in the group representing Hudson's Bay Company Society.

From the skeletal remains of these individuals, 12 bone samples were analyzed. The samples consisted of 25-150 milligrams (dry weight) of compact bone from either the diaphysis shaft of the tibia or the squamous portion of the temporal bone (Table 2).

In addition to the human skeletal samples analyzed for lead levels, four faunal bone samples (mostly bison) were also analyzed (Tables 2 and 3). The faunal bones were recovered during excavations of the fort sites and are currently housed with the

Canadian Parks Service as part of the archaeological collections from Rocky Mountain House. The level of lead in the faunal bones is taken as an indication of the amount of naturally available (as opposed to anthropogenic) lead in the 19th century environment of the northwest plains. These samples consisted of 500-1000 milligrams of compact bone from the diaphysis shafts of various long bones (Table 2). A single soil sample recovered by Skinner (1971) from directly above the coffin of Burial 11 was also analyzed to determine the amount of readily soluble and exchangeable lead in the soil of the Seafort Burial Site. This is a necessary procedure in assessment of potential post-mortem diagenetic exchange of lead between bones and soil (see below).

TABLE 2: Bone Samples Collected and Analyzed

Sample	Individual	Sample Site	Dry Weight (gms.)	Ash Weight (gms.)
S1	Burial 1	R. Tibia, diaphysis	0.1143	0.0809
S4	Burial 2b	R. Temporal, squama	0.0254	0.0129
S5	Burial 2a	R. Temporal, squama	0.0570	0.0406
S6	Burial 3	R. Tibia, diaphysis	0.0553	0.0377
S9	Burial 4	R. Tibia, diaphysis	0.1148	0.0808
S15	Burial 7	R. Tibia, diaphysis	0.1509	0.1075
S21	Burial 11	R. Tibia, diaphysis	0.0481	0.0374
S24	Burial 12	R. Tibia, diaphysis	0.1331	0.0937
S27	Burial 7	R. Tibia, diaphysis	0.1284	0.[illegible]921
S28	Burial 4	R. Tibia, diaphysis	0.1399	0.1001
S29	Burial 2a	R. Temporal, squama	0.1416	0.1019
S30	Burial 2b	R. Temporal, squama	0.1174	0.0827
E7	Soil	Silty loam, pH 7.9	300 total	n/a
E9	Elk	L. Radius, diaphysis	0.8326	0.6138
E10	Bison	L. Femur, diaphysis	0.7906	0.5938
E11	Bison	L. Radius, diaphysis	0.5866	0.4213
E12	Bison	L. Humerus, diaphysis	0.9507	0.7510
E13	Bison	R. Tibia, diaphysis	1.0506	0.7756
E14	Bison	L. Tibia, diaphysis	0.7772	0.5918

TABLE 3: Summary of Faunal and Soil Specimens Analyzed

Sample	Cat. No.	Specimen	Context
E7	FcPr 100/11/228	Soil, grey brown silt loam	From "directly above" coffin, burial Number 11
E9	16R4E4	Elk, (Cervus elaphus), left radius, distal 1/3, young adult	From the N.W. Co. 1799-1821 fort site.
E10	15R23G7	Bison (Bison bison), left femur, distal 1/2, immature	From the H.B.C. 1835-1861 fort site, early period, pit feature no. 113
E11	15R23G6	Bison (Bison bison), left radius and ulna, distal 1/4, adult	From the H.B.C. 1835-1861 fort site, early period, pit feature no. 113
E12	15R14V6	Bison (Bison bison), left humerus, distal fragment, adult	From the H.B.C. 1835-61 fort site, late period, cellar, structure 1, feature no. 26
E13	16R4F5-4	Bison (Bison bison), right tibia, proximal 1/2, adult	From the N.W. Co. 1799-1821 fort site.
E14	15R35C3	Bison (Bison bison), left tibia, distal 1/2, adult	From the H.B.C. 1835-61 fort

METHODS

Determination of lead levels was accomplished using Isotope Dilution Mass Spectrometry (IDMS). Steps for collection and preparation of samples prior to measurement of lead on the mass spectrometer include: 1) sample recovery; 2) sample digestion; and 3) extraction and purification of lead. Sample recovery requires removal of an appropriate amount of bone from the skeleton. Table 4 outlines the steps involved in sample recovery. Table 5 outlines sample digestion procedures, and Table 6 outlines lead extraction and purification procedures.

IDMS is considered a definitive method for obtaining precise isotopic ratio measurements from which the quantity of lead in a sample is calculated. This method is often used to certify reference standards (Barnes et al. 1973, 1982; Machlan et al. 1979). For this study, the mass spectrometer measured the lead isotope ratios 206/204, 207/204, and 208/204. To calculate the amount of lead in the sample, it is first necessary to split the digested, solubilized sample into two aliquots. One becomes the isotope ratio (IR) aliquot used to determine the composition of the lead in the sample, while the other becomes the isotope dilution (ID) aliquot used to determine the amount of lead in the sample. The ID aliquot is "spiked" with a known amount of one lead isotope (^{206}Pb in this case), and the resultant isotopic ratios are measured on a mass spectrometer. From the isotopic ratios measured for the ID and IR aliquots, the amount of lead in the ID aliquot is calculated (Barnes et al. 1982:954). Isotopic composition was measured on a VG Micromass 30 mass spectrometer at the University of Alberta, Edmonton. Repeat analyses of analytical standard lead (NBS SRM 981) allowed correction of isotopic ratios for mass fractionation, and gives a minimum analytical error in ratios of approximately 0.1%. This error was added to the individual measurement error determined for each sample.

Sampling and chemical procedures were undertaken in a manner so as to avoid contamination of samples. Tools were thoroughly cleaned with distilled water between extraction of different samples. Following collection and between procedures, the samples were stored in closed, air-tight containers or a sealed desiccator. Chemical procedures were carried out in a "clean lab" with filtered air. Acid reagents were purified by vapour distillation. Vessels were of either platinum, teflon or silica, and were cleaned by boiling in 1:1 nitric acid, and rinsing with deionized distilled water.

Reagent blank lead (average 15 ng), the amount of contaminant lead introduced during chemical procedures, had no effect within error for all samples containing greater than 1 μg of lead. The effect was minimal for samples containing less than 1 μg of lead. Tables 4 and 5 present μg/g values corrected for blank lead by subtracting the amount of lead in reagent blanks from the amount of lead in the sample ID aliquots.

TABLE 4: Bone Sample Recovery Procedures

1) Remove and discard c. 0.5 mm of periosteal surface of sample site using electric Dremel drill with stainless steel burr bit (removes potentially post mortem diagenetically altered surficial bone)
2) Collect sample (bone dust) in vial using hand drill with 1/4" titanium plated steel twist drill, avoid drilling all the way through to endosteal surface if possible
3) Examine sample under microscope and remove any foreign particles or discoloured bone fragments

TABLE 5: Bone Sample Preparation Procedures

1) Dry bone dust at 110 °C for 24 hours in weighed platinum dish
2) Equilibrate to room temperature and weigh
3) Ash sample at 450 °C in muffle furnace for minimum 48 hours or until grey-white
4) Equilibrate to room temperature and weigh
5) Digest sample with 6-8 ml 1:1 HNO_3 in weighed teflon beaker
6) Let stand closed on hot plate at 80 °C for 12 hours
7) Equilibrate to room temperature and weigh
8) Split sample, circa 1/4 of sample (2.5-2 ml) becomes ID aliquot
9) Weigh ID aliquot into teflon beaker
10) Spike ID aliquot with appropriate amount of 206 Pb

TABLE 6: Lead Purification Procedures

1) Evaporate sample aliquot in teflon beaker to 1/2 volume or conc. HNO_3
2) Cool and pour solution into silica centrifuge tube containing two drops of lead free saturated $Ba(NO_3)_2$ solution
3) Agitate with teflon stirring rod to precipitate $(Ba,Pb)(NO_3)_2$
4) Centrifuge and discard supernatant solution
5) Dissolve precipitate in minimum amount of H_2O
6) Repeat steps 2, 3, and 4 for second purification
7) Dissolve dried precipitate in circa 1 ml 1.5N HCl, forms $(PbCl_4)^{-2}$
8) Purify Pb:Chloride in anion exchange column, wash with 4 X 1 ml, 1.5N HCl, strip Pb with 3 X 2 ml H_2O
9) Collect in teflon beaker and add 1 drop lead free H_3PO_4
10) Evaporate solution down to single drop phosphoric acid containing Pb
11) Load drop for mass spectrometry onto refined rhenium filament with lead free silica gel

The soil sample was prepared in order to determine the amount of readily exchangeable soil lead and not the amount of total soil lead. Guided by procedures outlined by Pate and Hutton (1988), a 300 gram sample of dry soil was saturated with distilled, deionized water. This paste was covered and left to stand for 24 hours, following which an additional 400 ml of water were added. The sample was again left to stand for eight hours. The water was filtered under vacuum from the soil. Recovery was slightly greater than 400 ml of water. The solution was evaporated to dryness in a teflon jar. The residue was taken up in 5 ml of concentrated nitric acid and 20 ml of water and again evaporated to dryness in a platinum dish. The residue was then ashed in a muffle furnace at 450 °C for 48 hours. The ashed residue was digested in nitric acid and taken through the same preparation and purification procedures as the other samples. Soil PH was determined by adding 40 ml of water to 20 grams of soil. The paste was left to stand for 1/2 hour, stirred then left to stand for an additional hour. The Ph of the paste/standing water was measured using a Ph meter.

DIAGENESIS

To interpret lead data in archaeological bone in terms of the once living persons and their culture, one must be confident that the lead represents metabolic lead and not diagenetic lead. Diagenesis is defined in anthropological trace element studies of bone as "postmortem alterations in the chemical constituents of bone following deposition in soil" (Sandford 1992:86). It must be addressed when interpreting lead content of buried bones. Its importance is reflected by the amount written on it (e.g. Edward and Benfer 1993; Grupe 1988; Grupe and Pipenbrink 1988; Hancock et al. 1987; Klepinger et al. 1986; Kyle 1986; Lambert et al. 1985, 1989, 1990; Pate and Hutton 1988; Patterson et al. 1987:169-174; Price 1989; Price et al. 1992; Reinhard and Ghazi 1992:188-189; Sandford 1993; Sillen 1989; Waldron 1981, 1983; Waldron et al. 1979; Weber 1992; Williams 1988). Lead may be taken up by bone from soil, or leeched from bone, although there is some question as to which takes primacy (see Jaworowski 1990:176-181; Patterson et al. 1987:169-170).

A number of procedures were performed to minimize and to detect the effects of diagenesis. Only compact bone samples were analyzed as compact bone, being denser and generally thicker than trabecular bone, is less easily affected by diagenesis than trabecular bone (Grupe 1988). Since the endosteal and periosteal surfaces of bone undergo the greatest degree of diagenetic change in buried bone (Lambert et al. 1989), these surfaces were not included in the bone samples, nor were bone particles which were dark in colour. The general condition and colour of bone can be used as an indicator of the degree to which diagenesis has occurred (Edward and Benfer 1993:191-192). The more the bone colour approximates the colour of fresh bone, light, pale yellow to ivory, the less likely diagenesis has occurred. The overall condition of the Seafort skeletal remains is very good, and the colour of the bone samples ranged from yellow to ivory coloured. Moreover, it is a general rule that the longer bones have been buried the greater the potential for significant diagenetic change (Sandford 1992:88). As the Seafort skeletons were, at most, buried for 135 years, diagenesis was probably not significant. It should be noted, however, this general trend can be highly variable temporally and spatially.

To investigate further and to control for diagenesis, a soil sample from just above the coffin of burial 11 was analyzed for lead. It is assumed to be representative of the soil over the whole site. Pate and Hutton (1988) argue that the amount of readily soluble and exchangeable ions of an element in soil better reflects the availability of these ions for chemical exchange with bone, than does the total amount of the element in the soil. Large proportions of the total amount of many elements in soil, lead included, are insoluble in soil solutions because they are firmly bound into soil mineral crystal structures, or are in relatively insoluble compounds. Following this reasoning, the amount of available exchangeable lead in the soil sample was analyzed and determined to be 0.012 $\mu g/g$. This is considerably less than the amount of lead measured in any of the samples including the faunal bones. Furthermore, lead is more readily mobile in acidic soils than in basic soils (Davies 1990:190; Zimdahl and Skogerboe 1977). The PH of the soil sample was determined to be 7.9 which is not conducive to lead mobility. As such, it is concluded that there were not significant amounts of chemically available lead in the soil, and that the soil PH would not have promoted chemical exchange.

Probably the best evidence against diagenesis in the Seafort samples, is that the isotopic composition of the exchangeable soil lead is significantly different than the lead in any of the skeletal samples (Chapter 3:55 this volume). If diagenesis had been extensive, it would be expected that the composition of the lead in the bones would closely match that in the soil. This procedure provides a good test of whether or not diagenesis of lead had occurred in a sample (Chapter 2:55 this volume). It is recommended that, in future anthropological studies of skeletal lead, comparison of the isotopic composition of exchangeable soil lead with that of skeletal lead be done routinely as a test for diagenesis. Given the above considerations, it is concluded that the lead measured in the Seafort skeletal samples is metabolic lead.

RESULTS

Tables 7 and 8 present the lead levels (μg/g ash weight) calculated for the samples. Measured raw data for all samples is presented in Appendix 1. Figure 2 presents the data in graphical form, and Figure 3 illustrates the bone lead levels of the Seafort individuals against age at death. As no replicate analyses were carried out on the samples, and to be conservative in estimating error, the errors reported in Tables 6 and 7 were assigned at ±0.1%, a typical measurement error for Pb concentration determinations using IDMS (Gramlich et al. 1977). This accounts for unknown sources of systematic measurement error. In addition, an error value was calculated for each sample by summing absolute errors (1 sigma) brought into the calculation by each individual known source of error (i.e. in isotopic ratio measurements). If this value was equal to or exceeded ±0.05% it was added to the above error figure. In all cases it did, giving an average overall error of ±0.5%.

The average lead level for all the samples is 61 μg/g (S.D. = 68). This is considered to be misleadingly high as an estimate of the typical skeletal lead level of people in the fur trade. The level of lead in samples S4 and S30 from individual 2b contained twice as much lead as the next closest samples, and on the order of four or five times as much as the rest of the samples. These samples from individual 2b may represent the upper end of the range of values for the population as a whole. However, such levels translate into potentially toxic levels of blood lead (see below), and would be considered exceedingly high (particularly for an 18 year old) in modern populations (Wittmers et al 1988:384). On this basis, the skeletal lead level of individual 2b is considered to represent an atypical magnitude and mode of lead exposure experienced by people of the fur trade. Removing samples S4 and S30 from the calculation gives an average of 35 μg/g (S.D. = 31). The average for the adults (20+ years) is 37 μg/g (S.D. = 34). Grouping the individuals based on apparent cultural affinity gives an average of 46 μg/g (S.D. = 36) for adult individuals (4, 7, 11, and 12) closely associated with fur trade society. This value is considered to represent the typical skeletal lead level of adults living and working in the western fur trade in the 19th century. The average value for the subadult individuals 1 and 3 is 26 μg/g (S.D. = 16.45). The average value of 12.46 μg/g for samples S5 and S29 from individual 2a is the best estimate obtained for the typical skeletal lead level of old adult Indians of the northwestern plains in the 19th century.

Some intra-individual variation in lead levels is apparent in some of the individuals (4 and 2b) upon which two samples were analyzed. This is not unexpected given the relatively small area of bone from which samples were collected, c. 0.25 cm^3. Researchers have recognized that variations in concentrations of bone elements can be significant over small areas (Grupe 1988:128; Jaworowski 1990:179-181; Klepinger et al. 1986; Lindh 1980). As a consequence, Sandford (1992:93; see also Wittmers et al. 1988:389) recommended that c. 3 square centimetres of bone be used in analyses to provide a homogenous sample which factors out the effects of the potential variability in elemental concentrations. However, for this study, it was not possible to take such large samples of bone due to

TABLE 7: Bone Lead Levels in the Seafort Individuals

Sample	Burial	Age	μg/g Pb (Ash Wt.) ± S.E.
S1	1	12-16 (14)	37.90 ± 0.20
S5	2a	40-65 (50)	12.85 ± 0.06
S29	2a		12.07 ± 0.05
S4	2b	15-20 (18)	159.90 ± 0.80
S30	2b		224.00 ± 3.00
S6	3	4-6 (5)	14.63 ± 0.06
S9	4	30-40 (35)	28.90 ± 0.10
S28	4		50.10 ± 0.40
S15	7	22-25 (23)	11.95 ± 0.05
S27	7		10.87 ± 0.07
S21	11	40-60 (45)	70.90 ± 0.40
S24	12	30-40 (35)	101.50 ± 0.70
			Mean = 61.30 S.D. = 68.46
			Mean (-S4&S30) = 35.17 S.D. = 30.79

TABLE 8: Lead Levels in Faunal Bone and Soil of Rocky Mountain House

Sample	μg/g Pb (Ash Wt.) ± S.E.
E7 Soil	0.01235 ± 0.00005 (total dry wt.)
E9 Elk	0.422 ± 0.003
E10 Bison	0.454 ± 0.002
E11 Bison	1.017 ± 0.005
E12 Bison	0.659 ± 0.005
	Mean (Faunal) = 0.638 S.D. = 0.274

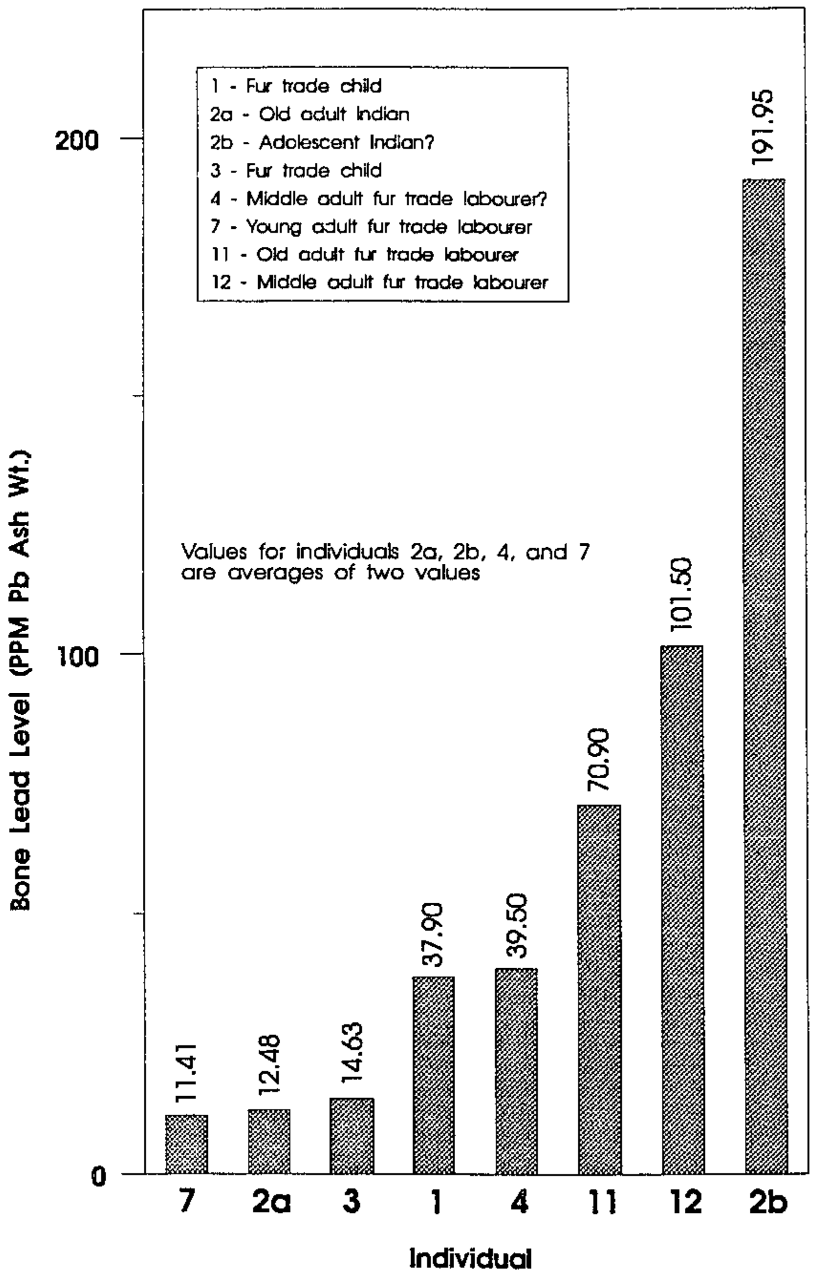

Figure 2: Bone Lead Levels for the Seafort Individuals.

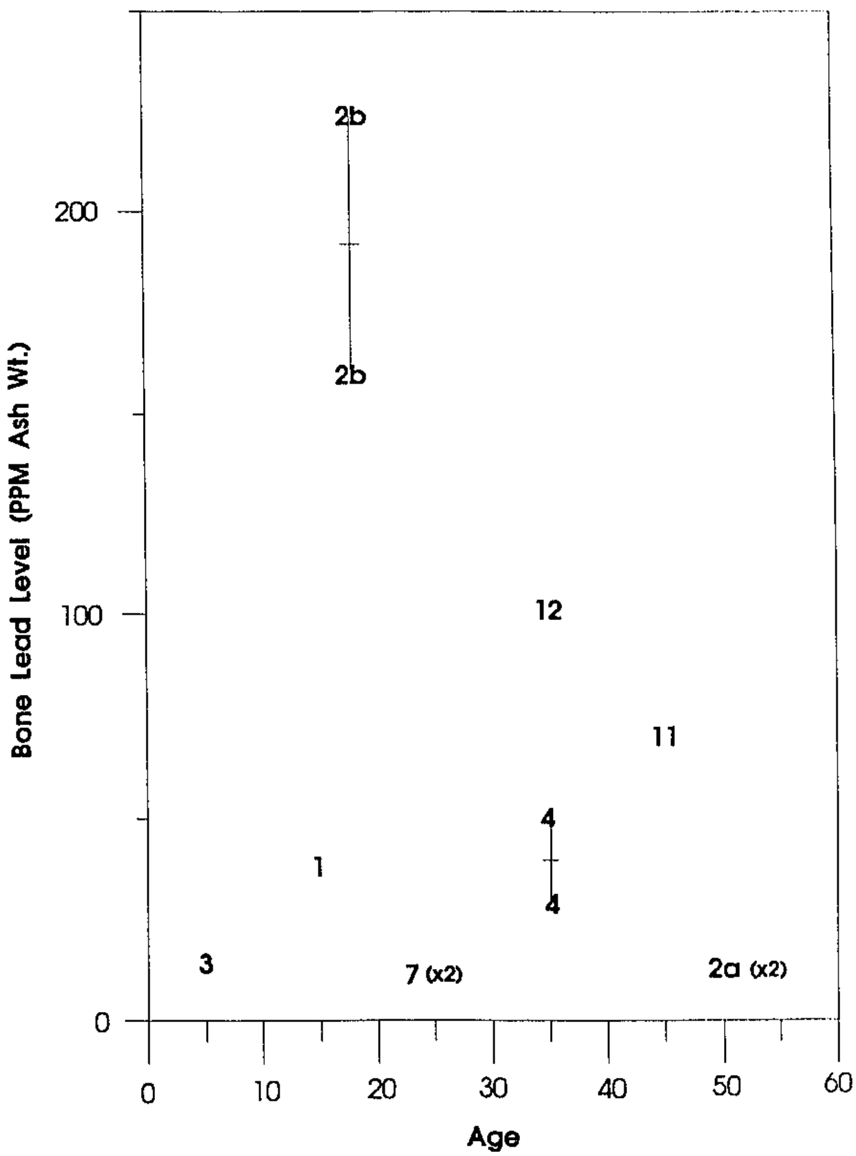

Figure 3: Bone lead level vs age at death for the Seafort individuals (numbers indicate specific individual).

conservation concerns. As such, it is recognized that the values obtained for those Seafort individuals upon which only one sample was analyzed, possibly do not reflect the potential variability in lead levels within those individuals. However, the values obtained are considered to be the best estimates for the skeletal lead levels of these individuals.

The average lead level for the faunal bones is 0.64 (S.D. = 0.27), remarkably lower than levels in the human remains. The variability in the lead levels of the faunal specimens is probably a consequence of the variable ages of the animals. The two younger animals represented by samples E9 and E10 have the lower values, which is consistent with the trend for accumulation of lead in the skeleton with age. The level of H_2O exchangeable lead in the soil was calculated to be 0.012 $\mu g/g$. It is emphasized that this value does not reflect total soil lead, but rather represents the amount of readily soluble lead.

DISCUSSION

Lead Sources

The source of the lead in the Seafort individuals is discussed in detail elsewhere (Chapter 3 this volume). As such, only a brief outline of lead sources is presented here. The isotopic composition of the lead in the Seafort skeletal samples suggests that all the individuals were exposed to essentially the same two general sources categorized as natural sources and anthropogenic sources (Chapter 3:60 this volume). However, exposure to these sources was not necessarily via the same routes or of the same degree of magnitude. Food and water from the local environment, including such staple foods as pemmican (Dickason 1992:199), would have contributed natural lead to these individuals. However, the total amount from such sources would be small as indicated by the low levels of lead in the faunal bones (Table 8). The meat would have even lower levels of lead as lead accumulates in the skeleton, and animal muscle tissues are known to have low lead levels (Ewers and Schlipkoter 1991:981). The isotopic composition of the lead in the faunal specimens is significantly different from that of the human skeletal samples from all the Seafort individuals except individual 2a (Chapter 3:55 this volume). The lead in individuals 1, 3, 7, 11, and 12 is considered to be almost exclusively anthropogenic in origin. The lead in individuals 2b and 4 appears to have resulted from significant contributions from both anthropogenic and natural source (Chapter 3:60 this volume). The composition of the lead in individual 2a closely resembles the composition of lead in the faunal remains (Chapter 3:59 this volume). Based on this observation, and the relatively low level of lead observed (Table 7), particularly in terms of the individual's advanced age, it is concluded that anthropogenic lead contributed little to this individual.

A number of anthropogenic lead sources could have contributed to the lead burden of Seafort individuals. Numerous lead items and products containing lead were used during the fur trade. Of these, those that introduced lead to food and beverages would be the most significant. Such sources are the most ubiquitous, affect the greatest number of people, and ingestion is the primary route via which lead enters the body. These type of sources include in order of decreasing potential significance: cooking vessels, particularly copper kettles with lead soldered seams (Dickason 1992:104), copper itself contains trace lead (West 1982:58) and in the 19th century lead added during smelting (Dennis 1963:132) which could be mobilized during cooking; leaded ceramic glazes and glassware from which lead could be leeched (McCord 1954; Taylor and Bull 1986); lead may also have been present in, and possibly leeched from the japanned surface of cups and pots (japanning is a decorative and protective surface treatment for metals, Ross 1988:173) that were very common items used by the men of the fur trade (e.g. H.B.C.A. B60/d/1); alcoholic beverages such as wine and rum were used in the fur trade, and in the 19th century often contained significant amounts of lead (Wedeen 1984); lead shot, used in hunting fowl and small game, if lodged in the meat could have been ingested or have contaminated the meat; lead foil used as packaging for tea (Carpenter 1977:36; Grandjean 1975:20) could have contaminated the tea; food preserved in cans could have been contaminated by lead soldered seams of the cans (Kowal et al 1991; Mitchell and Aldous 1974); and luxury items such as pewterware (Grandjean 1975:14; McCord 1954). It should be noted that there is no archaeological evidence of canned food or pewter at Rocky Mountain House (Steer et al. 1979). Of these sources, copper kettles are considered the most significant, because they represent the most common potential source, and the isotopic composition of lead from copper kettle fragments recovered from the 1835-1861 fort site is essentially the same as the composition of the lead in the seafort individuals (Chapter 2:p). Another potentially significant source of lead is tobacco. The men and women of the fur trade era smoked considerably and almost always had tobacco on hand (H.B.C.A. B60/d/1; Ray 1974:142-144). In modern society, smokers have generally higher blood lead levels than non-smokers (Mahaffey 1978:15; Moore 1986:173). Occupational exposure to lead in the fur trade could have been highly significant in particular cases. Generally, however, it would have affected only a small number of people. The blacksmith, whose job it was to cast lead balls and shot and work with lead in other ways such as soldering, could have been significantly exposed. Moreover, coal contains lead, and when burned, lead is released to the air and could then be inhaled (Grandjean 1975:26). Other occupational exposure involved such things as the buffalo hunting practice of holding gun balls in the mouth for ease of loading while on the run. A potentially serious form of chronic and perhaps acute exposure was the practice, by Indians, of chewing lead scraps into shot and balls (Carpenter 1977:36). The prevalence of this practice cannot be estimated, however, as only the one reference to it has been found.

Lead in the Seafort Individuals

The lead burden of the Seafort individuals can be examined in a number of ways. The following discussion proceeds from the general to the specific. First, the degree of exposure to lead experienced by these people as compared to modern and other populations is examined. Subsequently, patterns in the lead levels, as reflective of varying exposure for the Seafort individuals, is explained. This explanation is in terms of criteria such as social identity, age, and life history as gleaned from and supported by historical, archaeological, and osteological information. Finally, the potential health effects of the lead levels observed are explored. These discussions and interpretations illustrate the nature and consequences of the lead environment of 19th century Hudson's Bay Company fur trade society.

Lead Environment at Rocky Mountain House in Historical Perspective

The lead environment of mid 19th century fur trade society appears to have resulted in lead levels greater, on average, than that seen in people of modern urban industrial areas. The average value for the Seafort individuals (excluding individual 2b considered to represent atypical exposure, see above) is 35 μg/g ash weight. For the adults only, it is 37 μg/g. In order to compare these values with those reported in various other studies, they can be converted into a dry weight basis by multiplying by 0.7 (Stack 1990:202), giving respective values of 24.5 μg/g and 25.9 μg/g. For the two Seafort subadult individuals 1 and 3 the dry weight average is 18.2 μg/g. Jaworowski (1990:178-179, 182) summarizes the bone lead values reported in the literature for countries around the world and through time. The average value determined for the Seafort material is similar to the highest modern value of 25 μg/g (dry wt.) reported from Great Britain. Modern average values (dry wt.) for other parts of the world are lower: e.g. U.S.A. 17 μg/g; France 12 μg/g; Germany 7.8 μg/g; and Denmark 1.5 μg/g.

The relatively higher skeletal lead levels for the Seafort material as compared to modern lead levels is consistent with a trend illustrated by other studies that over the last 200 years, "typical" skeletal levels of lead have been decreasing (Jaworowski 1990). The Seafort data indicates that the "typical" lead burden of Canadians has been decreasing. For instance, compare 18.2 μg/g from the Seafort subadults with 4.9 μg/g for modern Canadian children (Forbes et al. 1976). Given the small sample size represented by the Seafort individuals, the relative amount of the decrease cannot be estimated. However, the trend is apparent. Jaworowski (1990:186) has proposed that this decrease in "typical" skeletal lead levels is a result of improved living conditions and more hygienic conditions and cultural practices surrounding lead. In western society over the last 50 to 100 years, lead has been greatly reduced or eliminated from cooking utensils, paint, tableware, water pipes, cosmetics, gasoline, and many other things.

There are few studies of the lead levels in 19th century people from other areas around North America, particularly Canada. These few, however, consistently demonstrate that the lead burden of North Americans has decreased over the last 100-200 years. Aufderheide (1990) found an average lead level of 52.7 μg/g bone ash in individuals from the Harvie cemetery, a 19th century cemetery of a pioneering family. This value is roughly comparable to the Seafort material, considering that the Harvie cemetery sample contains numerous older adults, and that lead accumulates in the skeleton with age (Wittmers et al. 1988). Lalich and Aufderheide (1991) report on lead levels from 27 individuals interred at Snake Hill, a military cemetery from the War of 1812. The average value determined for adults (mean age 25.5 years) was 31.3 μg/g bone ash, again comparable to the Seafort material. Reinhard and Ghazi (1992) measured lead levels in the remains of late 18th - early 19th century Omaha Indians. The average values (ash weight) obtained was

185 µg/g for adult males and 23.5 µg/g for adult females. The value for adult males is remarkably high, and the proposition that it reflects metabolic lead must be viewed with some caution. From their report (Reinhard and Ghazi 1992) it appears that the potential for diagenetic effects was great, notwithstanding the authors' justifications otherwise. Nevertheless, there appears to be ample evidence that human skeletal lead levels at the beginning of the 19th century were greater than those of modern populations.

Aufderheide et al. (1988) suggest that examination of lead levels in unknown human skeletal remains can be useful for determining whether such remains are ancient or modern. It is assumed under this application, that a low skeletal lead level would support the proposition that the remains are not modern. However, given the above trend of decreasing skeletal lead levels since the end of the industrial revolution, this assumption would not hold for historic period remains. Moreover, the wide variability observed in skeletal lead levels for modern and historic populations (the Seafort individuals included) indicates that any given individual could have a low skeletal lead level. Given these considerations, only in particular cases, where independent evidence exists for the relative age of the individual, would measurement of the levels of lead in the skeleton assist in determination of whether the remains are ancient or modern. This begs the question of whether determination of lead levels is useful for this purpose.

Trends in Lead Exposure at Rocky Mountain House

Lead accumulates in the skeleton with age (Wittmers et al. 1988). These researchers (1988:384) report "typical" modern bone lead values for the U.S.A. stratified by age category. The average values for the tibia (ash wt.) are: 29.0 µg/g for the >75 age group, 24.2 µg/g for the 51-75 age group, 16.6 µg/g for the 36-50 age group, 5.9 µg/g for the 21-35 age group, 2.3 µg/g for the 13-20 age group, and 0.0 for the 0-2 age group. They had no samples from the 3-12 age group, but interpolating would give a value of approximately 1.0 µg/g. These values are all lower than values obtained from the Seafort material, when stratified for age, except for individual 2a, who had a lead level that falls into the extreme lower end of typical levels for modern individuals of the same age (Fig. 4). This pattern is consistent with the conclusion derived from the archaeological context and the isotopic composition of the lead in this individual (Chapter 3 this volume), that individual 2a was probably an Indian and had little association with fur trade society and its accompanying lead environment.

In people younger than 60, lead accumulates in the skeleton linearly with age (Wittmers et al. 1988:388). Individual variance from a linear model in a given skeletal population is assumed to reflect varying individualized exposure (Lalich and Aufderheide 1991:258). The rate of accumulation on an absolute basis is dose related; with greater amounts of available lead there will be a greater absolute rate of absorption. As such, the variation of an individual's skeletal lead level from a model of linear accumulation for the population as a whole is indicative of the relative magnitude of exposure compared to the other individuals of the population. Stack (1990:202) presents a summary of values for

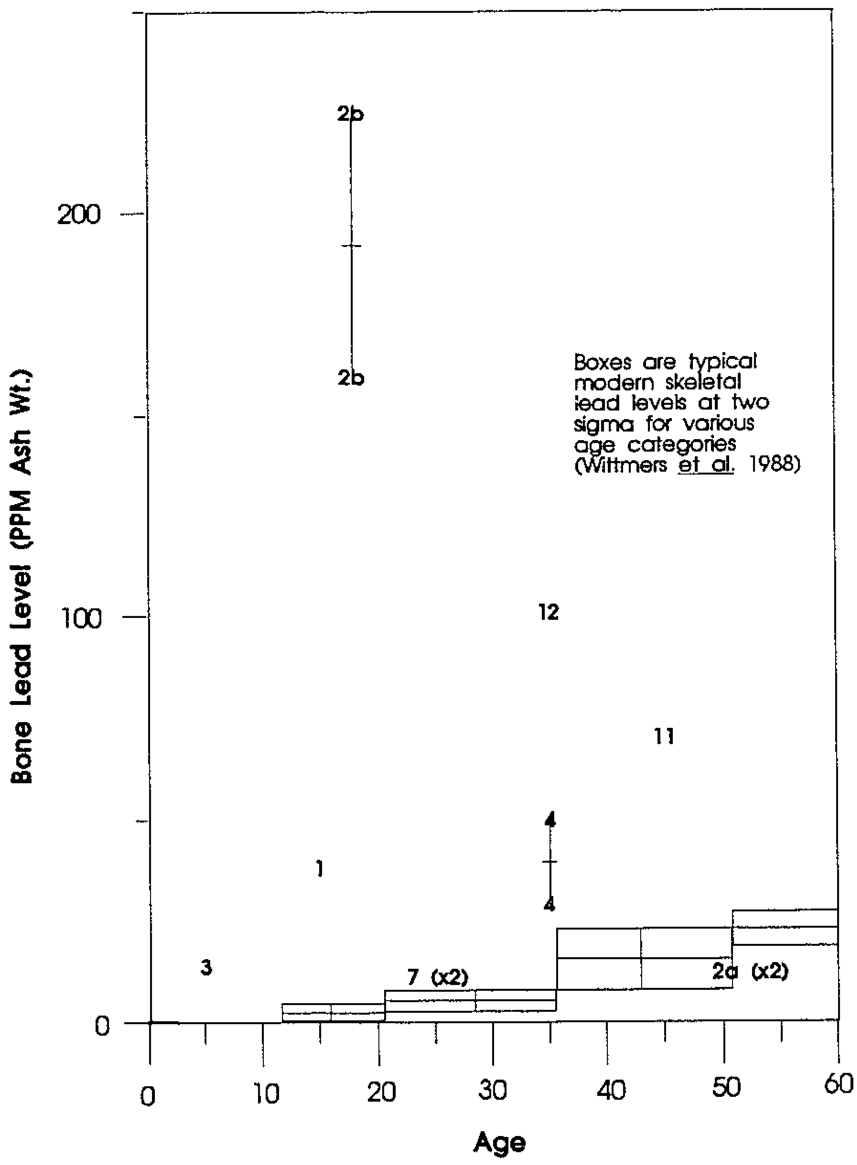

Figure 4: Bone lead level vs age at death for the Seafort individuals compared with modern lead levels for various age categories.

modern accumulation rates. He states that in an environmentally favourable area, the accumulation rate is on the order of 0.5 µg/g/yr (dry wt.). In areas of industrial exposure this increases up to and above 1.0 µg/g/yr.

Figure 3 illustrates the distribution of bone lead based on age at death for all the samples. A single best value for the age of each individual (indicated in brackets in Table 2) was used in this and later plots. No apparent linear trend is visible, suggesting an overall trend, for the population as a whole, towards individualized lead exposure (Lalich and Aufderheide 1991:258). If age were the single most important factor determining the relationship of the levels of lead accumulated in the Seafort individuals, there would be a readily apparent linear increase in lead levels with age. Such a distribution would suggest that all the individuals were exposed to the same amounts and sources of lead. This, however, is not the case. Thus, it is clear that the Seafort individuals were not all similarly exposed to lead over their lives.

To attempt to factor out some of the variability observed in lead levels plotted against age for the Seafort individuals, the sample can be stratified. Individuals 2a and 2b were probably Indians and not Hudson's Bay Company employees or part of fur trade society at Rocky Mountain House, and therefore, were exposed to different amounts and sources of lead. These data points can be removed from the plot. Figure 5 illustrates the distribution of bone lead levels based on age at death for all the samples except those from individuals 2a and 2b. This plot gives a weak regression equation (r=+0.63). The trend towards individualized exposure is lessened, but, nevertheless, is still apparent. This variability in exposure probably results from varying circumstances in the life histories of the individuals. This is not surprising since fur trade society was made up of people from numerous places and of diverse cultural backgrounds. Given this inherent variability in the backgrounds of people of the fur trade, a larger sample size could potentially increase the value of the correlation coefficient observed in Figure 5, but probably not considerably. The average rate of accumulation from this plot is 1.2 µg/g/yr (dry wt.), comparable to, yet slightly higher than modern values from industrial areas (Stack 1990:202). This rate is consistent with the higher absolute values for lead levels observed in the Seafort individuals than in modern populations. It is interesting to note that individual 2a, treated as a unique case, gives an accumulation rate of 0.17 µg/g/yr (dry wt.), with a range from 0.22-0.13, lower than modern values from presumed environmentally favourable areas. This rate is consistent with the low levels of lead available in the general environment around Rocky Mountain House as indicated by determinations on the faunal bones (Table 7).

As stated above, the variability in exposure to lead indicated in Figure 3 is probably a consequence of the variable life histories of the individuals, and consequently variable exposure to lead. To test this, the known similarities in life histories between the individuals can be accented in order to modify the parameters of the plot. Specifically, these individuals all lived for some part of their lives in fur trade society, and furthermore, died in that context. The question becomes, how long were these people associated with fur trade life? Alternatively, how long were these

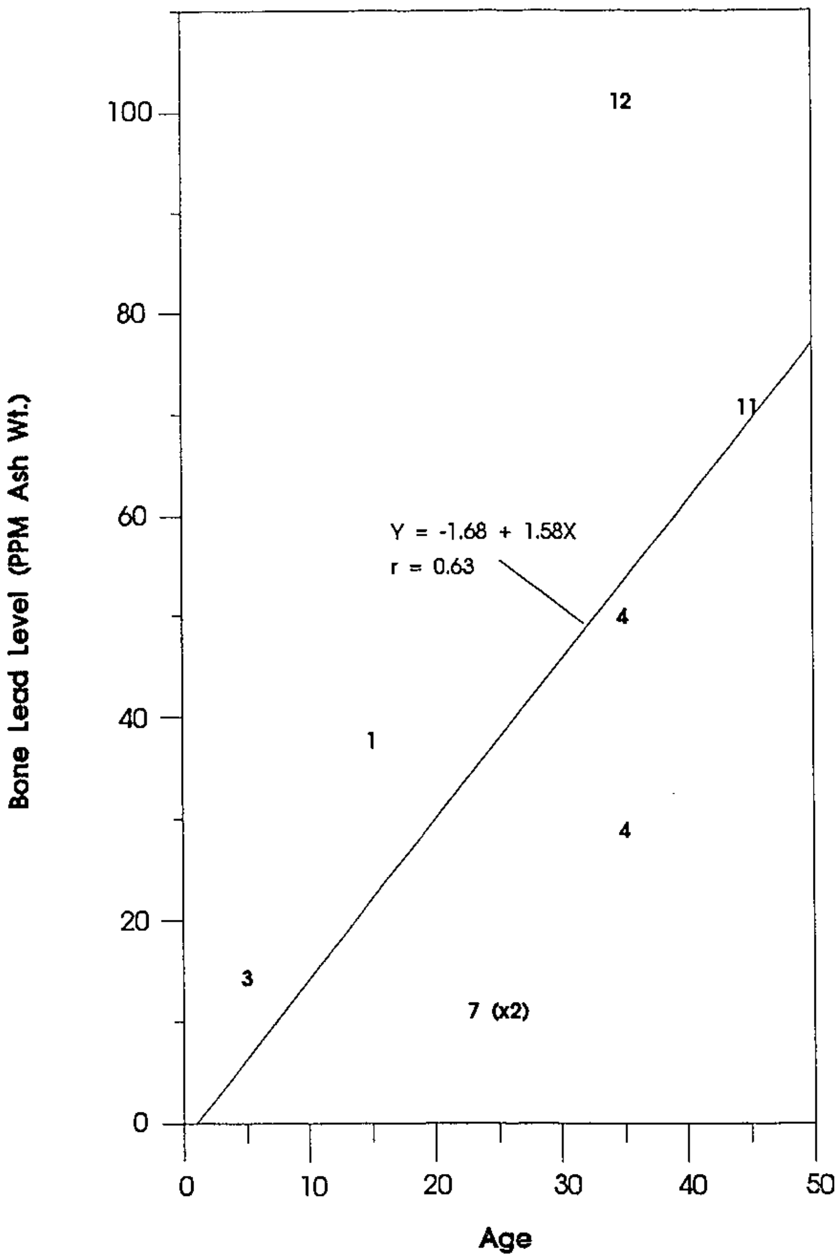

Figure 5: Bone lead level vs age at death for the Seafort individuals thought to be living in fur trade society.

individuals all exposed to the same lead environment? If it is assumed that individuals 4, 7, 11, and 12, considered to be Hudson's Bay Company labourers, began service at the age of 18, this value can be subtracted from their ages. This provides an estimate of the length of association that these individuals had with fur trade society and its accompanying lead environment. Individuals 1 and 3, are assumed to have been born and raised in this environment, therefore their ages at death reflect their length of association, and individual 2a, although thought to have been Indian, is arbitrarily assigned a value of 1 year of association, as most evidence, other than burial at the post, suggests little affiliation with the post. Individual 2b is not included, being considered atypical as outlined above. Figure 6 illustrates the plot of these estimates of length of association against the skeletal lead levels. This plot gives a relatively strong regression equation (r=+0.78). The increase in the correlation coefficient, as compared to the plot against age in Figure 3, supports the above proposition that individual variability in lead exposure apparent for the Seafort individuals results from aspects of the individuals life histories that were not a part of fur trade society. Moreover, it suggests that lead exposure for people living in fur trade society was relatively constant and equal between individuals.

It is recognized in the above exercise, that the sample size is extremely small, and that the assumptions are just that. For instance, there is significant variability in the age estimates of the individuals. Moreover, the assumption that the adult males began service with the Hudson's Bay Company at 18 is clearly an estimate. Also, lead accumulated prior to association with the fur trade may have been significant and is not incorporated into the model. Incorporating such data (if it were known or could be estimated) may or may not strengthen the apparent relationship. As a consequence, the slope of the line in Figure 4 cannot be used as an estimate of the accumulation rate of lead for people of the fur trade. However, this manipulation does appear to account for some of the variability observed in the lead levels of the individuals, in regard to accumulation over time. Moreover, the assumptions are based on historically documented social processes, and supported by archaeological context and osteological information. It is not proposed here that the trend illustrated is proven, or that at this stage it could be used as a predictive model; rather the trend is merely suggested.

The Health Effects of Lead at Rocky Mountain House

Most modern studies of lead toxicity relate toxic responses to blood lead levels. Blood lead levels can be approximated from bone lead levels using an age integrated regression equation reported by Corruccini et al. (1987:238; see also Christofersson et al. 1984; Stack 1990:203): tibia Pb (μg/g wet wt.) = 0.03 x blood Pb (μg/dl) x years of exposure - 0.9. To reflect bone ash weight, the result is multiplied by 0.531. For skeletal remains age at death is usually considered to be years of exposure. This regression equation has r=+0.82. It is not considered extremely precise in that it is based on a relatively small sample (n = 83), and cases with higher than approximately 100 μg/g Pb were not a part of the sample. There is no proof of the equation's continuing linearity given higher bone lead values. However, it provides an

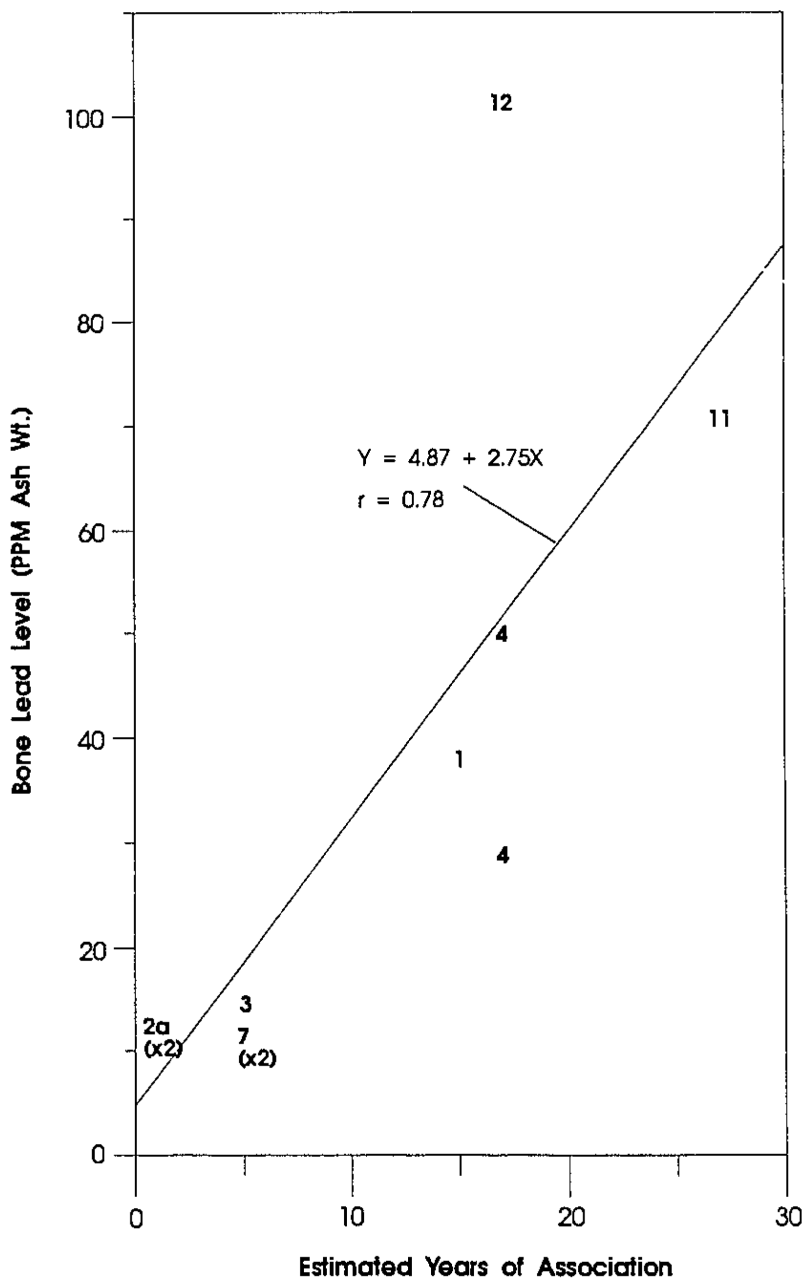

Figure 6: Bone lead level vs estimated years of association with fur trade society for all Individuals except 2b

approximation of blood lead levels which assist in evaluating potential health effects. Such evaluations must be tempered by recognition that bone lead kinetics vis-a-vis dose-response relationships are not fully understood (Rabinowitz 1991). Table 9 presents the results of calculating blood lead levels for the Seafort individuals (based on estimated age at death) from the observed skeletal lead levels. The estimated years of association with fur trade society for the Seafort individuals were not used in the above equation for years of exposure because of the uncertainty in these estimations, and the imprecision of the equation itself. Doing so would increase the values of the determinations for blood lead levels for the adult individuals. However, it would not be possible to evaluate the veracity of the results.

TABLE 9: Estimated Blood Lead Levels for the Seafort Individuals

Sample	Individual	Estimated Blood Lead (μg/dl)
S1	1	49
S5	2a	5
S29	2a	5
S4	2b	158
S30	2b	221
S6	3	55
S9	4	15
S28	4	26
S15	7	10
S27	7	9
S21	11	28
S24	12	52

Handler et al. (1986:404) outline the severity and symptoms of acute lead poisoning (plumbism) in relation to blood lead levels (Table 10; see also Ratcliffe 1981; Wedeen 1984). Mild symptoms can include appetite loss, nausea, and vomiting, while slightly higher levels can lead to intestinal cramping, and constipation accompanied by severe pain. The nervous system begins to be affected with higher levels of lead as it blocks or slows electrical conductivity across synapses resulting in such things as weak grip, wrist and ankle drop, or palsy. Moreover, the brain will begin to be affected causing nervous convulsions which in severe cases can lead to coma and death (Handler et al. 1986:407). Numerous insidious effects of lead intoxication, (particularly resulting from low level chronic exposure) other than the easily observable ones outlined above, occur as well (see below and Handler et al 1986:407; Lucier and Hook 1991; Ratcliffe 1981; Wedeen 1984).

TABLE 10: Expected Severity of Poisoning Symptoms at Various Blood Lead Levels (adapted from Handler et al. 1986:404-405)

Blood Lead (μg/dl)	Expected Severity of Symptoms	Symptoms
0-39	None	None
40-79	Mild	Appetite loss etc.
80-119	Moderate	Colic
120-199	Severe	Nervous Ailments
>200	Very Severe	Coma, Death

Comparison of the calculated blood lead levels of the Seafort individuals with Table 10 suggests that individuals 2a, 4, 7, and 11 had no apparent symptoms. Individuals 1, 3, and 12 possibly had mild symptoms, while individual 2b possibly had severe to very severe symptoms. Given that the calculation of blood lead is an approximation, and the uncertainty surrounding the use of bone lead as a measure of dose-response relationships, it cannot be reasonably concluded that individuals 1, 3, and 12 did in fact suffer from mild symptoms of lead poisoning. The possibility exists, however, for chronic lead poisoning, and considering that two of the individuals are children, who are generally more susceptible to lead intoxication (Ratcliffe 1981:26-29), it must remain a serious consideration.

For individual 2b, however, the bone lead level and the calculated blood lead level are exceedingly high, particularly as this individual is an adolescent. As the lead is most probably metabolic lead, it is likely that individual 2b was acutely lead poisoned and exhibited various symptoms of plumbism, though the severity of the symptoms must remain unclear. It is sufficient to say that this individual's lead burden may have contributed to the individual's death. How individual 2b could have become poisoned must also remain unclear. What can be concluded is that this person ingested relatively large amounts of lead, compared to the other individuals, over an unknown period of time. This could have been either a single massive dose, or a relatively long term dose of smaller amounts. Unfortunately, as Rabinowitz (1991) states in regard to using bone lead as an index of exposure and risk: "Although it would be useful to distinguish between two extreme types of exposure, a single high dose or a long-term, lower dose, we are not yet able to do so" (1991:36). Although he does suggest that chronic (long term) exposure, as opposed to acute exposure, would provide a relatively greater bone lead signal (1991:36). While it is tempting to invoke the practice mentioned above, of chewing lead to make shot, as the manner in which this individual ingested lead, it cannot be directly supported. It is pointed out, however, that the lead in individual 2b is anthropogenic in origin, and its composition closely matches that of lead and copper in use at the 1835-1861 fort (Chapter 3 this volume).

Based on the skeletal levels of lead observed, and the estimated blood lead levels calculated, it appears that the lead environment of Hudson's Bay Company fur trade society did not create serious health problems given normal modes of exposure to lead. However, it is apparent that the possibility existed for individuals to become poisoned given the presence of lead artifacts and items containing lead, and the various cultural practices surrounding their use. The prevalence of acute poisoning in the fur trade context, however, cannot be fully evaluated given the current data.

CONCLUSION

The above discussion has illustrated a number of aspects of the lead environment experienced by people working and living in 19th century Hudson's Bay Company fur trade society. One trend that is apparent is that the people of fur trade society were exposed to more lead than people today. The data gathered for the Seafort individuals provides additional evidence that this trend has been a worldwide phenomenon over the last 200 years (Jaworowski 1990). Further research on the lead burden of people living in 19th century pre-confederation Canada will probably continue to support this historical model. Jaworowski (1990; see also Jaworowski et al. 1985a; 1985b) explains this relative decrease in peoples' "typical" lead burden, since the passing of the industrial revolution, as a consequence of improved hygienic conditions surrounding lead. The trend continues today, an obvious example being the elimination of lead as a gasoline additive (Ewers and Schlipkoter 1991:1003). It is emphasized here, that such improvement is essentially independent of the magnitude of world production and use of lead and regardless of the fact that pollution of the general world environment by lead has increased perhaps as much as 100,000 times above the preindustrial "natural" environment (Patterson et al. 1987). Thus supporting the proposition that the most significant compartment of the global lead cycle as outlined by Nriagu (1978:8), in terms of lead exposure, is the immediate fetch environment of an organism. In other words, for a particular people in a particular time and place, it is the uses of, and cultural practices surrounding lead that are the significant factors determining exposure, and it is not the magnitude of world production of lead, or the magnitude of pollution of the global environment with lead, that are particularly significant. The magnitude of the pollution of the world environment, cannot, therefore be measured meaningfully through the analysis of human tissues. Rather environmental samples such as soil, plant remains, and animal bones would provide appropriate samples for such an endeavour.

Although exposure to lead was greater during the fur trade than it is today, it probably did not result in a significant increase in overt adverse health effects for people. The risk of such effects, however, was probably greater then than now. The blood lead levels calculated for the Seafort individuals who are thought to have been a part of Hudson's Bay Company fur trade society (nos. 1, 3, 4, 7, 11, and 12), do not suggest acute exposure resulting in symptoms of plumbism. Further historical research with the specific goal of identifying historical mention of symptoms of plumbism such as colic, palsy or gout in the fur trade could prove enlightening.

Individuals 2a and 2b represent an intriguing case. Both of them have been assigned a cultural affiliation with Indian groups of the region, based on archaeological and lead isotope information (Chapter 2:p this volume). The most interesting aspect of the lead data derived from these individuals is that they represent the two extremes of the lead environment of the fur trade at Rocky Mountain House, and yet, probably being indians, they would not have been living in fur trade society. Individual 2a appears to have been exposed to little or no anthropogenic lead, while individual 2b was almost assuredly lead poisoned by it and had visible symptoms of plumbism. It is very unlikely, however, that these symptoms were understood by this individual or other people. It is tempting to wonder what, the then unperceived, role lead may have played in the events leading up to the unique context of burial 2. These events, however, remain impossible to know. Lead may have been another of the "diseases" brought by Europeans to the Indians.

Although acute lead poisoning may not have been a significant health problem in the fur trade, chronic lead poisoning from low level exposure to lead may have been prevalent. Chronic lead poisoning has been related to a wide variety of ailments including kidney disease, high blood pressure, anaemia, neurological disorders, behavioral aberrancies, decreased fertility, and increased still births (Handler et al. 1986; Ratcliffe 1981; Wedeen 1984). Adverse health effects from chronic exposure are greatest in children and in pregnant, lactating, and older women (Silbergeld 1991). The various aliments listed above have been related to blood lead levels as low as 25 μg/dl, the currently accepted "safe" limit for blood lead in children (Hotz 1986:1). The data collected in this study, however, cannot address chronic lead poisoning except peripherally. The relatively greater degree of exposure that fur trade people experienced than that experienced today, as indicated by the Seafort data, suggests that chronic exposure must be seriously considered in further lead studies centred on the fur trade. Additional data collection such as determining mortality profiles from skeletal populations of individuals of the fur trade, and the collection of lead data from neonatal skeletons could allow chronic exposure to begin to be addressed.

Typically, this study brought to light a number of areas that warrant further research. The most general of these is the need for a comparative data base examining the lead burden of people of the fur trade in Western Canada. This is the only study to date which examines the fur trade from the point of view of lead exposure. Such future studies, particularly of larger samples, with better documented historical contexts, and if possible with more complete biographical information on the individuals would be valuable in clarifying or disproving the trends that became apparent from the sample examined here. Additional research into the sources of lead in the fur trade would be valuable, such as further historical investigation of cooking practices and the analysis of artifacts representing potential sources of lead. Replication experiments on food preparation procedures could prove enlightening. Ultimately, all such research would provide valuable insights, adding to the understanding of life in pre-confederation Canada.

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CHAPTER 5

LEAD ANALYSIS OF THE SEAFORT BURIALS: SUMMARY AND DIRECTIONS FOR FUTURE RESEARCH

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INTRODUCTION

The analysis and interpretation of skeletal lead has become common in anthropological research employing chemical analyses of human tissues (e.g. Aufderheide et al. 1988; Chapter 2 this volume). Lead is an ubiquitous trace element found throughout the world in rocks, soil, vegetation, water, and biological life forms (Nriagu 1978). Humans and other animals take up lead from their environment through diet and respiration. Once absorbed into the blood stream, lead is quickly distributed throughout the body. The primary sink for absorbed lead is the skeleton, where it accumulates over an individual's life (Wittmers et al. 1988). The skeleton contains approximately 90% of the body burden of lead, and the turn-over rate of lead in the skeleton is very slow with a half-life of approximately 10-30 years (Rabinowitz 1991; Wittmers et al. 1988). Thus, skeletal lead can be considered to reflect an individual's lifetime exposure to it (Aufderheide et al. 1988).

In anthropological investigation of skeletal lead, trace lead found in individuals of a skeletal population is generally taken to reflect cultural information about the individuals and the population in terms of ante-mortem exposure to lead. Exposure subsumes a wide array of factors that result in variable exposure to lead between and within groups both in terms of the magnitude of exposure and the sources to which individuals are exposed. These factors include geographical location, the level of lead technology, socio-economic class, occupation, and the specific cultural practices surrounding lead and its uses. The totality of these factors influencing an individual or cultural group make up the lead environment of the individual or group (Chapter 3 this volume:35). By analyzing skeletal lead levels and/or the isotopic composition of skeletal lead, insight into the nature of the lead environment is gained. From this, and in conjunction with archaeological, historical, and osteological information known about the population, cultural inferences can be made.

Aufderheide et al. (1988) summarize the conventional anthropological applications of skeletal lead analysis. These applications include: assessment of the extent of lead technology in a cultural group; separation of two socioeconomic subgroups within a population; identification of unique social or occupational roles of individuals within a population; prediction of health effects; separation of mixed skeletal remains; and identification of human remains as modern or ancient. These applications focus on measuring the levels of lead in skeletal remains. Chapter 4 (this volume) presents the results of a study investigating the levels of lead in eight individuals from the Seafort burial site associated with the 19th century fur trade at Rocky Mountain House in what is now Alberta.

Recently, analysis of the isotopic composition of trace lead in skeletal remains has allowed investigation into the particular source(s) of the lead in skeletal remains (Kowal et al. 1990, 1991; Molleson et al. 1986; Reinhard and Ghazi 1992). Such studies represent a development out of research using lead isotope data to ascertain the source(s) of lead as an environmental pollutant (Ault et al. 1970; Chow et al. 1974) and as the cause of lead poisoning (Manton 1977; Rabinowitz 1987; Rabinowitz and Wetherill 1972; Yaffe et al. 1983). Chapter 3 (this volume) presents an application of skeletal lead analysis of the 19th century Seafort burials, using isotopic composition to address questions of group affinity.

LEAD ISOTOPE ANALYSIS OF THE SEAFORT SKELETONS

The isotopic composition of the lead in the Seafort individuals was collected using mass spectrometry. Such data provides information about the source(s) of lead to which individuals were exposed. Using this data, the cultural affinities of the Seafort individuals were investigated (Chapter 3 this volume).

The radiogenic origins of three of the four stable isotopes of lead give lead from any given geologic deposit (source) a characteristic isotopic "signature" (Cumming et al. 1990; Faure 1986; Gale 1989). As lead does not fractionate measurably in biological systems, including human metabolism, the isotopic composition of skeletal lead reflects the source(s) of lead to which individuals were exposed. It is assumed that different cultural groups will be exposed to different sources of lead through both natural processes and cultural practices. Given this assumption, individuals of different cultural groups should have skeletal lead of different isotopic composition.

Through analysis of a number of contemporaneous lead artifacts, and artifacts containing lead which represent anthropogenic lead, and a number of faunal bones which represent natural lead, the primary sources of lead in the Seafort individuals were identified. This identification allowed the individuals to be associated with the mid 19th century Rocky Mountain House fort (1835-1861). Moreover, the isotopic composition of the skeletal lead allowed the individuals to be grouped into at least two and possibly three groups. Using historical, archaeological, osteological, and ethnographic information, in conjunction with the lead isotope data, these groups were assigned cultural identities. Individuals 2a and 2b, are suggested to have been Plains Indians. Individuals 1, 3, 7, 11, and 12 are suggested to have been Hudson's Bay Company employees and/or people closely associated with fur trade society. Individual 4 is also suggested to have been associated with fur trade society. However, this individual appears to have been less closely affiliated than the others.

LEAD LEVELS IN THE SEAFORT SKELETONS

Using isotope dilution mass spectrometry the levels of lead in the Seafort skeletons were determined. Such data provides information about the amount of lead to which the Seafort individuals were exposed over their lives, and provides insight into the general lead environment experienced by people working and living in 19th century Hudson's Bay Company fur trade society (Chapter 4 this volume).

It was determined that people associated with fur trade society in the mid 19th century were exposed to greater amounts of lead than people are exposed to today. The levels of lead in those Seafort individuals presumed to have been living and working in fur trade society, were consistently greater than the levels of lead in modern individuals from the same age categories. These data support other similar data suggesting that this trend has been a worldwide phenomenon over the last 200 years (Jaworowski 1990). Jaworowski (1990) explains his relative decrease in peoples' "typical" lead burden, since the passing of the industrial revolution, as a consequence of improved hygienic conditions surrounding lead.

Additionally, as lead accumulates in the skeleton with age, variation from a linear model of accumulation vs age for a population suggests individualized lead exposure for the individuals of the population (e.g. Lalich and Aufderheide 1992). A relatively high degree of individualized exposure is apparent for the Seafort individuals. However, in an attempt to account for some of the variation, and to test the hypothesis that lead exposure in the fur trade was relatively equal between individuals, an estimate of length of association with the fur trade that each of the Seafort individuals had was plotted against the measured skeletal lead levels (Chapter 4 this volume:104). A stronger linear relationship was achieved than that based on lead levels vs age at death. Based on this, it is suggested that lead exposure in the fur trade was relatively consistent and equal between individuals, and that the individualized exposure apparent for the Seafort individuals was a consequence of exposure to lead during portions of the individuals' lives outside the fur trade.

Although exposure to lead was greater during the fur trade than it is today, it probably did not result in a significant increase in overt adverse health effects for people. The risk of such effects, however, was probably greater then than now. The blood lead levels calculated for the six Seafort individuals who are thought to have been a part of Hudson's Bay Company fur trade society do not suggest acute exposure resulting in symptoms of plumbism. Individuals 2a and 2b represent an intriguing case. Both of them have been assigned a cultural affiliation with Indian groups of the region, based on archaeological and lead isotope information (Chapter 3 this volume). The most interesting aspect of the lead data derived from these individuals is that they represent the two extremes of the lead environment of the fur trade at Rocky Mountain House, and yet, probably being indians, they would not have been living in fur trade society. Individual 2a appears to have been exposed to little or no anthropogenic lead, while individual 2b may have been lead poisoned and have had visible symptoms of plumbism. It is unlikely, however, that these symptoms were understood by this individual or other people. It is tempting to wonder what, the then unperceived, role lead may have played in the events leading up to the unique context of burial 2. These events, however, remain impossible to know. Lead may have been another of the "diseases" brought by Europeans to the Indians.

Although acute lead poisoning may not have been a significant health problem in the fur trade, chronic lead poisoning from low level exposure to lead may have been prevalent. Chronic lead poisoning has been related to a wide variety of ailments including kidney disease, high blood pressure, anaemia, neurological disorders, behavioral aberrancies, decreased fertility, and increased still births (Handler et al. 1986; Ratcliffe 1981; Wedeen 1984). Adverse health effects from chronic exposure are greatest in children and in pregnant, lactating, and older women (Silbergeld 1991). The various aliments listed above have been related to blood lead levels as low as 25 μg/dl, the currently accepted "safe" limit for blood lead in children (Hotz 1986:1). The data collected in this study, however, cannot address chronic lead poisoning except peripherally. The relatively greater degree of exposure that fur trade people experienced than that experienced today, as indicated by the Seafort data, suggests that chronic exposure must be seriously considered in further lead studies centred on the fur trade.

FURTHER RESEARCH

Typically, this study brought to light a number of areas that warrant further research. The most general of these is the need for a comparative data base examining the lead burden of people of the fur trade in Western Canada. This is the only study to date which examines the fur trade from the point of view of lead exposure. Such work would be valuable in providing a data base which would provide suitable comparative flexibility to address a wide variety of questions using skeletal lead data. Such future studies, particularly of larger samples, with better documented historical contexts, and if possible with more complete biographical information on the individuals, would allow the trends that became apparent from the sample examined here to be clarified or disproved. Additional research into the sources of lead in the fur trade would be valuable, such as further historical investigation of cooking practices and the analysis of artifacts representing potential sources of lead. Replication experiments on food preparation procedures could prove enlightening.

Further research on the lead burden of people living in 19th century pre-confederation Canada would probably continue to support the historical model for decreasing "typical" lead levels. It is emphasized here, that this decrease in peoples' lead burden appears to be independent of the magnitude of world production and use of lead and regardless of the fact that pollution of the general world environment by lead has increased perhaps as much as 100,000 times above the preindustrial "natural" environment (Patterson et al. 1987). The most significant compartment of the global lead cycle as outlined by Nriagu (1978:8), in terms of lead exposure, is the immediate fetch environment of an organism. In other words, for a particular people in a particular time and place, it is the uses of, and cultural practices surrounding lead that are the significant factors determining exposure, and it is not the magnitude of world production of lead, or the magnitude of pollution of the global environment with lead, that are particularly significant. The magnitude of the pollution of the world environment, cannot, therefore be measured meaningfully through the analysis of human tissues. Rather environmental samples such as soil, plant remains, and animal bones would provide appropriate samples for such an endeavour.

The health effects of lead in the 19th century could be further investigated. Additional data collection such as determining mortality profiles from skeletal populations of the fur trade, and the collection of lead data from neonatal skeletons could allow chronic exposure to begin to be addressed. More specifically, historical research with the goal of identifying historical mention of symptoms of plumbism such as colic, palsy or gout in the 19th century could be undertaken.

The success achieved in this study using lead isotope data for addressing questions of cultural affinity and using the isotopic composition of skeletal lead as a source tracer, should be pursued further. The development of a large comparative data base derived from populations of known cultural affiliation from a known time period could assist in the assignment of unknown skeletal remains to a cultural group and time. As well, a study examining the isotopic composition of bone lead in modern populations from different geographic or urban areas could be started. Such a data base could assist in forensic investigations of unidentified found human remains.

A last potentially fruitful area for further research would be to pursue the use of lead isotopic signatures of historic fur trade artifacts as a method of dating the artifacts. If copper and lead artifacts from known time periods were to be analyzed, the lead isotopic compositions of the artifacts may define a changing time dependent trend. By defining this trend with a large enough data base, artifacts with unknown contexts, or from historic sites or burials with unknown or ill defined temporal placements could be dated through measurement of the lead isotopic composition and comparison with the defined trend.

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APPENDIX 1

MEASURED RAW DATA

SEAFORT HUMAN SKELETAL SAMPLES MEASURED RAW DATA

SAMPLE	BURIAL	BONE TYPE	DRY WT. (gms.)	ASH WT. (gms.)	IR ALIQ. WT. (gms.)	ID ALIQ. WT. (gms.)	Pb 206 SPIKE WT. (gms.)	208/206 +/- S.E. (ID only)	206/204 +/- S.E.	207/204 +/- S.E.	208/204 +/- S.E.
S1-IR/ID	1	Compact	0.1143	0.0809	7.1543	2.3327	0.3755	0.685396 +/- 0.000015	18.504892 +/- 0.002183	15.627984 +/- 0.001666	38.511425 +/- 0.004227
S2-IR	1	Trab.	0.0748	0.0434	-	-	-	-	18.496 +/- 0.006	15.620 +/- 0.008	38.485 +/- 0.013
S4-IR/ID	2B	Compact	0.0254	0.0129	7.4621	2.0942	0.5137	0.368918 +/- 0.000022	18.594533 +/- 0.013733	15.649835 +/- 0.012600	38.635106 +/- 0.030282
S5-IR/ID	2A	Compact	0.0570	0.0406	6.9957	2.2831	0.5368	0.116393 +/- 0.000022	19.013713 +/- 0.018997	15.650385 +/- 0.026466	38.939181 +/- 0.049241
S6-IR/ID	3	Compact	0.0553	0.0377	7.418	2.2816	0.4589	0.136346 +/- 0.000020	18.515716 +/- 0.030716	15.661755 +/- 0.012550	38.513422 +/- 0.024243
S7-IR	3	Trab.	0.0635	0.0330	-	-	-	-	18.600915 +/- 0.003800	15.655850 +/- 0.005748	38.605768 +/- 0.014091
S9-IR/ID	4	Compact	0.1148	0.0808	7.0444	2.4444	0.4789	0.488880 +/- 0.000006	18.601521 +/- 0.015165	15.604330 +/- 0.013073	38.549271 +/- 0.025449
S10-IR	4	Trab.	0.0746	0.0372	-	-	-	-	18.911414 +/- 0.001614	15.668356 +/- 0.001082	38.809287 +/- 0.004123
S11-IR	4	Compact	0.0237	0.0140	-	-	-	-	18.657717 +/- 0.005291	15.658118 +/- 0.004162	38.676977 +/- 0.009725
S15-IR/ID	7	Compact	0.1509	0.1075	7.9926	2.3324	0.4650	0.276796 +/- 0.000014	18.449474 +/- 0.005299	15.627504 +/- 0.006712	38.468937 +/- 0.028025
S16-IR	7	Trab.	0.1809	0.1105	-	-	-	-	18.484228 +/- 0.007670	15.639827 +/- 0.006241	38.559449 +/- 0.017825
S17-IR	7	Compact	0.0583	0.0359	-	-	-	-	18.431990 +/- 0.009172	15.609893 +/- 0.006987	38.427663 +/- 0.009349
S21-IR	11	Compact	0.0481	0.0374	7.3611	-	-	-	18.418210 +/- 0.008322	15.610904 +/- 0.005365	38.369026 +/- 0.022309
S21-ID	11	Compact	0.0481	0.0374	-	2.3220	0.4943	-	77.063860 +/- 0.029418	15.614446 +/- 0.008570	38.397457 +/- 0.026317
S22-IR	11	Trab.	0.0839	0.0435	-	-	-	-	18.417 +/- 0.004	15.620 +/- 0.004	38.426 +/- 0.009
S23-IR	11	Compact	0.0871	0.0615	-	-	-	-	18.435308 +/- 0.002085	15.611898 +/- 0.002991	38.420001 +/- 0.007223
S24-IR	12	Compact	0.1331	0.0937	7.1219	-	-	-	18.461 +/- 0.002	15.627 +/- 0.002	38.487 +/- 0.005

Continued...

SEAFORT HUMAN SKELETAL SAMPLES MEASURED RAW DATA (Continued)

S24-1D	12	Compact	0.1331	0.0937	-	2.335	0.5045	-	34.793221 +/- 0.002473	15.636176 +/- 0.000795	38.503788 +/- 0.003929
S25-1R	12	Trab.	0.2291	0.1196	-	-	-	-	17.420629 +/- 0.007133	15.563892 +/- 0.016092	37.326704 +/- 0.018404
S26-1R	12	Compact	0.1038	0.0751	-	-	-		18.520305 +/- 0.001533	15.640632 +/- 0.001994	38.557680 +/- 0.003286
S27-1R	7	Compact	0.1284	0.0921	4.1853	-	-	-	18.435 +/- 0.013	15.612 +/- 0.007	38.452 +/- 0.003
S27-1D	7	Compact	0.1284	0.0921	-	2.4951	0.5067	-	120.03204 +/- 0.055305	15.613693 +/- 0.008877	38.405018 +/- 0.023315
S28-1R	4	Compact	0.1399	0.1001	4.3062	-	-	-	18.642523 +/- 0.033785	15.641527 +/- 0.031438	38.644143 +/- 0.067138
S28-1D	4	Compact	0.1399	0.1001	-	2.4675	0.4593	-	37.731043 +/- 0.024269	15.649106 +/- 0.006945	38.625404 +/- 0.005443
S29-1R/1D	2A	Compact	0.1416	0.1019	4.6617	2.5142	0.5252	0.346973 +/- 0.000193	19.206166 +/- 0.006301	15.719035 +/- 0.003340	39.128932 +/- 0.008458
S30-1R/1D	2B	Compact	0.1174	0.0827	4.6004	2.4892	0.5318	1.556576 +/- 0.000176	18.560882 +/- 0.002347	15.622540 +/- 0.002053	38.560521 +/- 0.006173

SEAFORT ARTIFACT SAMPLES MEASURED RAW DATA

SAMPLE	MATERIAL	WEIGHT (GMS.)	206/204 +/- S.E.	207/204 +/- S.E.	208/204 +/-S.E.
A1	Copper	0.8407	18.375483 +/-0.003512	15.622564 +/-0.004965	38.408811 +/-0.009178
A2	Copper	0.3877	18.500678 +/-0.005351	15.690551 +/-0.007350	38.688656 +/-0.012123
A3	Pipe Bowl Residue	0.0259	18.468895 +/-0.001531	15.669380 +/-0.002275	38.595420 +/-0.005027
A4	Lead Ball	0.0104	18.471533 +/-0.005958	15.708409 +/-0.004957	38.702793 +/-0.011345
A5	Lead Shot	0.0058	18.670666 +/-0.003730	15.734933 +/-0.004135	39.079064 +/-0.008854
A7	Copper	0.7675	18.208921 +/-0.007071	15.642623 +/-0.005713	38.390225 +/-0.013236
A8	Lead Shot	0.0104	18.594343 +/-0.008916	15.894044 +/-0.007130	39.313587 +/-0.025081

SEAFORT ENVIRONMENTAL SAMPLES MEASURED RAW DATA

SAMPLE	TYPE	DRY WT. (GMS.)	ASH WT. (GMS.)	IR ALIQ. WT. (GMS.)	ID ALIQ. WT. (GMS.)	Pb 206 SPIKE WT. (GMS.)	208/206 +/- S.E. (ID ONLY)	206/204 +/- S.E.	207/204 +/- S.E.	208/204 +/- S.E.
E7-IR/ID	Soil	300	n/a	7.6173	2.4411	0.5213	0.616693 +/- 0.000075	18.093972 +/- 0.001941	15.612306 +/- 0.001820	37.882063 +/- 0.005668
E9-IR/ID	Moose Bone	0.8326	0.6138	7.2315	2.5618	0.5535	0.066723 +/- 0.000283	18.841171 +/- 0.066920	15.578377 +/- 0.043813	38.563853 +/- 0.097788
E10-IR/ID	Bison Bone	0.7906	0.5938	7.3445	2.5586	0.5650	0.066931 +/- 0.000035	19.029417 +/- 0.016180	15.695250 +/- 0.013789	38.839094 +/- 0.035644
E11-IR/ID	Bison Bone	0.5866	0.4213	7.3569	2.5496	0.5593	0.101424 +/- 0.000037	18.804048 +/- 0.020487	15.645647 +/- 0.017217	38.650468 +/- 0.042689
E12-IR/ID	Bison Bone	0.9507	0.7510	7.1983	2.6051	0.5461	0.121586 +/- 0.000341	18.893343 +/- 0.027489	15.659727 +/- 0.029374	38.756265 +/- 0.037641

ANALYTICAL BLANKS MEASURED RAW DATA

BLANK NO.	WT. OF SOLUTION (GMS.)	WT./AMT. OF Pb 206 SPIKE	208/206 +/-S.E. (ID ONLY)	206/204 +/- S.E.	207/204 +/- S.E.	208/204 +/-S.E.	COMMENTS
B1-ID	9.5688	4 ngm. of Pb 206 added	0.775730 +/- 0.000243	-	-	-	8ml of 1:1 HNO3. Carried on from digestion through columns.
B2-IR	-	-	-	18.388 +/-0.02	15.471 +/-0.02	37.809 +/-0.04	6ml of 1:1 HNO3. Carried on from digestion through columns. Run on 354.
B3-ID	-	7.5 ngm of Pb 206 added	0.240673 +/- 0.000373	-	-	-	400ml of H2O carried through procedures along with sample E7.
B4-ID	4.7249	0.3656 gms. of spike #4	0.040439 +/- 0.000005	-	-	-	5ml of 1:1 HNO3. Carried on from digestion through columns.

^{206}Pb SPIKE #4 COMPOSITION

^{206}Pb - 1.02475 µg/g
^{207}Pb - 0.00010 µg/g
^{208}Pb - 0.00015 µg/g