APPLIED GIS TO MODEL OBSIDIAN DISTRIBUTION ON THE SNAKE RIVER PLAIN

by

Talissa D. Cota, B.A.

A thesis
submitted in partial fulfillment
of the requirements for the degree of

Master of Science
in the Department of Anthropology

Idaho State University

Summer 2022

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The members of the committee appointed to examine the thesis of TALISSA D. COTA find it satisfactory and recommend that it be accepted.

John V. Dudgeon, Ph.D.,

Thesis Chair

Charles A. Speer, Ph.D.,

Committee Member

Kirsten G. Mink, Ph.D.,

Committee Member

Keith T. Weber, GISP,

Graduate Faculty Representative

ACKNOWLEDGEMENTS

I cannot take full credit for the success and completion of this research since numerous people were contributors that deserve recognition. First, I would like to thank the entire Anthropology Department for their patience during this process and for giving me the opportunity to pursue my childhood dream of archaeology. It has been a bumpy journey for me, but one well worth enduring. I would also like to thank my advisor, Dr. John Dudgeon, for numerous reasons. First, this research would not exist without him. I learned GIS and developed the skillset to generate the data for this project, but I cannot take credit for an idea that belongs to him; I am most appreciative of him allowing me to take it and run with it because it was a good one that I hope will benefit the archaeological community in some way or another. I also cannot discount the numerous hours he has spent helping me during the analysis and final stages of writing this thesis. His feedback/input has helped solidify this scholarly work. I could not thank him enough for Additionally, I was introduced to GIS during my first semester of graduate school under John's advisement, which was early enough for me to pursue a Graduate Certificate in Geotechnology. I was introduced to a passion and now have a future full of opportunity because of it. Much thanks to my advisor for directing me to the wonderful world of GIS which has ultimately altered the trajectory of my career.

I would like to thank my Committee Members, Drs. John Dudgeon, Charles "Andy" Speer, Kirsten Mink, as well as Keith Weber for their helpful edits, comments, and feedback and for their overall patience throughout this long process. A special thanks to Keith Weber, Director and founder of the GIS Training and Research Center at ISU, whose knowledge and expertise also helped to solidify this research. Actually, it likely made this research. Keith supplied a 10-m surface elevation raster of the study area (vs. 30-m DEM) and taught me how to automate geoprocessing in ArcGIS Pro through Python scripting. Without his help, I would not have been able to generate nearly as much data, and the data would have had a high degree of error. Hundreds of hours spent to generate data full of error; that was not this ending thanks to Keith.

I would also like to give a big shout out and thank you to Dr. Carrie Bottenberg and Dr. Donna Delparte for their assistance, support, and overall passion and enthusiasm for GIS. The passion that they displayed in the classroom spread like wildfire and took me under, which has undeniably been one of the most exciting periods of my lifetime. Much love to everybody at GIS TReC and the entire GIS community at ISU for their support, enthusiasm, and overall helpfulness while learning and developing the skill.

Additionally, I would like to give a special thank you to my friend, Alyssa Farnes, who I am most grateful to have befriended several months ago when I began my internship at GIS TReC. Alyssa is the one of the most positive, passionate, and delightful persons I have ever met, and she pulled me out of a dark funk that I had been trapped in for longer than I would like to admit. I would like to thank her for listening to me talk about archaeology, obsidian, cultures, GIS, LCPs, aliens, anthropology, graduate school, and a bunch of other random stuff during most days at work. I would also like to thank her for her contributions to this research and for providing input/feedback on ideas that I presented to her; Alyssa pointed out that obsidian sources tend to lie on the boundaries of calderas, and voila, a nice 3D map illustrating obsidian sources in relation to the volcanic fields on the Snake River Plain now exists. Additionally, she never fails to impress me with her own brilliant ideas that she mentions to me on a weekly basis. Having the opportunity to work with her, and the entire phenomenal team at GIS TReC for that matter, has been one of the best experiences of my life and has only reinforced the idea that more brains are better than one; we need to help each other out and work together if we want to progress with our research, and most importantly, in life.

Additionally, much thanks to Amy Commendador at the Earl Swanson Archaeological Repository and the Idaho State Historical Society for supplying the locations of archaeological sites. Charles Shaw was a huge help with reformatting lots of LCP data in Excel, thank you very much. Thank you to Evelin Paucar who explained the math behind Tobler's hiking function to me; without her expertise, I may have never figured out how to revise the footpath algorithm into one with reduced travel rates. Much thanks to my group members in the ISU Thesis and Dissertation Summer Writing Workshop, Thane Kindred, Micaela Wilson, and Jill McDonald, whose comments/edits on working drafts were beyond helpful when drafting a final version.

Thanks to my colleagues and friends at the Center for Archaeology, Materials, and Applied Spectroscopy, Kateea Peterson, Pam Pascali, and Evelin Paucar for giving me a shoulder to cry on and offering support when it seemed that the world was falling apart around us. Pursuing a graduate degree during a global pandemic is not optimal, but sometimes life happens and the show must go on; the sooner one recognizes that the better the outcome will be. On that note, I would also like to thank the Anthropology Collections Manager at the Idaho Museum of Natural History, Amber Tews, for her support and encouragement throughout the duration of both my undergraduate and graduate studies. The number of people that have reached out to me to offer support/encouragement, both in the academic and non-academic environments, exceeds what I can mention here. Know that I am most appreciative of you all for your kindness and compassion. Much love to my family and friends who have patiently waited for me to finish so that I can spend some quality time with them again. Thank you all for helping me to achieve a childhood dream and life goal! Si vous pouvez le rêver, vous pouvez le faire!

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ABSTRACT

Applied GIS to Model Obsidian Distribution on the Snake River Plain

Thesis Abstract-Idaho State University (2022)

Archaeological evidence suggests human occupation in Idaho dating back to the terminal Pleistocene. Many prehistoric stone tools recovered from the region were crafted from obsidian. The Snake River Plain contains over 100 known outcroppings of obsidian with 23 distinct geochemical variations. By geochemically characterizing obsidian artifacts and lithic quarries in the region via X-ray Fluorescence, the localities that people used to exploit these lithic raw materials can be known.

This study incorporates artifact provenance data with GIS modeling of least-cost travel paths to identify spatial patterns in the distribution of obsidian artifacts in relation to their origin. A set of spatial analysis geoprocessing tools introduced in 2020 for ArcGIS Pro software is paired with Tobler's off-path hiking function to calculate time approximations for obsidian procurement. Additionally, to facilitate future research, a geodatabase was created that contains artifact provenance data for Idaho as well as the data generated from this study which will serve as Idaho's permanent digital database for geochemically sourced artifacts.

Results indicate there are two preferred obsidian sources, located in the eastern and western regions of Idaho, and transported throughout the state. Bear Gulch (58%) and Timber Butte (56%) obsidian showed the highest rate of transport followed by Big Southern Butte (44%), Brown's Bench (40%), Owyhee (40%), Malad (32%), Cannonball (30%), and Obsidian Cliffs (26%).

Keywords: Snake River Plain, least-cost path, geochemical sourcing, Tobler's hiking function

CHAPTER 1: INTRODUCTION

Idaho's geologic past resulted in the formation of numerous lithic quarries exploited by pre-colonial people, and some remnants of their culture remain in the archaeological record in the form of obsidian artifacts. Geochemical sourcing techniques and Geographic Information Systems (GIS) have advanced considerably over the past two decades regarding their overall efficiency providing researchers with a higher quantity of data to work with and more sophisticated techniques for visualizing, computing, and analyzing spatial data than were available at the turn of the millennium. By using these advancements in geochemical sourcing and GIS, archaeologists can quickly and accurately identify locations where the igneous glass used to make stone tools formed, and visualize and analyze the geospatial locations in GIS software. Geochemical sourcing studies have been used to infer prehistoric mobility (Black 2014; Clegg 2016; Krauel 2017; Kumm 2020), but attempts to dive deeper into the understanding of prehistoric movement of lithic materials using recent advancements in GIS technology are limited.

GIS applications to study obsidian distribution and conveyance on the Snake River Plain (SRP) are steadily increasing in popularity. Previous obsidian research has focused on various areas such as analyzing conveyance zones (Fowler 2014; Holmer 1997), identifying spatial patterns (Holmer 1997; Plager 2001), analyzing distribution from parent source via straight-line distance (Marler 2004) and small-scale LCP modeling (Harris 2014; Henrikson 2008; Marler 2004). Research shows that Idaho obsidian travels great distances, but some obsidian sources move farther distances from their point of origin and other obsidians stay localized (Henrikson 2008; Holmer 1997; Plager 2001). Additionally, profilometry testing has shown that obsidian sources are highly variable in terms of their roughness, which is a means to assess one of several qualities of obsidian (Krauel 2017; Kumm 2020).

This research aims to draw from theoretical perspectives in optimality theory and integrate advancements in GIS and geochemical sourcing to create a comprehensive archaeological study involving recorded observations generated through validated scientific techniques and an eclectic suite of geoprocessing tools to analyze, visualize, and interpret the data in a spatial context. Tobler's off-path hiking function is applied in a state-of-the-art geoprocessing toolset introduced in July 2020 for ArcGIS Pro to perform LCP analysis.

The objectives of this study are to (1) calculate the distance and energy expenditure approximations for SRP obsidian procurement in units of time, (2) create visualizations illustrating obsidian distribution and frequencies as well as predictive travel routes involving both directions of travel and Euclidean (straight-line) paths in the region, and (3) build an interactive, spatially-representative digital database of obsidian provenance data to serve as a permanent database for geochemically sourced artifacts in Idaho.

This research will be productive for identifying spatial patterns in the distribution of obsidian, identifying frequency and dispersion disparities between obsidian sources, and modeling plausible prehistoric travel routes. Additionally, the resulting database from this project will be particularly fruitful for facilitating future research on obsidian in Idaho and for ultimately furthering our understanding of prehistoric selection and usage of this lithic material.

CHAPTER 2: BACKGROUND

The Snake River Plain

Stretching nearly 400 miles across southern Idaho, the Snake River Plain (SRP) is a geologic depression formed by the passage of the North American plate 15-16.5 million years ago over a magmatic hotspot (Hughes et al. 1999) that now resides underneath Yellowstone National Park. The basin is divided into two regions based on geographic formation. The western SRP is a northwest-trending rift basin that primarily contains middle Miocene to late Pliocene (11-3 Ma) arkosic and tuffaceous fluvial-lacustrine sedimentary deposits (Beranek et al. 2006). The eastern SRP, in contrast, is a northeast-trending bimodal volcanic field capped with fluvial-aeolian sediment that marks the late Miocene to Holocene (10-0 Ma) passage of the hotspot (Beranek et al. 2006). The physiography of the eastern SRP is primarily comprised of Quaternary volcanic landforms such as basaltic lava flows, shield volcanoes, and rhyolitic domes (Hughes et al. 1999).

The movement of the North American Plate over the past 17 million years across Idaho in a northeast direction caused several violent volcanic eruptions (Pierce and Morgan 1992). People have exploited at least 101 lithic quarries in Idaho since the end of the Pleistocene; these obsidian quarries were formed by lava extruded from Earth's surface during the movement of the North American Plate over a magmatic hotspot (Pierce and Morgan 1992). Figure 1 illustrates approximate boundaries for the volcanic fields and the resulting lithic quarries.

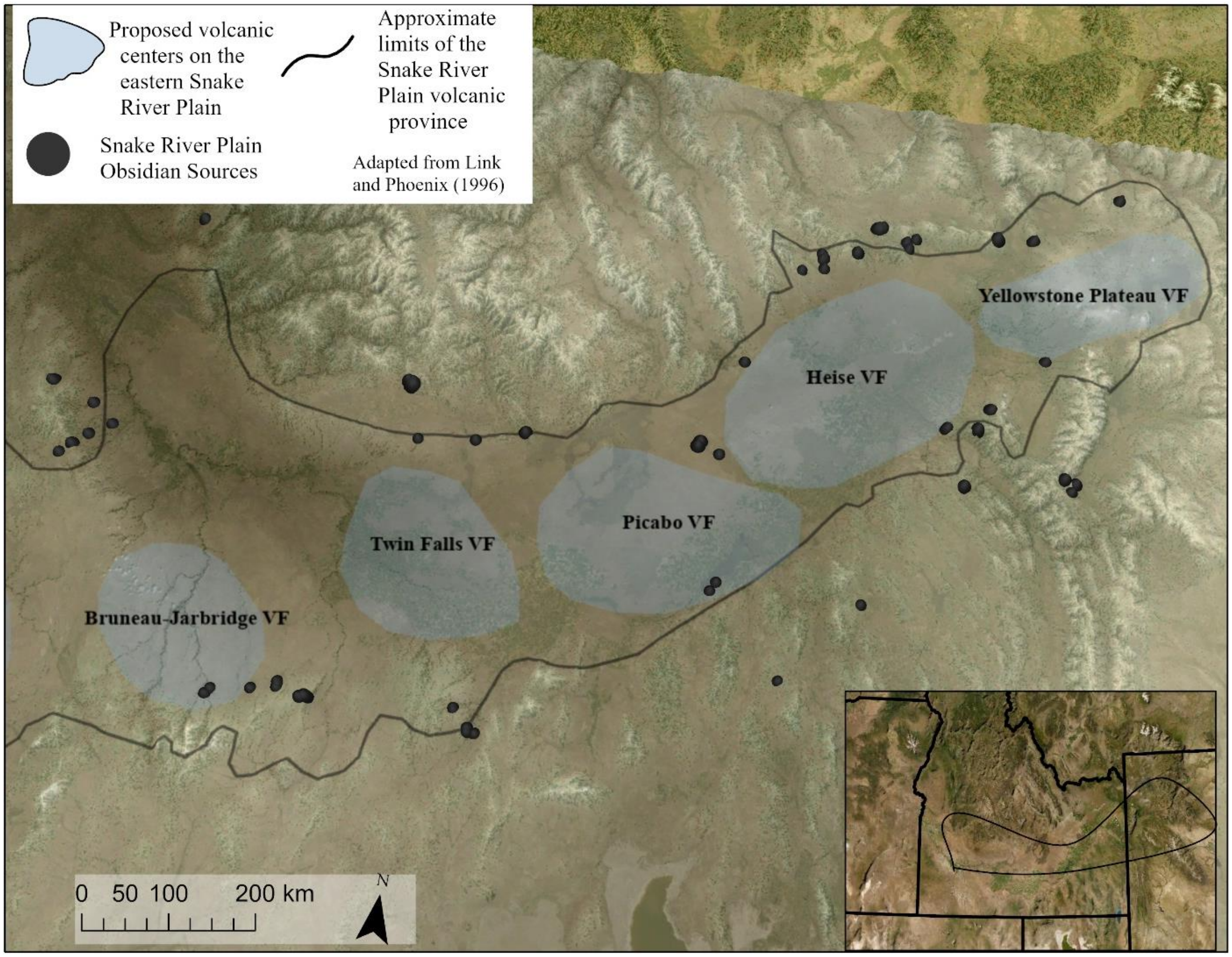

Figure 1. Approximate boundaries for the volcanic fields (VF) on the SRP are shown in blue. The cones represent the lithic quarries exploited by pre-colonialists (Adapted from Link and Phoenix 1996).

Mountain ranges surround the SRP, and the region is semi-arid, receiving less than 10 inches of precipitation a year, typically during the winter and early spring. The plain is fed by numerous rivers from the surrounding Rocky Mountains that form the Snake River Aquifer (Henrikson 2003; Keene 2016). Vegetation on the SRP consists primarily of sagebrush steppe with perennial grasses and riparian zones containing cottonwoods, willows, and sedges with pinyon-juniper zones, mountain mahogany woodlands, and ponderosa pine at higher elevations (Plew 2000). Food resources on the SRP are concentrated in a few relatively rich patches that were not encountered randomly (Henrikson 2004). Besides Camas Prairie, the SRP does not contain any permanent streams, although 1200 or more ephemeral ponds appear during the spring depending on precipitation and drought conditions (Henrikson 2004). A patch choice model for the eastern SRP predicted that riverine resource patches were the most desirable locations for seasonal sedentism (Henrikson 2004). Locations, where cultural materials have been recorded plotted against a hydrology map (Idaho Department of Water Resources 2020), supports this notion (Figure 2).

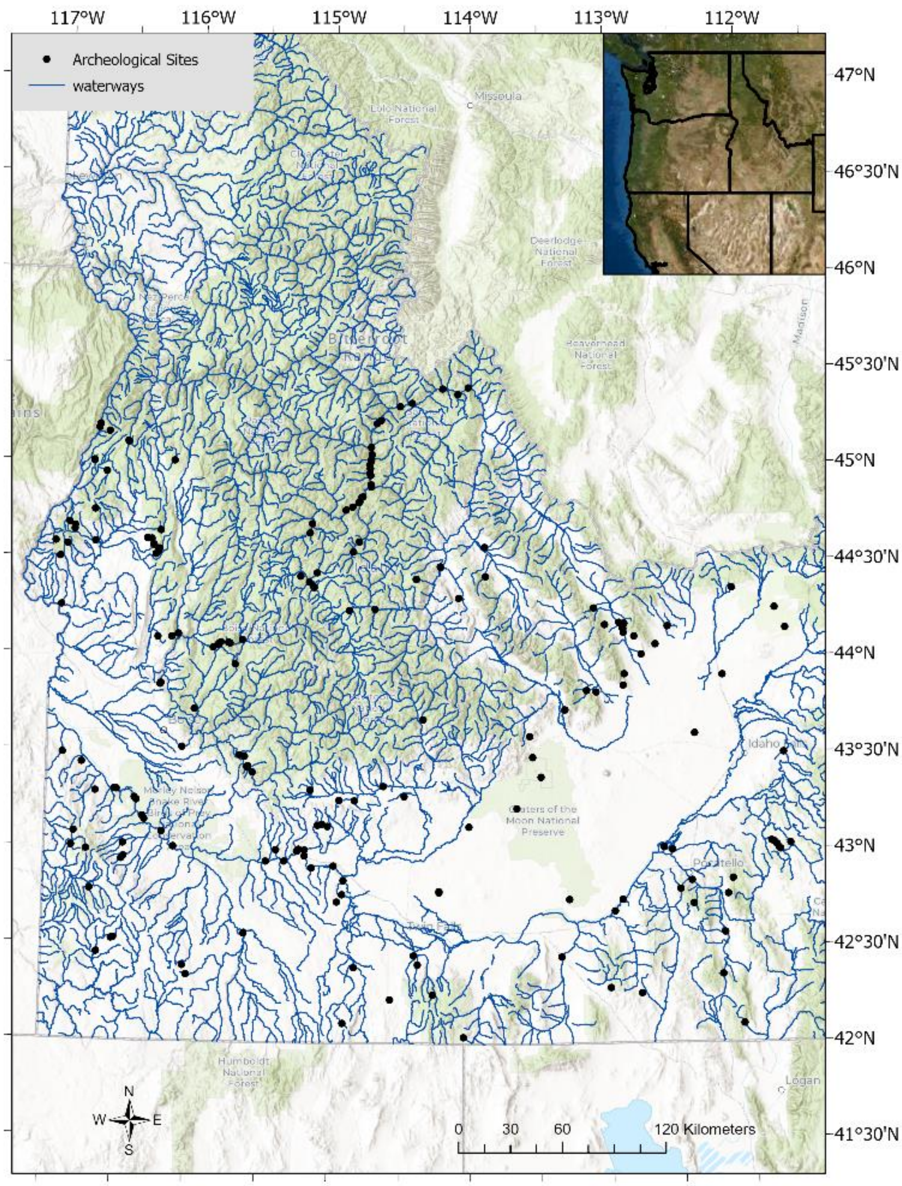

Figure 2. Archaeological sites in relation to water sources. Map scale is 1:250,000.

Culture History

Archaeological evidence suggests long-term occupation of humans in Idaho extending back to the terminal Pleistocene, a period when several species of extinct megafauna mammals populated the region such as *Camelops sp., Mammuthus sp., Canis dirus, Smilodon sp., Arctodus sp.,* and *Megalonyx sp.* (Butler 1978). In 2019, archaeological evidence was discovered in western Idaho at Cooper's Ferry, indicative of human occupation predating previously accepted notions for the migration of the first people into the Americas. Radiocarbon dating of materials from the Cooper's Ferry site, located in the Columbia River basin, indicates that people arrived there between 16,560 and 15,280 calibrated years before present (cal B.P.) (Davis et al. 2019). Additionally, unfluted stemmed projectile points that predate Clovis point technology were discovered in the earliest occupation phases of the site, and due to physical similarities, may support early cultural connections with Northeastern Asian traditions (Davis et al. 2019).

Furthermore, the radiocarbon dates of materials from the site indicate that people were present before the opening of an ice-free corridor approximately 14,800 years ago which contradicts the previous idea of travel from Canada into North America through the ice-free corridor and lends support to the hypothesis of initial human migration occurring via a Pacific coastal route (Davis et al. 2019). Although this recent discovery is the earliest evidence of human occupation in Idaho and arguably one of the most significant, there are several other notable archaeological sites in the state indicating early human occupation.

In 1989, highway workers near Buhl, Idaho encountered human skeletal remains, and excavation of the burial revealed the remains of a Paleoindian woman between 17-21 years of age at the time of death who lived 10,675 ± 95 BP (Green et al. 1998). The Wasden site, located 20 miles west of Idaho Falls, is comprised of three collapsed lava tubes believed to have been used as a funnel to trap bison. Initial excavation of the site during the 1970s yielded the earliest evidence of bison procurement in a "bison bone bed" representative of over 70 individual bison that are believed to have resulted from two separate kill events that occurred approximately 8,000 BP (Butler 1978). In addition to stone tools and pottery, excavations of the Wasden site have also yielded bones from mammoths, camels, dire wolves, lions, and prehistoric bison (Painter 2021). Likewise, artifacts recovered from the Wilson Butte Cave also indicate an early human occupation with cultural materials recovered from the site radiocarbon dated to 12,550 ± 500 BP (Crabtree 1969). Research involving cold storage and bison procurement on the SRP shows that the Bobcat and Scaredy Cat Caves were utilized during the Middle Holocene and activities at the Tomcat and Fortress Caves occurred during the Late Holocene (Henrikson 2003).

In an ethnographic study involving Basin-Plateau Indigenous Cultures, Steward (1938) noted distinctive subsistence patterns between the Shoshone who lived above and below Shoshone Falls. Steward (1938) observed that the Shoshone residing below the falls primarily subsisted on fish, root, and seed crops during the spring and traveled north to Camas Prairie where they spent the summer months. The presence of natural springs and extensive marshlands attracted plentiful game and provided adequate subsistence throughout the summers. In contrast, after wintering at the Fort Hall Bottoms, the people residing on the eastern SRP dispersed in small groups during the spring in all directions to procure various resources. Some groups headed into the South Hills for deer, elk, berries, and pinyon nuts or traveled west to Shoshone Falls to fish during the spring salmon runs. Other groups traveled northwest to Camas Prairie to harvest camas or west across the Continental Divide in search of bison. During the early fall, additional groups moved east into western Montana and Wyoming to stage communal buffalo hunts before returning to the Fort Hall Bottoms for winter (Steward 1938). The disparity between the groups likely resulted from the presence of Shoshone Falls, a prominent geologic feature formed by the Bonneville Flood that rises over 200 feet within the Snake River Canyon and serves as the easternmost limit of anadromous fish runs along the Snake River (Steward 1938).

This subsistence pattern, commonly referred to as the seasonal round, occurred annually; however, individual groups altered the direction of travel each year. The purpose of the seasonal round was to procure resources as they become available throughout the year. This seasonal pattern may have resulted from years of accumulative knowledge of resources on the SRP; over time, as people became more knowledgeable of the seasonal availability of resources, the seasonal round may have been incorporated as a means to reduce variability (John Dudgeon, personal communication, May 13th, 2022).

Human Behavioral Ecology

Human behavioral ecology (HBE) is a branch of evolutionary ecology that began during the 1970s to study the fitness-related behavioral trade-offs that humans face in particular environments. In general, we expect to see in the natural world behavior that is close to optimal in terms of maximizing fitness given the ecological conditions that are faced; this expectation serves as a hypothesis-generating engine about which behaviors should be observed under which ecological conditions (Nettle et al. 2013). The initial application of HBE in archaeological inquiry focused on foraging theory and hunter-gatherer studies but has recently broadened to involve the study of many aspects of human behavior such as cooperation, life history, mating, and trade (Bird and O'Connell 2006; Winterhalder and Smith 2000).

HBE enables the derivation of testable hypotheses from graphical and mathematical models that are anchored in basic principles of evolution by natural selection (Winterhalder and Smith 2000). Because fitness cannot typically be measured directly in the archaeological context, measuring the consequences of behavioral strategies in some more immediate proxy currency related to fitness such as survival, mating success, or energetic return is employed (Nettle et al. 2013). All HBE models involve four parameters that are required to be defined beforehand: (1) the fitness-related goal, (2) a currency for measuring relevant costs and benefits, (3) a set of constraints that characterizes the social and environmental context, and (4) a decision or alternative set that describes the range of behavioral options to examine (Winterhalder and Smith 2000).

Although this research is not a traditional implementation of optimal foraging theory (OFT), which is often used to explore resource acquisition or exploitation, OFT can be appropriately applied to this study. Technological decision-making is a growing area of interest in archaeological research. Herzog and Goodale (2019) notes that in circumstances where resource access is competitive and there is variation in strategies to solve for a particular goal, natural selection should favor the strategy that solves the problem with a least-cost path over other available strategies. This is because humans have limited energetic budgets and those individuals that can save energy while solving particular problems that optimize their somatic interest are able to convert energetic surpluses into other endeavors that also increase reproductive success (Herzog and Goodale 2019).

This study incorporates frameworks derived from HBE to explore plausible routes that pre-colonial people might have preferred to take to travel through Idaho. The defined variables used in this model are (1) fitness-related goal = obsidian procurement, (2) currency = time (hr), (3) set of constraints that characterizes the environment = 10-m surface elevation raster of study area to account for topography, (4) a decision or alternative set = the broad range of route choices. It should be noted that the time currency generated from this study is likely a reduced estimation for obsidian procurement considering that pre-colonial life was vastly different from customs present today. People were not in a hurry to get anywhere nor were they constrained to any one place. As noted by Kelly (1992), it is unlikely that obsidian procurement occurred as an independent event and may be part of a foraging foray. The LCPs generated in this study represent travel to and from obsidian quarries, but it is likely that people participated in other activities during their quest to procure high-quality tool stone.

Geochemical Sourcing and Obsidian Research

This research makes broad use of the spatial occurrence patterns of obsidian, a ubiquitous archaeological tool stone found on the Snake River Plain, as a means to identify how far a preferred material moves from the localized quarry sites and across the SRP, to areas of manufacture, use and/or discard. In order to do this, we must identify and find the home quarry of any tool stone artifact occurring in the ~200 archaeological sites reviewed for this thesis. To accomplish this, we need some rule or generalization that clarifies our ability to identify far flung artifacts back to their quarry sources with high confidence.

In 1977, Weigand and colleagues proposed the “Provenance Postulate” to fill this role of an empirical approach to linking artifacts back to their sources. The Provenance Postulate posits that some qualitative or quantitative chemical or mineralogical difference exists between natural sources that exceeds the qualitative or quantitative variation within each source (Weigand et al. 1977). In other words, obsidian is tacitly chemically homogenous at the level of source or outcrop, but has distinct chemical variations between sources permitting separation of these sources by chemical differences that can be plotted in coordinate or statistical space. The chemical composition of obsidian varies depending on the environmental factors at the time of eruption (Black 2014). Since certain chemistries or element sets are unique to the geologic history of particular regional obsidian sources, the Provenance Postulate allows artifacts to be sourced back to the origin of the lithic material through geochemistry sourcing (Black 2014; Weigand et al. 1977).

Obsidian provenance is a common research interest for archaeologists in Idaho due to the prevalence of obsidian artifacts recovered from the region. Holmer (1997) estimated that 90% of artifacts recovered from any single archaeological site in eastern Idaho were crafted from obsidian. This is unsurprising considering that Idaho contains 23 chemically-distinct sources of obsidian at 101 localities. Typically, geochemical sourcing can be accomplished through a variety of techniques such as x-ray fluorescence spectrometry (XRF), laser-ablated inductively coupled plasma mass spectrometry (LA-ICP-MS), or neutron activation analysis (NAA). Most of the data used in this analysis were generated from several studies that used a Bruker portable x-ray fluorescence spectrometer (pXRF) at Idaho State University to geochemically characterize obsidian artifacts, or were sent to the Northwest Research Obsidian Studies Laboratory (NWROSL) where pXRF was also used for obsidian characterization. For this reason, XRF is the sole geochemical sourcing technique further elaborated on in this paper.

XRF is a technique commonly used by archaeologists for obsidian provenance studies because it is a non-destructive means to quickly characterize lithic materials to a known geologic source (Black 2014; Krauel 2017). XRF spectrometry measures trace element abundance in units of weight to weight (i.e., parts per million, ppm, milligrams per kilogram, etc.), and the chemical concentrations can be compared to known obsidian source geochemical profiles using various statistical techniques such as stepwise non-discriminant function or bivariate plots (Krauel 2017; Kumm 2020).

Geochemical sourcing of obsidian contributes significantly to our knowledge and understanding of prehistoric lifeways in the intermountain west due to the prevalence of lithic quarries and obsidian artifacts in the region, and the ability to distinguish between distinct obsidian locales by their chemical composition. Geochemical characterization of artifacts is a widespread research interest of students in the ISU Anthropology Department due to the availability of equipment utilized for compositional analysis at the Center for Archaeology, Materials, and Applied Spectroscopy (CAMAS). Additionally, the Earl Swanson Archaeological Repository (ESAR), which curates and maintains artifacts recovered from eastern and southeastern counties in Idaho, is a division of the Idaho Museum of Natural History on ISU's campus. These resources provide convenient access for ISU students to gain hands-on experience in compositional analysis and sourcing and perform typological analysis on artifacts.

Students and researchers in the western part of the state, specifically at Boise State University, also conduct a considerable amount of artifact sourcing. The NWROSL, a facility in Corvallis, Oregon, that provides analytical services for trace element provenance studies, performs the majority of sourcing for these studies using XRF. Most of the data for geochemically characterized cultural lithic materials involved in this study came from studies where the lithic materials were sourced at ISU or NWROSL. University of Idaho professor Dr. Robert Lee Sappington played a crucial role in identifying and chemically characterizing obsidian sources on the SRP during the 1980s (Holmer 1997). Unfortunately, artifacts curated at the University of Idaho were not included in this study.

Geochemical characterization of artifacts is becoming an essential tool for understanding prehistoric lifeways because the data informs us of where people were in the past and, if typologically analyzed, when they were exploiting lithic materials. Prior obsidian provenance studies in Idaho have facilitated our knowledge of prehistoric obsidian usage and mobility on the SRP and are an integral part of this study. The numerous contributors to this study are discussed further in the following chapter.

Obsidian provenance studies provide utility for studying the movement of prehistoric Indigenous Groups. Harris (2014) hypothesizes that the majority of 101 obsidian artifacts from the Kyle Canyon Springs site (10-BT-08) would source from Big Southern Butte because it is the closest obsidian locality to the site and provides some specific benefit in lower energy costs to procure. Results indicate, however, that most of the obsidian analyzed originated from American Falls Walcott, located at a greater distance from 10-BT-08. Likewise, in an analysis of artifacts recovered from the Idaho National Laboratory (INL), a higher quantity of obsidian artifacts were made from Timber Butte, a source located in western Idaho, than several sources on the eastern SRP (Marler 2004). The corpus of SRP obsidian studies indicates a high variability between sources regarding utilization, transport distance, and overall quality. Due to discrepancies between the expected and observed frequencies of distinctive obsidian sources represented in the archaeological record of the SRP, it is evident that prehistoric people preferred some obsidian sources to others. However, the contributing factors for prehistoric preferential selection of these lithic resources are largely unknown.

Geospatial Technology and Least-Cost Path Analysis

Geospatial technology is a term used to describe a broad range of modern tools that aid in the geographic mapping and analysis of human societies, and the Earth and its processes. It includes various technologies such as GIS, Global Positioning Systems (GPS), Remote Sensing, Airborne Light Detection and Ranging (LiDAR), geophysical survey, imagery from Unmanned Aerial Vehicles (UAV), Photogrammetry, and more (McCoy 2021). The incorporation of geospatial technology into archaeological research has had a profound impact on the discipline. Chase et al. (2012) contend that archaeology is undergoing a geospatial revolution characterized by a "rapid change…focused on outlining large-scale natural and human-built landscapes" and that its transformations to archaeology are comparative to those of the radiocarbon revolution.

McCoy (2021) attempted to define the geospatial revolution by conducting a nearly exhaustive literature review of online literature involving geospatial technology in archaeology and found that 2005 marks the year that studies involving geospatial technology rapidly increased from 12 publications per year to 230 publications per year. McCoy (2021) recorded 997 published papers that relate to GIS and archaeology, with remote sensing and satellite imagery following close behind at 980 and 984, respectively. For my own work, I present a GIS-based archaeological study that implements a type of spatial analysis known as least-cost path(way) or optimal route analysis to model prehistoric travel routes using geochemically sourced artifacts as a proxy for movement.

Least-cost paths (LCPs) are mathematically-generated movement models that have been used in archaeology to understand regional social and economic networks (Moutsiou and Agapiou 2019; Howey 2007), to reconstruct ancient trade routes, roadways, or historical journeys (Güimil-Fariña and Parcero-Oubiña 2015; Howey 2007; Murphy IV 2015; Seifried and Gardner 2019), or to explain site location (Bell and Lock 2000), among others.

There are numerous variables that are of utmost importance to take into consideration when designing an LCP study. Topography is a crucial aspect to consider for studies aiming at modeling movement. The analysis of the topography of the study area is essential in LCP studies because it assists with identifying natural features that may impede or facilitate travel on foot. These variables, such as waterways, elevation, and land cover, can be used to construct cost surfaces for analyses, which are conducive for generating least-cost paths that are more representative of prehistoric mobility than straight-line distance (Howey 2007; White and Barber 2012). Herzog (2014) stresses the importance of starting with a simple model, so that it can be refined in an iterative fashion. Since this study is designed to look at broad patterns across a large portion of Idaho, the LCP model was designed in the simplest fashion by including a surface elevation model with Tobler's cost function applied. Arguably one of the most important components of an LCP study is the surface elevation raster that the accumulated cost surface (ACS) is constructed from (Fisher and Tate 2006; Kantner 2012). An ACS, also known as a friction surface represents the cost to travel per cell and is created by applying one or more mathematical transformations to one or more spatial datasets to create a single set of estimates that describes the difficulty of moving from one particular cell of the raster to an adjacent cell (Herzog 2014: White 2015).

Traditionally, limitations in the availability of high-resolution data or computing power have constrained archaeological case studies requiring the usage of high-resolution raster surface elevation models. The majority of research on error and uncertainty has been conducted on surface elevation rasters in grid format (i.e., USGS DEM) (Fisher and Tate 2006). Kantner (2012) recommends using a surface elevation model with a resolution of 30 m or finer. Although error can be reduced by incorporating high-resolution, high-accuracy surface elevation raster layers, such as those created using LiDAR technology, uncertainty will still be propagated in the LCP result because error cannot be entirely eliminated (Lewis 2021). It should also be mentioned that surface elevation datasets represent the current elevation of the landscape which may be misrepresentative of past conditions, especially in regions prone to earthquakes and flooding.

Cost-path algorithms differ according to whether they are isotropic or anistropic. Isotropic models assume that the travel cost is consistent regardless of which direction the space is crossed; whereas, anistropic models are dependent on the direction of travel (Gietl et al. 2007; Kantner 2012; Silva and Pizziolo 2001). Tobler's hiking function is the most popular cost algorithm incorporated into archaeological studies modeling movement (Gorenflo and Gale 1990; Lucero et al. 2021; Richards-Rissetto and Landau 2014; Taliaferro et al. 2010; White and Barber 2012; Wood 2006). Tobler's hiking function was used in the first LCP study in archaeological inquiry, which aimed to map regional settlement patterns in the southern Basin of Mexico to determine patterns of settlement interaction (Gorenflo and Gale 1990). Tobler's hiking function is an anisotropic model that has the ability to account for up-hill and down-hill travel while assessing the time necessary to traverse the given surface (Taliaferro et al. 2010). The function is expressed as:

$$w = 6\exp^{\{-3.5*\mathrm{abs}(S+0.05)\}}$$

where W is the speed of movement on foot represented as kilometers per hour and S is the slope measured as vertical change over a given horizontal distance (Lucero et al. 2021; Taliaferro et al. 2010; Tobler 1993). Using this function, a maximum walking velocity is achieved at down-grades between five and seven degrees which equates to 6 km/h, and the base walking pace for traversing a surface with zero degree slope is 5.037 km/h (Taliaferro et al. 2010; Tobler 1993).

The estimates for Tobler's hiking function were first recorded by Imhof in 1950 and are based on marching data from the Swiss military hiking a known route (Kantner 2012). The high walking pace estimations produced by the hiking function have been noted (Herzog 2020) and there have been attempts to modify the formula (Máruqéz-Perez et al. 2017; Sandor 2018). A multiplier of 0.6 or 1.25 can be applied to Tobler's hiking function for off-path or horseback travel, respectively.

Hunter-gatherer research on mobility of contemporary tribes have shown that, although fully capable of traveling at high speeds, foraging communities tend to travel at reduced speeds (Marlowe 2010). Marlowe (2010) notes that the Hadza hunter-gatherer tribe in northern Tanzania take between six and seven hours to move 11 km on average; a distance that can be easily covered within three to four hours. Tobler's off-path hiking function reduces the maximum walking velocity of 6 km/h to 3.6 km/h with a base speed reduced from 5.037 km/h to 3 km/h (Lucero et al. 2021). This study incorporates Tobler's off-path hiking function, with a multiplier of 0.6, because it produces cost estimations that may be more representative for hunter-gatherer mobility.

Since Tobler's hiking function calculates walking velocity, the reciprocal of the formula was used to calculate pace. The vertical factor represents the effort to overcome slopes. In general, it is more costly to overcome steep slopes than flatter slopes. A vertical factor table representative of values for Tobler's off-path hiking function was revised from Tobler's footpath function vertical factor table (Tripcevich 2009) to generate reduced travel times. The first column of the table represents the degree of slope and the second column represents the time it takes (m/hr) to travel through the cell.

Distance Toolset versus Legacy Distance Toolset

The Distance Toolset introduced at the Esri User Conference in July 2020 introduces six new distance tools, and applies a better algorithm compared to the earlier cost distance and path distance functions (Johnston et al. 2021). The new algorithm examines all directions out of a cell rather than eight, avoids distance distortion caused by cell centers, and the output back direction rasters produce ranges from 0-360 rather than 1-8 (Johnston et al. 2021). The prior algorithm used for LCP analysis in ArcGIS uses the node and link cell representation used in graph theory where each center of a cell is considered a node and each node is connected to adjacent nodes by multiple links (Esri, n.d.). Each link has an impedance associated with it and the LCPs are derived from the costs associated with cells at each end of the link and from the direction of movement through the cells (Esri, n.d).

The recently incorporated algorithm measures the cost distance in all directions by reconstructing a continuous accumulative surface instead of finding paths through a network of cell centers. The surface reconstruction algorithm approach is superior to the prior algorithm because it uses concepts from differential geometry to calculate true distance and costs in all directions (Esri, n.d.). The surface reconstruction algorithm is similar to network-based algorithms except the addition of one extra step known as the Eikonal Step (Sethian and Vladimirsky 2000). The Eikonal Step reconstructs both the elevation of the accumulative cost surface and the direction of steepest descent starting from each cell's slope (Esri, n.d.), which eliminates the necessity of involving a slope raster in the model. For a more detailed description of the Eikonal Step, see Sethian and Vladimirsky (2000).

CHAPTER 3: METHODS AND RATIONALE

The foundation of this study is grounded in several avenues of theoretical inquiry ranging from human behavioral ecology to geochemical characterization, which contribute to the reliability of this study. Idaho is an ideal location to model prehistoric mobility because it contains nearly two dozen obsidian sources that are chemically distinguishable, and obsidian provenance studies have created a wealth of data that indicate which sources pre-colonial people exploited. Additionally, this study incorporates perspectives from human behavioral ecology, specifically optimal foraging theory, to create an empirically based optimality and predictive model of prehistoric travel on the SRP. Furthermore, this study uses a state-of-the-art toolset introduced by Esri in July 2020 that reduces error in least-cost path modeling in ArcGIS software by incorporating a surface-reconstruction algorithm, which eliminates the necessity to involve slope in the model. Finally, a product of this research is a permanent digital database containing obsidian sources, provenance data, and data generated from this study to be kept at the Idaho State Historical Society (ISHS) and ESAR to facilitate further research. Note that all supporting materials for this research are located at https://github.com/Cotatal2/LCP-Analysis-on-Snake-River-Plain.git .

Data Acquisition and Standardization

A search for obsidian provenance data in Idaho on Google Scholar, the CAMAS database, and the Idaho Archaeologist online journal repository turned up 224 sites, however, only 203 of those sites were included in this analysis due to restrictions on their use by stakeholders or federal/state agencies. The ESAR and ISHS provided locations for the archaeological sites and CAMAS provided locations for the obsidian sources in Idaho; archaeological sites located north of Idaho County were not included in this study. Data retrieved from 17 studies (Table 1) included lithic debitage and a variety of stone tools that were recovered in Idaho and geochemically sourced to a distinct source in Idaho or eastern Wyoming. In addition to Idaho obsidian quarries, three localities in Wyoming (Teton Pass 1 & 2 and Obsidian Cliffs) were used to generate the LCPs.

Table 1. Studies where obsidian provenance data were retrieved.

Author	Site(s)
Arkush and Hughes 2018	10-CL-23; 10-CL-11; 10-BT-08; 10-CL-03
Basso et al. 2016	10-EL-1367
Black, M. 2014	10-BN-23; 10-BV-48; 10-CN-05; 10-CN-06; 10-CR-52; 10-EL-110; 10-EL-215; 10-EL-294; 10-EL-110; 10-EL-1367; 10-EL-1577; 10-OE-3686
Clegg, A. 2016	10-OA-3
Dudgeon et al. 2015	10-BK-01
Eastman, M. 2011	10-EL-294
Harris, K. 2014	10-BT-08
Harris, K. 2011	10-BT-08
Hughes, R. 2005	10-CL-03
Keene, J. 2016	10-CL-03
Krauel, E. 2017	10-CA-33
Kumm, E. 2019	10-TF-31
Plager, S. 2001	Many
Plew, M. 2013	10-EL-110; 10-EL-215; 10-EL-1367
Vanwassenhove et al. 2018	10-EL-1417
Willson, C. 2005	10-CN-01; 10-CN-05; 10-CN-06; 10-EL-1477; 10-EL-1577; 10-EL-22; 10-EL-294; 10-EL-392; 10-AA-17; 10-OE-269
Zumkeller, B. 2020	10-CL-11

Altogether, 5,898 sourced lithic materials distributed throughout 203 localities in Idaho were used to analyze the frequencies and occurrences of distinguishable obsidian types throughout the region. The 203 localities where obsidian artifacts were recorded and known lithic quarries in the region were used for starting and destination points for the LCPs. Normalizing the data proved challenging because of the high variability of the quantity of sourced materials between sites. Only eight of the locations contained over 100 sourced materials. There were 67 sites that consisted of isolated finds. Seventy-four sites contained between two and nine sourced materials, and 31 localities contained between 10 and 99 lithic materials. Additionally, comparable variability in representation of materials existed between chemically distinguishable obsidian sources, with Timber Butte occurring at the most localities (103) and Jordan Creek obsidian appearing once in Canyon County.

Due to the broad range of observations, the study area was gridded into 53 x 47 km cells using the Fishnet Grid geoprocessing tool. The Spatial Join geoprocessing tool was used to add the total counts of obsidian observations for each cell from a point feature class containing records of obsidian frequencies for all of the sites (Figure 3). The frequency of materials for the distinctive obsidian sources were recorded (Figure 4). As Figure 3 illustrates, there was a broad range of fishnet grid frequency counts ranging from 0 to 2,094, with only eight cells exceeding 100 sourced materials. Due to sampling issues caused by the overall variability of data collected for the study, occurrences rather than frequencies were counted and used for analysis.

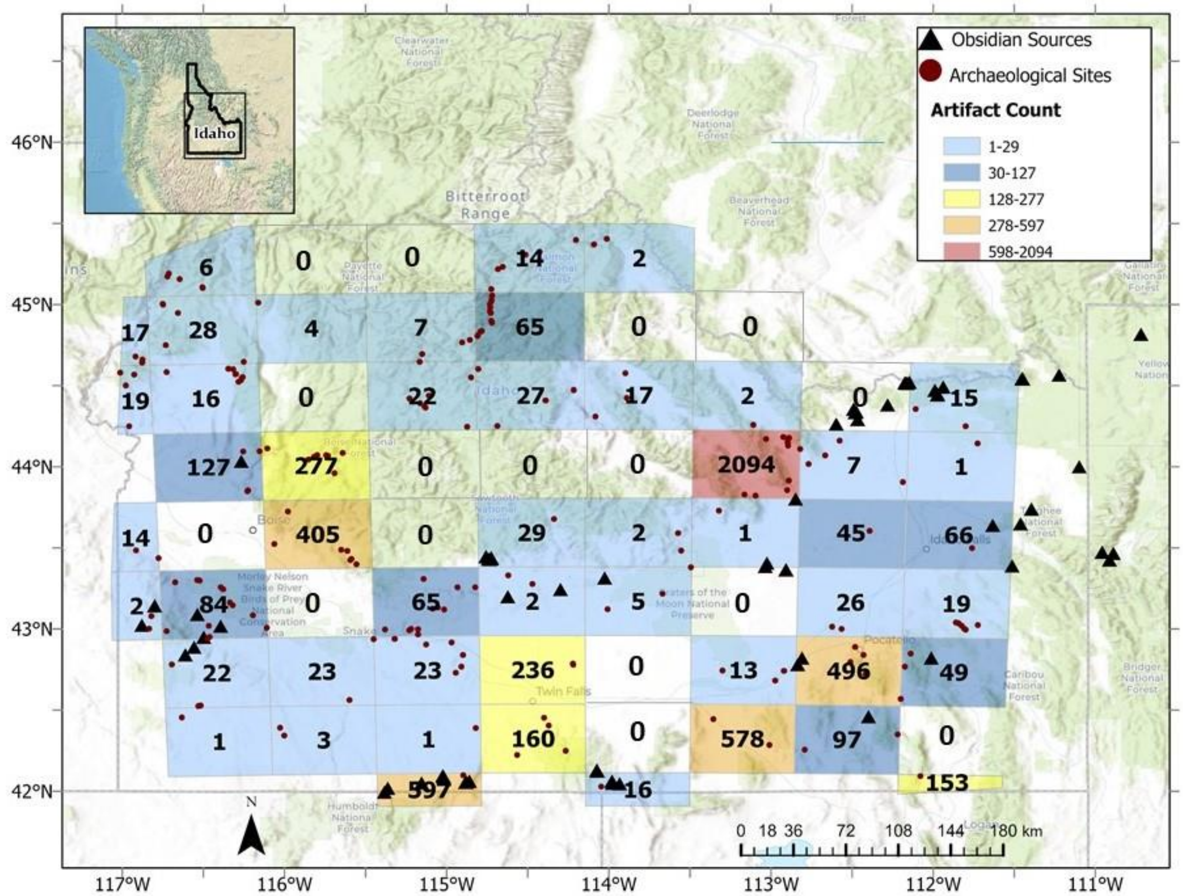

Figure 3. Result from using the Fishnet Grid and Spatial Join geoprocessing tools. Each cell is 53 x 47 km and represents the total number of geochemically sourced obsidian artifacts recovered within that area (n=5,898). Note that column A and rows 1 and 9 are reduced in size because they represent the boundary of the surface elevation raster and the non-shaded grid cells contain no data.

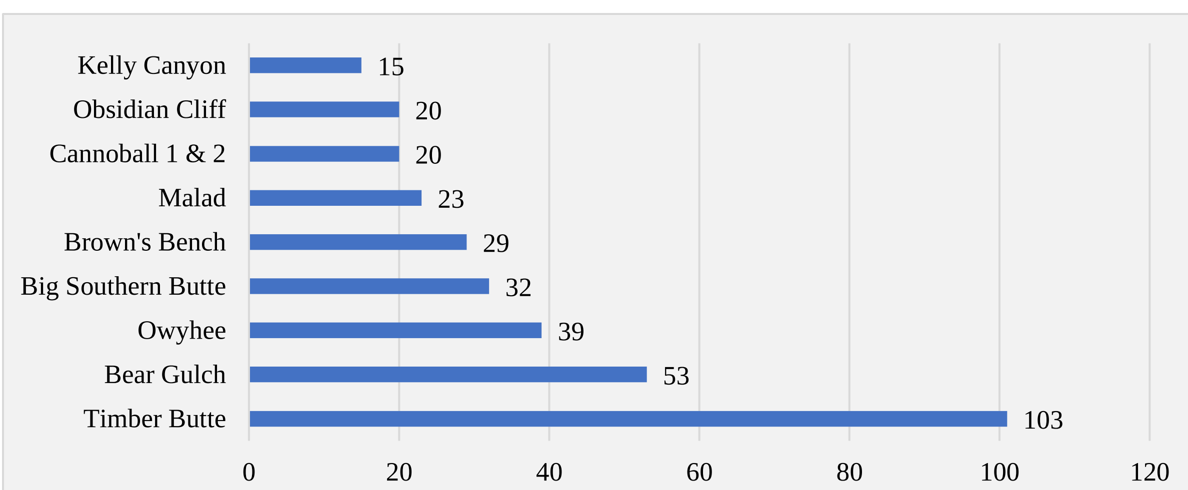

Figure 4. The number of occurrences for the top ten obsidian sources recovered from archaeological sites (n=203).

Geoprocessing Workflow

The GIS software used for this study was ArcGIS Pro 2.9.2. The project began by importing Excel spreadsheets containing coordinates for obsidian localities and archaeological sites into a project in ArcGIS Pro. All data were projected into North American Albers Equal Area projection using the Project and Project Raster geoprocessing tools. Multi-point feature classes were then created for obsidian sources that contained multiple exposures, such as Brown's Bench and Packsaddle, to generate LCPs from the "least-costliest" exposure in relation to the destination input.

Besides the spatial locations of obsidian sources and archaeological sites, the surface elevation raster and a Vertical Factor table representative of Tobler's off-path hiking function were the most significant components involved in this model. Ten-meter resolution surface elevation and hillshade raster layers (Weber 2022) were used in the Distance Accumulation geoprocessing tool and for visualization of the maps for LCP (see Appendices B and C) and Euclidean Distance calculations. The two raster layers were clipped to a polygon that represented the study area using the Clip Raster geoprocessing tool. The surface elevation raster, which is a raster layer that defines elevation values at each cell location, was pit-filled using the Fill geoprocessing tool to remove pits in the surface layer.

Geoprocessing for the project was accomplished through scripting to generate 81 distance surfaces for both directions and straight-line travel, and the geoprocessing pane to generate LCPs and add surface information to the paths. The Distance Accumulation geoprocessing tool was used to create the distance accumulation and back direction rasters required for the analysis; the simplest input into the tool is to supply an input source and a surface elevation raster, which generates raster layers for the shortest distance to the destination input (straight-line). Each cell in the output source raster generated from the Distance Accumulation geoprocessing tool contains a value that represents the impedance to travel through that cell, and the back direction raster determines the next cell along the shortest path to the destination (Johnston et al. 2021).

In addition to the 10-m surface elevation model, the vertical factor table was included in the Distance Accumulation geoprocessing tool to generate a cost of procurement for LCPs representing travel from obsidian sources to archaeological sites. By default, the tool calculates routes based on travel from the input source used in the Distance Accumulation geoprocessing tool to the input source used in the Optimal Path as Line geoprocessing tool. To calculate routes for the opposite direction of travel, the travel direction parameter in the Distance Accumulation geoprocessing tool was changed to “travel to source”. In this instance, “travel to source” refers to travel from input source in the Optimal Path as Line geoprocessing tool to the source input for the Distance Accumulation tool. Geoprocessing for the Distance Accumulation tool using a 10-m resolution surface elevation model took anywhere between 7.5 to 11 hours to complete for a single obsidian source. Fortunately, the following two geoprocessing tools used in this analysis took only minutes to run if errors were not encountered.

Once the raster layers were created in the Distance Accumulation geoprocessing tool, the Optimal Path as Line geoprocessing tool was used to generate the LCPs. The input source for the Distance Accumulation tool were the obsidian quarries, so the source input into the Optimal Path as Line geoprocessing tool were the point feature classes representing the archaeological sites. In addition to the input source, both raster layers created from the Distance Accumulation geoprocessing tool were input into the Optimal Path as line geoprocessing tool. The outputs were line feature classes containing values for the planimetric distance and cost. To calculate distance crossed over a geodesic surface and the average slope crossed, the Add Surface Information geoprocessing tool was used.

To complete this research in a timely manner, geoprocessing was executed on three computers in the GIS Training and Research Center (GIS TReC) so that cost surfaces and LCPs for both directions travel could be generated simultaneously. The third computer was used to calculate Euclidean Distance and create maps representing obsidian frequencies. Figure 5 illustrates the geoprocessing tools used to generate the LCPs and straight-line distance calculations. Least-cost paths were generated from 27 obsidian sources to the 202 archaeological sites included in this study for both directions of travel (movement between lithic quarries and archaelogical sites). Additionally, Euclidean distance for these paths were generated for comparative purposes. The use of three computers enabled the possibility of generating 20,904 LCPs representing optimal travel routes obsidian quarries and locations where obisdian artifacts had been recovered.

The term "possibility" is stated in the preceding paragraph because it was not feasible to generate all LCPs due to an "0100005: Unable to Allocate Memory" error in ArcGIS Pro software. The error was encountered on multiple occasions in separate projects while using geoprocessing tools, Modelbuilder, and Python scripts. Despite efforts to identify the issue by recording which runs the errors occurred on and working with Esri's technical support, the exact cause of the issue was not determined. It was impossible to generate 202 LCPs during a single run without receiving the error, so the archaeological site dataset was reduced multiple times to try to generate data for as many sites as possible; altogether, a total of 10 datasets containing approximately 20 sites per set were used to generate the LCPs. Although the memory error continued to occur, reducing the dataset minimized how often the error occurred.

Esri's technical team did not experience errors while troubleshooting this project and were unable to identify a solution. The computers for this research had 32 GB of installed RAM, whereas, a computer with 64 GB of RAM was used to troubleshoot, which may be a factor for why the error was not encountered on their side. At times, the reduced datasets of 20 did not resolve the memory error which required those datasets to be reduced further. Interestingly, there were some locations where generating LCPs was problematic for a specific obsidian source, but LCPs were generated without any issues from that location to other sources. Additionally, there were other times when generating a single LCP during a single geoprocessing run resulted in the error; this indicates that the memory error may be caused from an underlying issue where reducing the dataset will not resolve the problem.

Once LCPs were generated and additional surface information calculated, the Table to Excel geoprocessing tool was used in batch mode to export the data out of GIS into Excel files. The data was then reformatted and can be viewed at the project GitHub repository. Various attempts were made at visualizing site frequencies in ArcGIS Pro such as varying the symbology by size and using pie chartsfrom; these are also available for viewing on the GitHub Repository.

The Create Fishnet geoprocessing tool was used to used to create 53x47 km cells. When setting parameters in the tool, the user is given the option to specify whether the output feature class will be polyline or polygon. For this study, the polygon feature class was selected in order to allow data from the underlying archaeological site point feature class containing counts for sourced materials to be appended to the fishnet grid cells across the study area; this was accomplished using the Spatial Join geoprocessing tool.

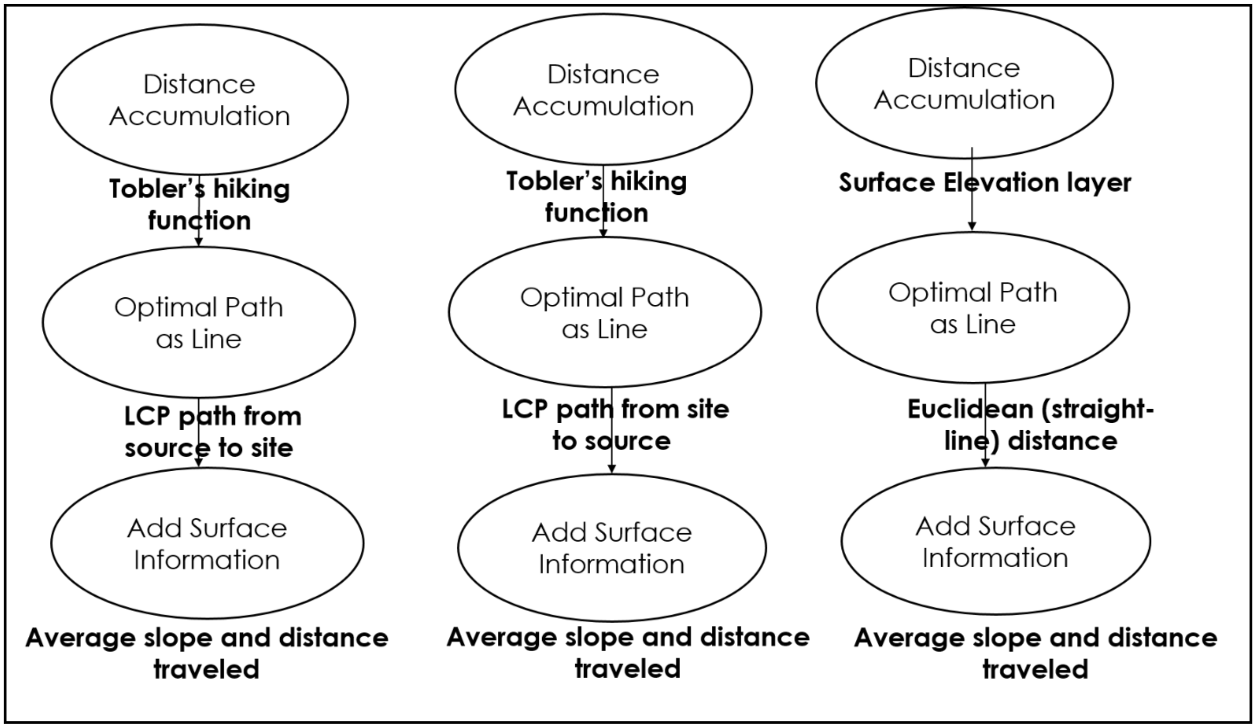

Figure 5. Geoprocessing workflow for generating least-cost and straight-line paths in ArcGIS Pro software, where the ovals represent geoprocessing tools. The left and middle columns represent LCPs for both directions of travel and the right column represents the straight-line distance. Each column was repeated 27 times to produce cost surfaces for obsidian sources and three sub-sources. Note that the surface elevation raster was used in addition to Tobler's off-path hiking function in the Distance Accumulation geoprocessing tool when generating the least-cost paths.

Once geoprocessing was completed for the project, the geodatabases containing travel routes that were generated on the three computers at GIS TReC were compiled into a single project geodatabase. Additionally, the obsidian source point feature classes and archaeological site point feature classes were compiled into the same geodatabase as the LCPs. The feature class attribute tables for the obsidian sources, obsidian frequencies, and archaeological sites were reformatted to reduce the projects required storage space. This was accomplished by replacing all "text" domains with coded value attribute domains; a complete listing of the coded values is located in the project repository.

CHAPTER 4: RESULTS

The majority of lithic materials in this study originated from obsidian source quarries Malad, Walcott, and Timber Butte (Figure 6), and Timber Butte, Bear Gulch, and Owyhee obsidian were recorded at the most locations with 103, 53, and 39 observations, respectively (Figure 4). Results of the study, however, indicate that Bear Gulch and Timber Butte are the most widely distributed obsidian sources in Idaho; Bear Gulch and Timber Butte obsidian were located throughout 58% and 56% of the study area, followed by Big Southern Butte, Brown's Bench, Owyhee, and Malad sources, respectively (Figures 7 & 8).

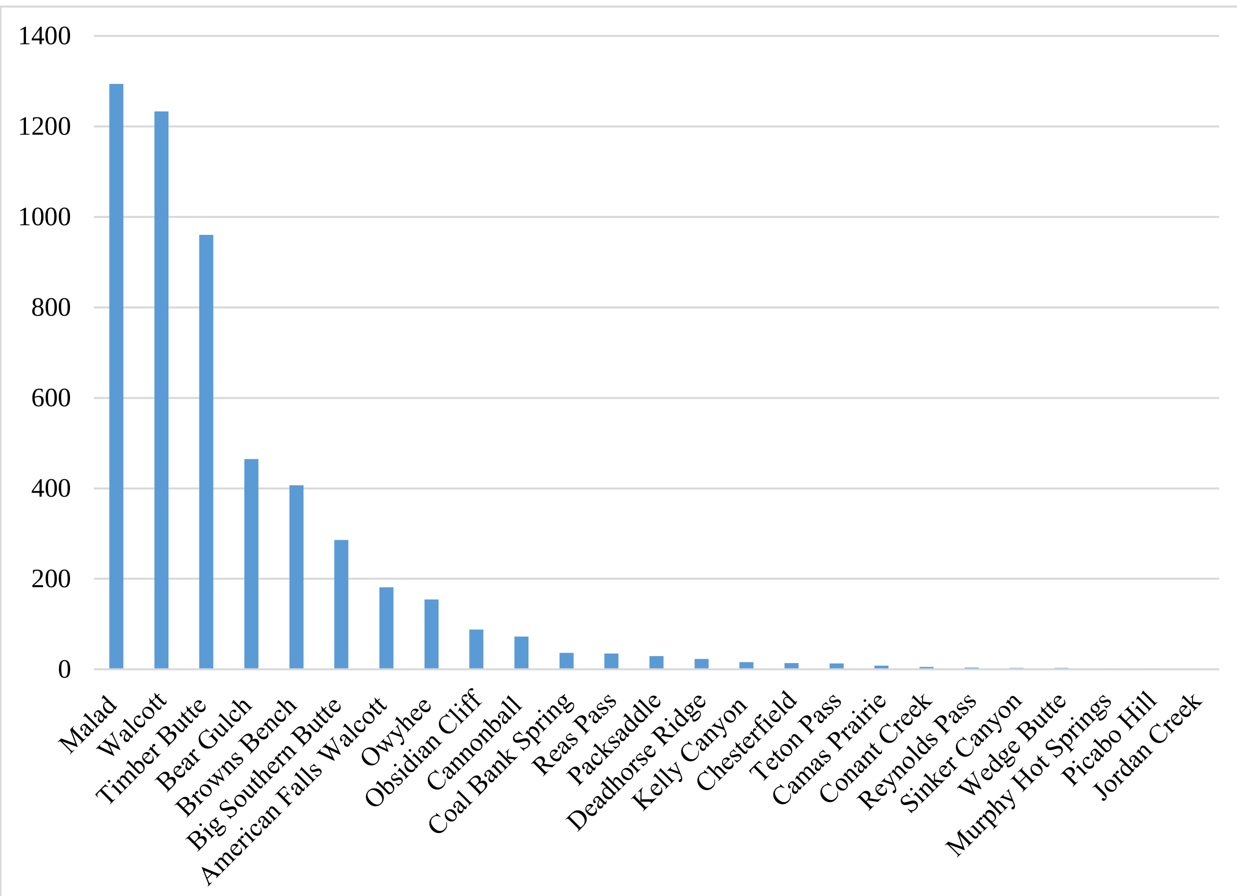

Figure 6. Total amount of geochemically sourced lithic materials in the study (n=5,334). The term "materials" includes obsidian debitage and numerous types of stone tools including, but not limited to, projectile points, spear points, scrapers, drills, bifaces, and unifaces.

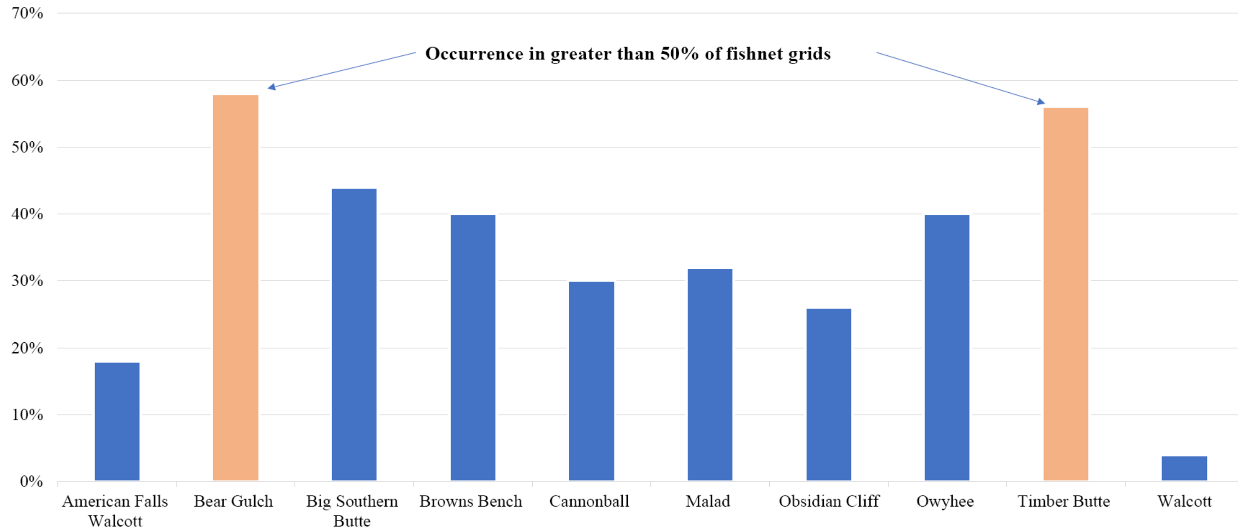

Figure 7. The most widely distributed obsidian sources in Idaho. Timber Butte and Bear Gulch obsidian were located in over 50% of the study area. Bars equal the percentage of fishnet grids with each obsidian source present (top 10; all greater than 1% of total sourced artifact count).

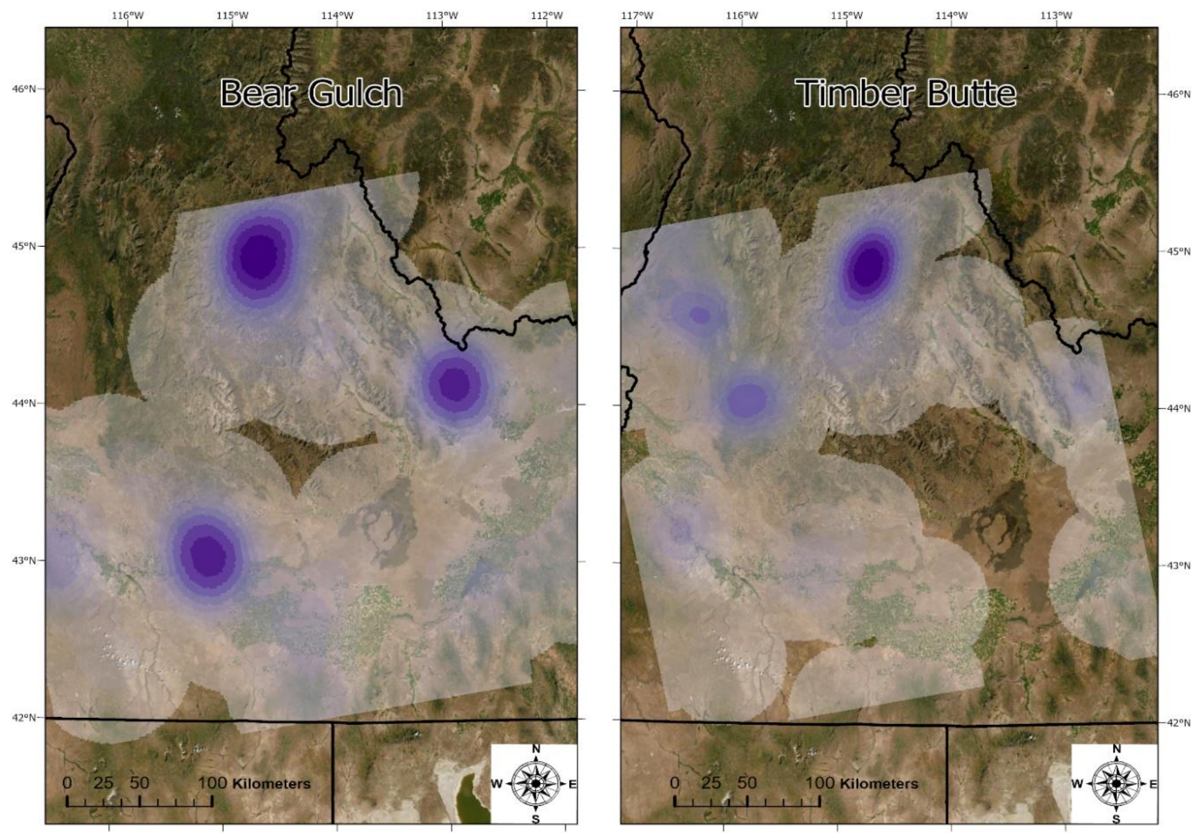

Figure 8. The Kernel Density geoprocessing tool was used to create heat maps for Timber Butte and Bear Gulch obsidian sources, which demonstrates that Bear Gulch is more widely distributed than Timber Butte.

Quantitative values for the distance (km), cost of travel (hr/km), and average slope were generated for all LCPs (see GitHub Repository). LCPs for both directions of travel between obsidian sources and archaeological sites were generated. The LCP visuals for observation-specific and predictive modeling for travel from obsidian sources to archaeological sites are located in appendices B and C.

CHAPTER 5: DISCUSSION

Idaho is an ideal location for constructing models of human movement and source use due to the numerous obsidian sources in the region and the means to distinguish between those sources. Archaeological evidence indicates that prehistoric people were aware of these lithic quarries due to the high quantity of obsidian artifacts recovered throughout the region. Prior geochemical research indicates that the exploitation rates between obsidian sources is highly variable (Fowler 2014; Kumm 2020; Plager 2001).

The majority of lithic material in the study originated from Walcott and Malad, thus it was surprising to find that those sources ranked 6th and 9th in their overall distribution. The discrepancy between the quantity of sourced material and its distribution is likely due to the variability in the data collected, as well as the primary research question from previous studies. Several of the studies focused on intensive sourcing of artifacts from heavily studied sites such as Wasden (10-BV-30), Bobcat Shelter (10-CL-11), Kyle Canyon Spring (10-BT-08), Wilson Butte Cave (10-JE-06), and Veratic Rockshelter (10-CL-03) (Harris 2014; Hughes and Smith 1993; Keene 2016). Additionally, a couple of studies focused on sourcing debitage (Clegg 2016; Fowler 2014), which would inevitably produce higher quantites than preform or finished artifacts. Timber Butte, Bear Gulch, Big Southern Butte, Brown’s Bench and Owyhee obsidian appeared in the most grid cells indicating that they are transported the farthest in the region.

Previous studies have noted Timber Butte, Malad, Big Southern Butte, Brown’s Bench, and Owyhee as the five prevalent sources in the region (Holmer 1997; Plager 2001; Plew and Willson 2007); however, this study suggests that Bear Gulch might be the dominating source of eastern SRP and that Malad obsidian may be preferred less than previously thought.

Holmer (1997) observed that obsidian from the southeastern moutains was never transported into the central mountains, and vice versa (Figure 9). The same phenomena was observed in this study with regards to the Timber Butte and Malad obsidian sources (Figure 10) .

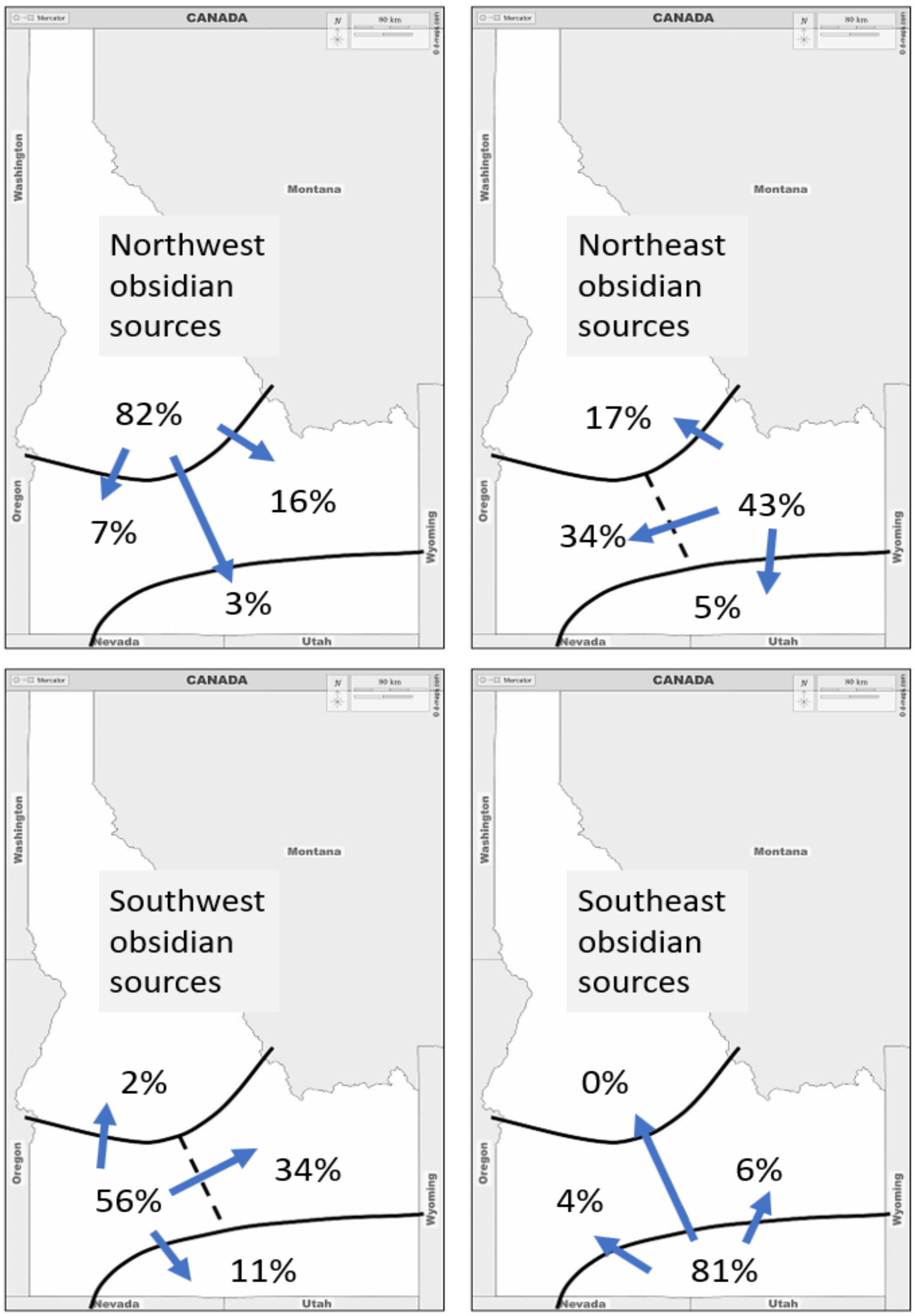

Figure 9. Percent and direction of movement of obsidian in Richard Holmer's study of volcanic glass use on the SRP. Adapted from Holmer (1997).

Timber Butte had the second highest rate of transport, yet there was no occurrence of it in the southeastern mountains (Appendix B: Figure 19). Malad obsidian was recovered on the northwestern side of the SRP, several miles prior to entering the central mountains (Appendix A: Figure 11). Holmer (1997) questioned whether the SRP acted as a barrier, whether the two mountain areas were homelands to groups of people who did not interact with one another, or whether people did not carry tools and raw materials into areas that had plenty of high-quality material already there. While this study doesn't shed any light on the question of ethnicity or interaction, it can be fairly certainly concluded from this research that the SRP did not act as an efficient barrier for travel.

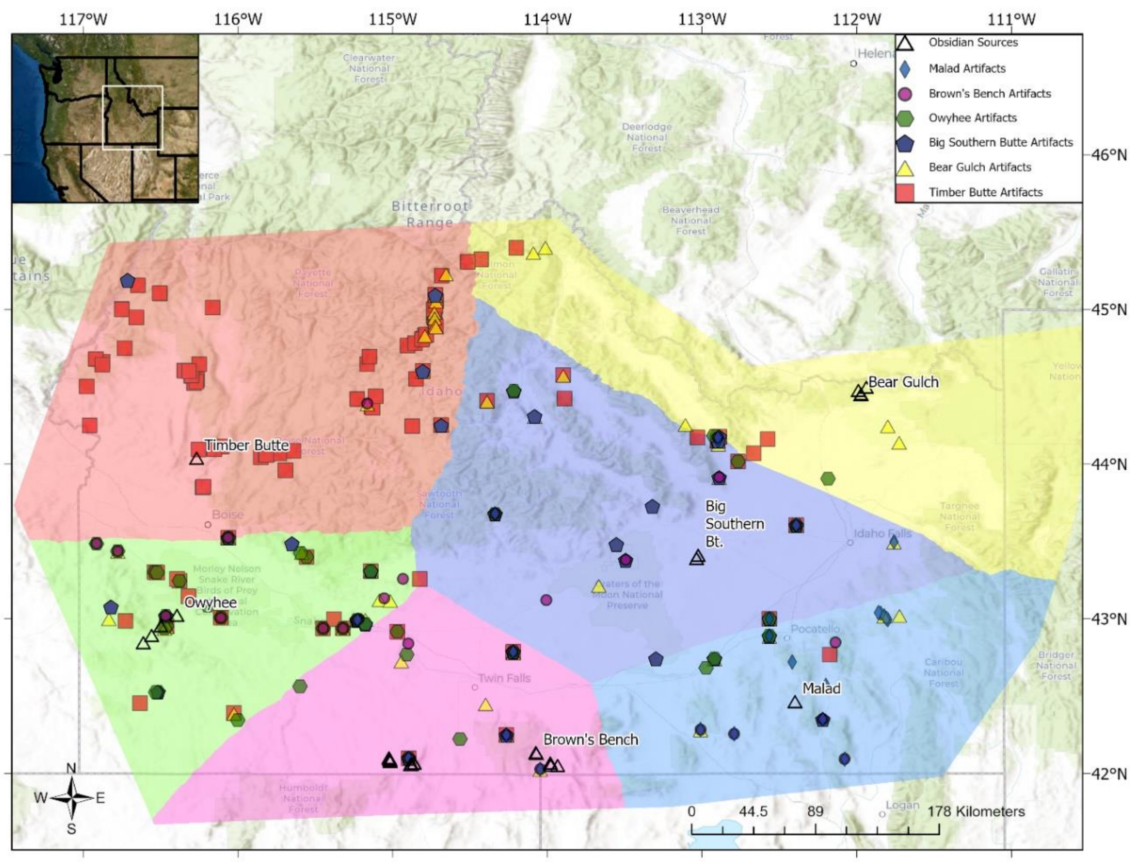

Figure 10. Distance Allocation showing the distribution of artifacts in relation to obsidian sources. The top six obsidian sources were used to divide the study area into "least-cost" regions. Each shaded region acts as a watershed and catchment area that delineates the areas of least effort for obsidian procurement on the landscape. The shapes represent obsidian artifacts and the colors correspond to which obisidan source it originated from.

This research has revealed some anticipated, as well as unexpected patterns in the obsidian distribution on the SRP. During its commencement, it was expected that the execution of this study would enable us to answer broad-scale questions about obsidian usage, distribution, and transport on the SRP, but the outcome seems to be the opposite where we are left with more questions. This study only scratches the surface in demonstrating the siginficance of incorporating GIS into archaeological research and further obsidian collection and testing will need to be performed before any strong conclusions can be made. Fortunately, this research has helped to identify research areas that will undeniably help to produce more conclusive results and inevitably ehance our knowledge and understanding of obsidian use and prehistoric mobility in the future.

Recommendations for Research

This research generated more questions than it answered and opened doors for fascinating areas of research to be conducted in the future; a few of the many avenues of future research are described in the following sections. Additionally, some limitations from the study are noted and recommendations are stated.

Typological Analysis

As noted by Henrikson (2004), LCP studies have been frusturated by the inability for inclusion of temporality due to the lack of data; this research is no exception. More often than not in geochemical research, the primary objective is to source obsidian, thus, minimal further testing is performed. Thousands of projectile points have been recovered from the region, yet little is known about many of them. Geochemical sourcing studies are of common interest in the region and data is readily available, yet typological analyses are limited. The ability to identify locations of origin on a prehistoric landscape is significant, but the ability to determine when obsidian sources were exploited and the variation in rates of exploitation throughout time is just as significant, if not more, in enhancing our knowledge and understanding of obsidian use.

Further Testing of Timber Butte and Owyhee Obsidian

It is evident that the two major obsidian sources in the region are Timber Butte in western Idaho and Bear Gulch in eastern Idaho. Extensive quality testing on obsidian from eastern Idaho has been performed at ISU, but Timber Butte was recently added to the collections during the summer of 2021; therefore, little is known about the quality of Timber Butte in comparison to eastern Idaho sources. Observations for Timber Butte obsidian nearly doubled all other sources and its distribution rate followed the top obsidian source, Bear Gulch, by only 2% (Figure 7). Determining the fracture predictability and smoothness of Timber Butte in comparison to the eastern Idaho sources will help to determine whether Timber Butte was highly exploited due to its quality or location, or some other factor as yet undiscovered. Timber Butte is the only known obsidian source in western Idaho located north of the Snake River (and SRP) and, if trending hypotheses about the first people in America are accurate, Timber Butte would have been the first obsidian quarry encountered by people moving inland from the Columbia River drainage basin. Furthermore, Timber butte would have been one of the only accessible obsidian sources for 2,000 years following the Bonneville Flood 14,000 years ago (Currey 1990). Likewise, further testing on Owyhee obsidian at ISU would vastly increase our understanding of obsidian use on the SRP.

Expanding Obsidian Source Database

There were 23 obsidian sources outside of the state where artifacts recovered in Idaho were sourced to. This study only included obsidian sources and archaeological sites located within state boundaries (beside Teton Pass and Obsidian Cliffs). It is not surprsing to find obsidian coming from out-of-state considering that the politically-defined state boundaries are certainly not representative of prehistoric travel and cultural boundaries. Expanding the obsidian database at ISU to include regional out-of-state sources would enhance future research by reducing error from these political boundaries that constrained this study.

GIS Applications

Now that LCPs have been generated to model movement on the SRP, the model can be refined to include additional variables such as landcover, waterways, or cultural boundaries. As noted by Herzog (2014), slope-dependent LCPs will often run in riverbeds, which was observed in this study. This is because the flow of water tends to follow the path of least-resistance as does slope-dependent LCPs. Given the distribution of archaeological sites in relation to water sources in Idaho, incorporating water into the model would be most productive. To accomplish this, input a line feature class representing watercourses into the barrier parameter in the Distance Accumulation geoprocessing tool. Ford crossings will need to be identified since travel past the barrier lines is prohibited. For additional instruction on how to incorporate river crossings into a LCP model, see Eric Langmuir's book *Mountaincraft and Leadership* (1995).

In addition to waterways, mapping Pleistocene lakes in the region and modeling paleoclimate may produce insightful results. Visit paleoclim.org to locate high-resolution paleoclimate data. Furthermore, Tobler's hiking function is a time-based cost algorithm. Insights might be gained from incorporating an energy-based algorithm. Additionally, some obsidian sources only had a couple of observations in the study area, but is this because the obsidian was low-use or because the obsidian was high quality and was transported outside of the state? Performing a regional-scale study similar to this that incorporates multiple states will help to distinguish definitive transport distances for obsidian sources.

Viewshed analyses are another form of spatial analysis that can delineate areas that are visible from a given location. Performing a viewshed analysis on the obsidian sources in Idaho will help to determine if visibility of a lithic quarry played a major role in preferential selection. It seems plausible that it may have some significance considering that a higher viewshed increases the safety of a traveler by reducing the chance of surprise attacks. Furthermore, if landmarks can be seen from a difference, the chances of getting lost are minimal. Lastly, statistical measures such as density clustering and spatial autocorrelation may be conducive to incorporate into future research.

The above paragraphs describe only a few of the many GIS applications that can be applied to enhance our knowledge and understanding of past cultures. It should be noted that GIS is rapidly evolving and, although not explicitly stated, numerous resources are available to assist with GIS-based research. Incorporating waterways and involving obsidian sources and lithic cultural materials outside of Idaho would be the most impactful to continue obsidian research from this model.

CHAPTER 6: CONCLUSION

Idaho's volcanic past makes it an ideal location to perform spatial analyses using geochemically-sourced data. This exploratory study involves applied GIS to look at a complex archaeological problem involving optimality and obsidian procurement on the SRP. Patterns in the distribution of obsidian were elucidated by simplifying an incomplete dataset and filling it in with more density. Additionally, a fine-tune geospatial model was integrated to predict how a person moves within the confines of the environment, which generated a quantitative currency to assess optimality. Furthermore, a permanent digital database was built to facilitate archaeological and geochemical research in Idaho.

This research reinforced the notion that obsidian does not typically remain localized and moves all over the landscape. It is evident by the distribution and transport distance of obsidian that some sources were preferred over others; something must be driving why some obsidian sources make it much further than others but the driving factor remains to be known. This study also helped to show that, although archaeological sites are predominantly situated near water, not all of them are. In fact, some high-occupation sites are located several miles from the nearest flowing water source.

Finally, this study generated a model that optimizes hypothetical travel over a difficult landscape. The model does not show what happened in the past, but it does demonstrate what could have happened. Archaeological excavations have occurred in Idaho for the past 70 years, and although scientific testing of cultural remains have already enlightened us on past lifeways, there is still so much waiting to be discovered. Error in the LCPs might be more prevalent on flatter slopes, such as on the SRP, but groundtruthing the mountain paths may uncover some interesting discoveries.

Although this research did not uncover the long sought after explanation for variation between obsidian sources in distance transport, I hope to have demonstrated the utility of GIS in studying human behavior. The incorporation of GIS in this research not only enabled us to generate an optimality model of prehistoric travel on the SRP, it also helped us to elucidate unexpected patterns in the distribution of archaeological sites and obsidian. This study confirms the idea that computers and mathematics can be implemented as useful research tools to better understand human behavior.

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Appendix A

Appendices B and C contain maps for travel from obsidian sources to archaeological sites. It was not feasible to include all supporting materials in this document. A GitHub project repository was created that includes Python scripts, the Vertical Factor table, datasheets (raw and final), maps and other visuals, and a directory file; these materials are located at https://github.com/Cotatal2/LCP-Analysis-on-Snake-River-Plain.git. Please refer to the directory file for a detailed description of the content.

Appendix B

This series of maps represent travel from obsidian sources to archaeological sites. Each map represents total observations for distinct obsidian sources. LCPs for American Falls Walcott, Wedge Butte, Bear Gulch, and Teton Pass II are not included (map for observations for Bear Gulch available on GitHub project repository. LCPs for all (or most in some cases) sites in the study are located in **Appendix C.**

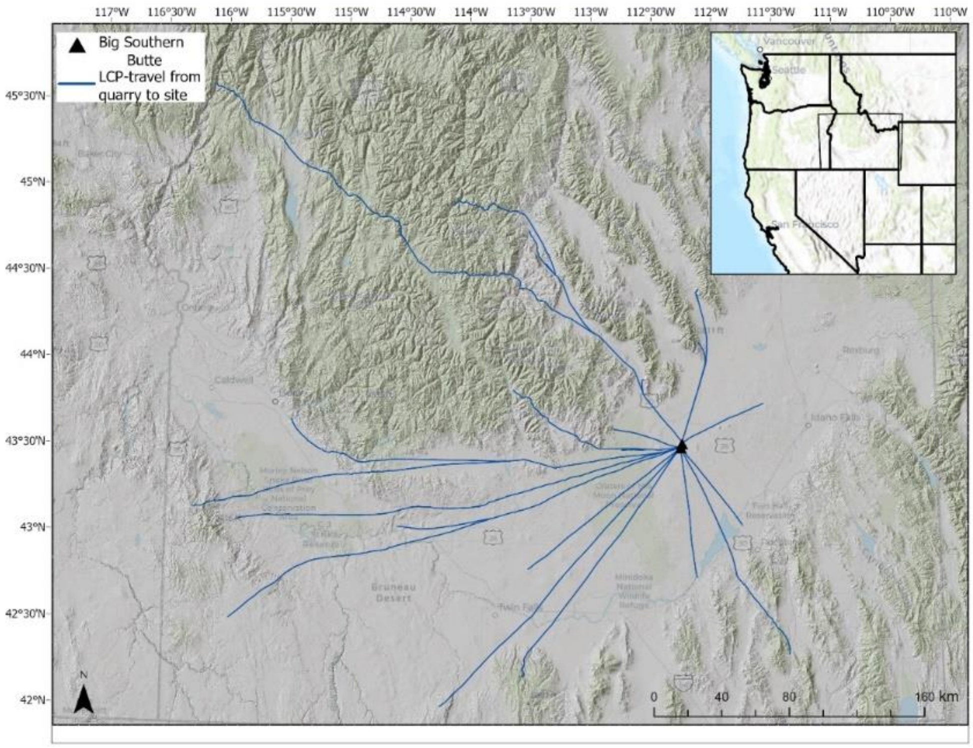

Figure 1. LCPs for Big Southern Butte. Map Scale is 1:2,100,000.

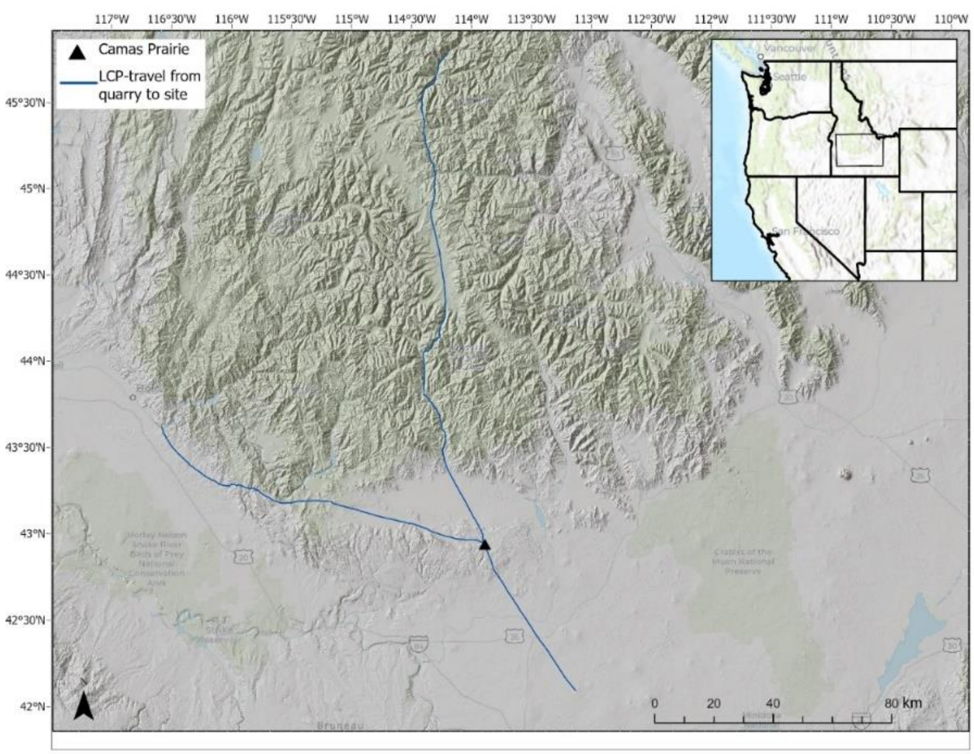

Figure 2. LCPs for Camas Prairie. Map Scale is 1:1,200,000.

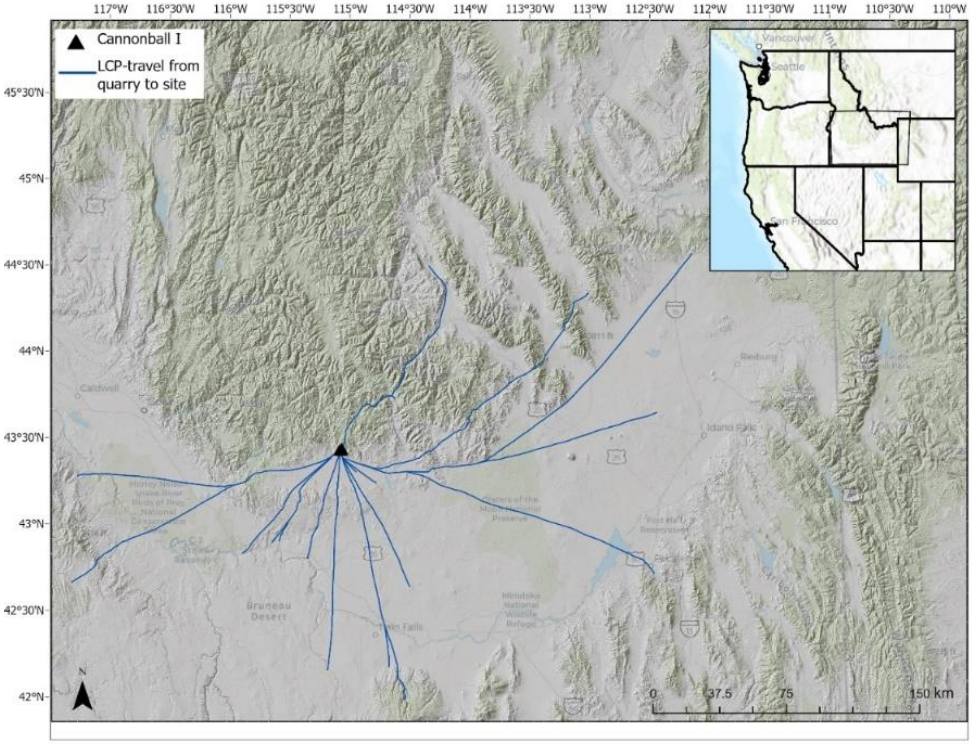

Figure 3. LCPs for Cannonball I. Map Scale is 1:2,000,000.

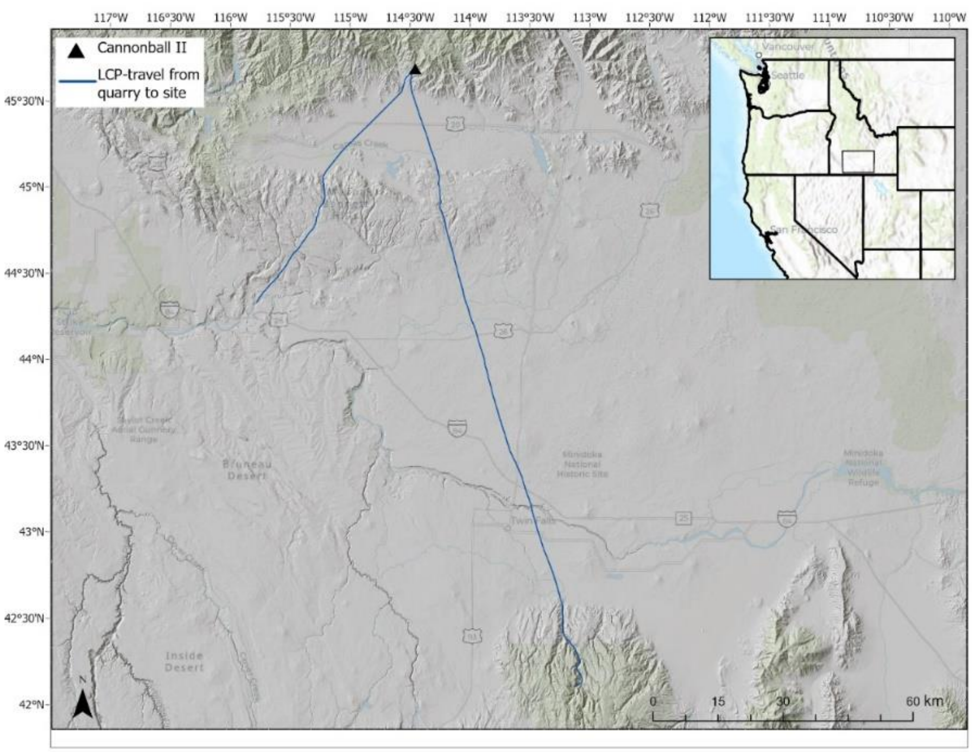

Figure 4. LCPs for Cannonball II. Map Scale is 1:819,200.

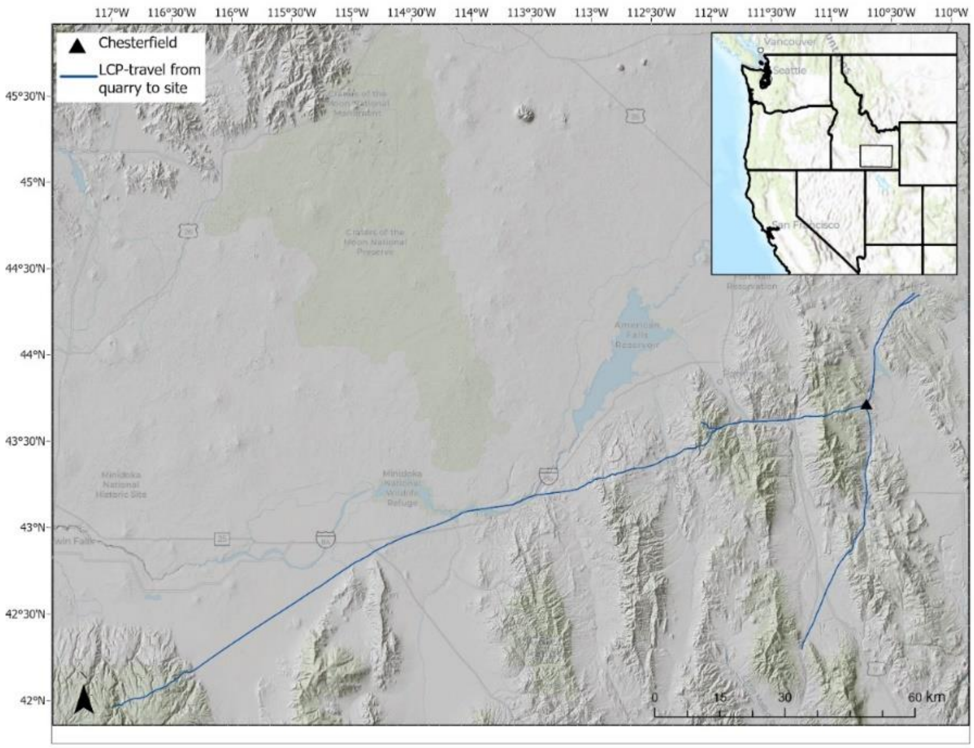

Figure 5. LCPs for Chesterfield. Map Scale is 1:819,200.

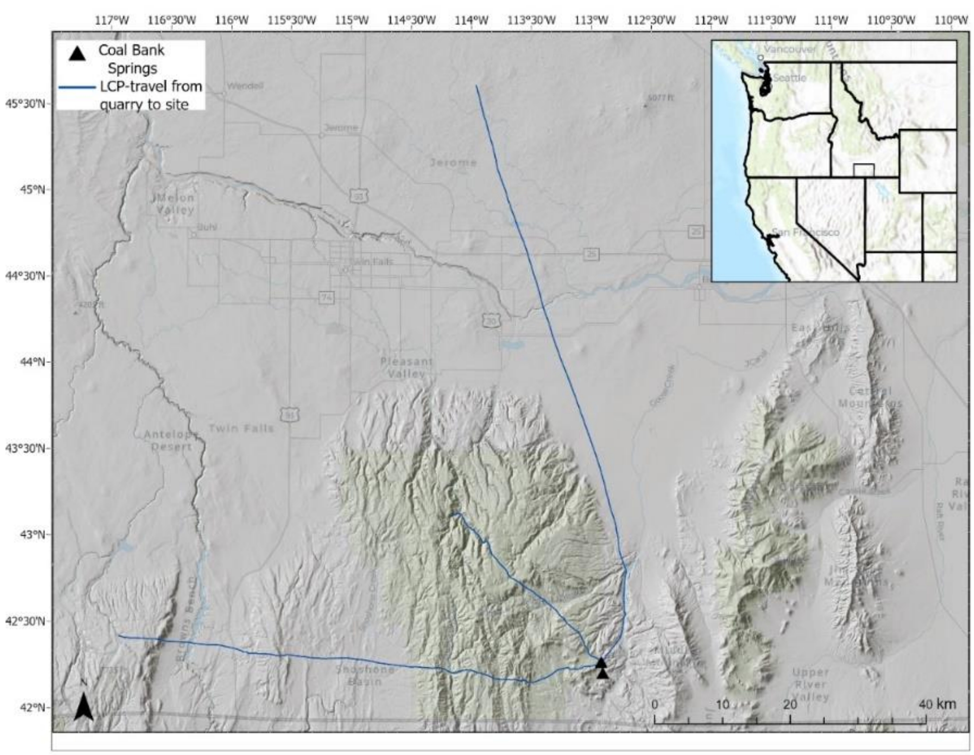

Figure 6. LCPs for Coal Bank Springs (subsources of Brown's Bench). Map Scale is 1:524288.

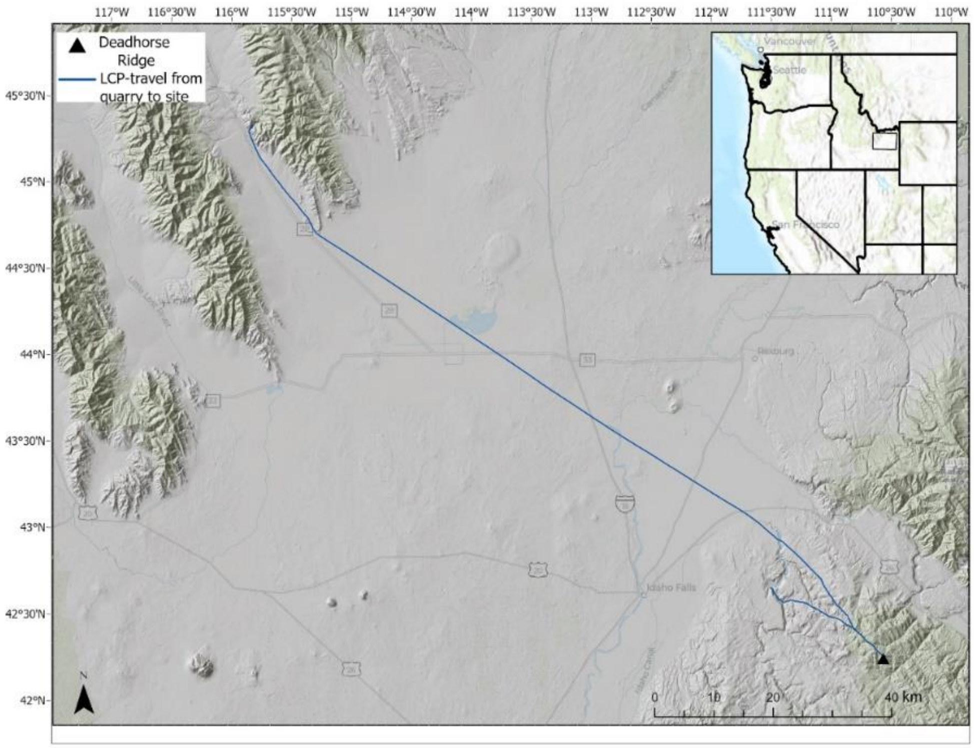

Figure 7. LCPs for Deadhorse Ridge (subsource of Packsaddle). Map Scale is 1:600,200.

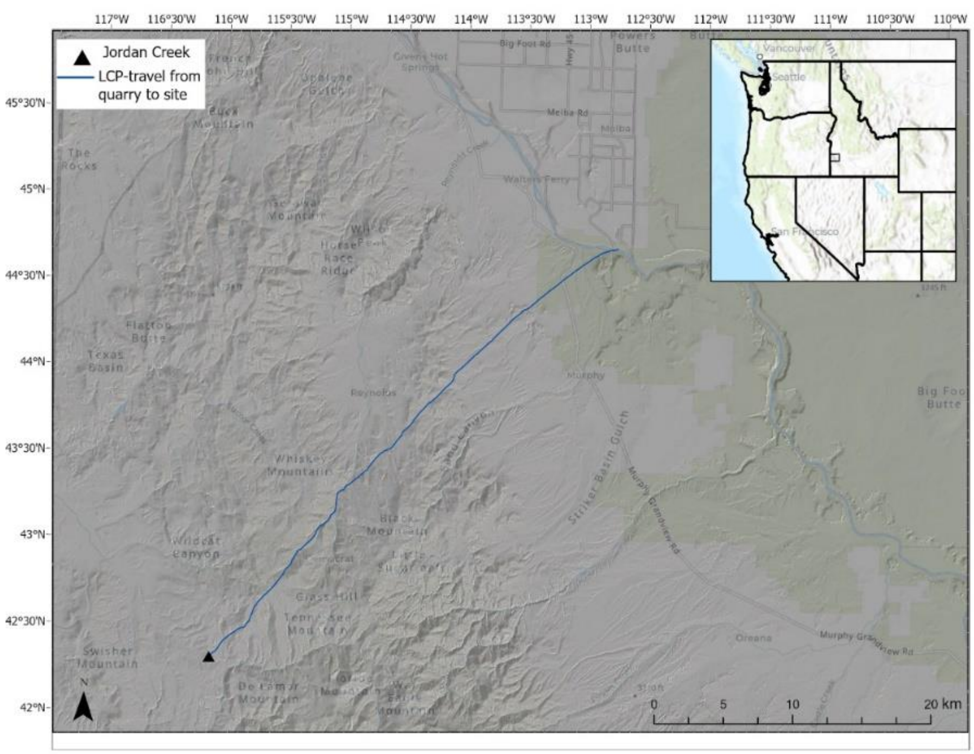

Figure 8. LCP for Jordan Creek. Map Scale is 1:256,300.

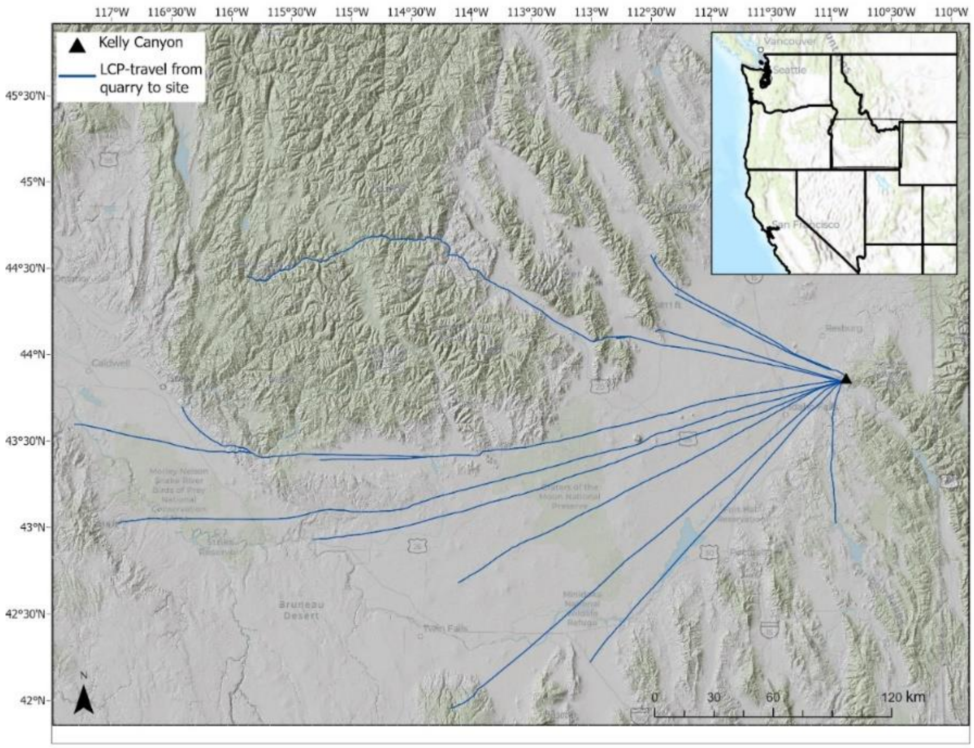

Figure 9. LCPs for Kelly Canyon. Map Scale is 1:1,800,000.

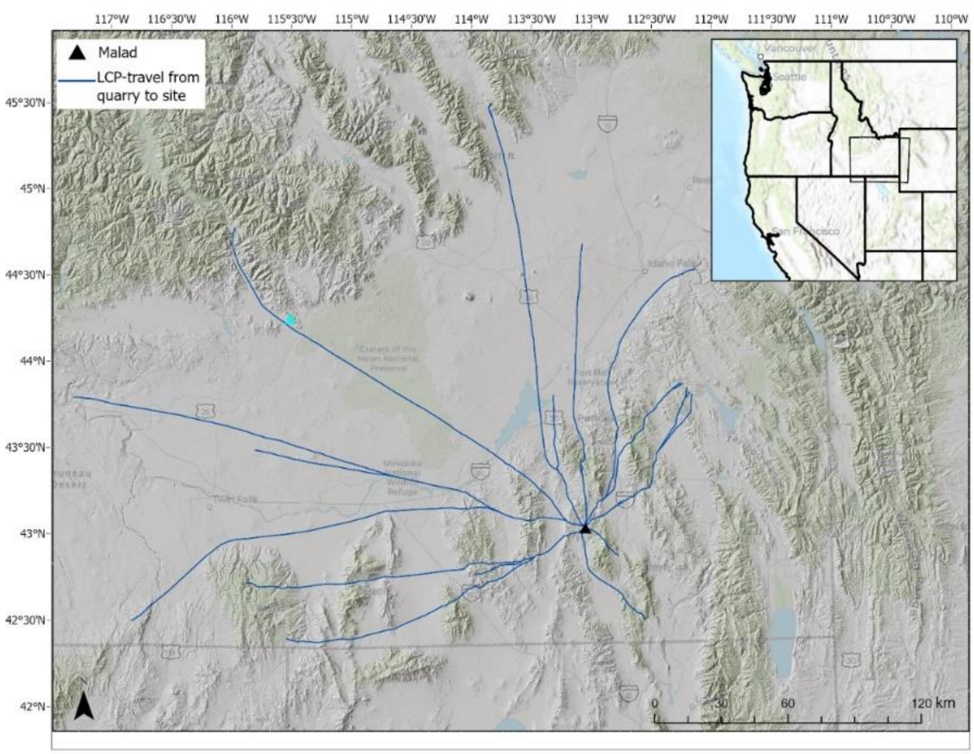

Figure 10. LCPs for Malad. Map Scale is 1:1,600,000.

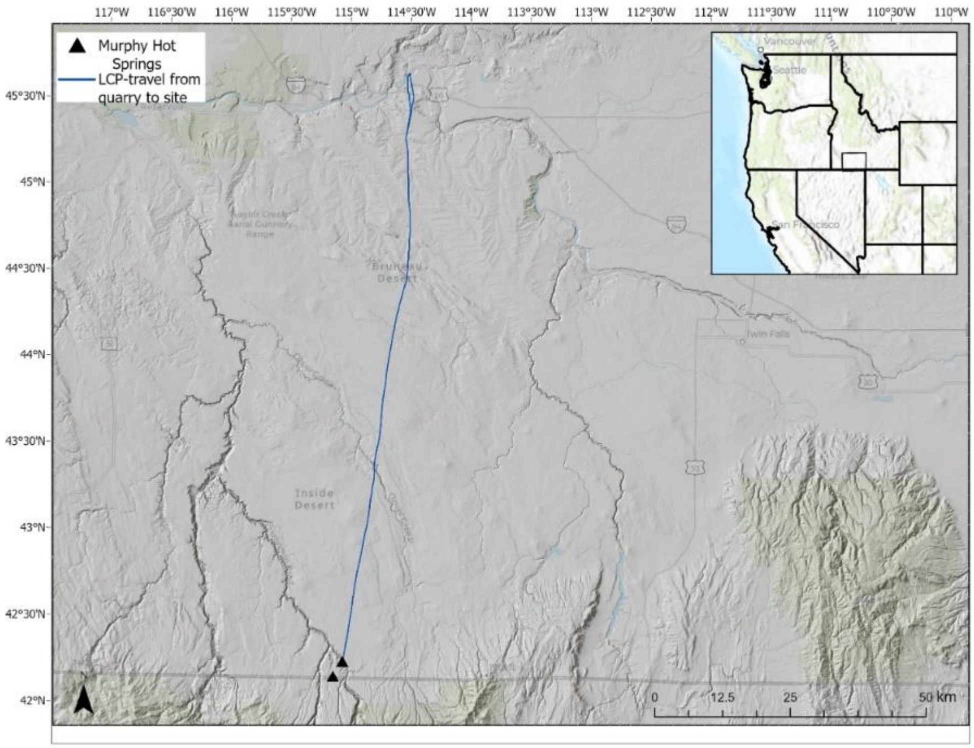

Figure 11. LCPs for Murphy Hot Springs. Map Scale is 1:655,360.

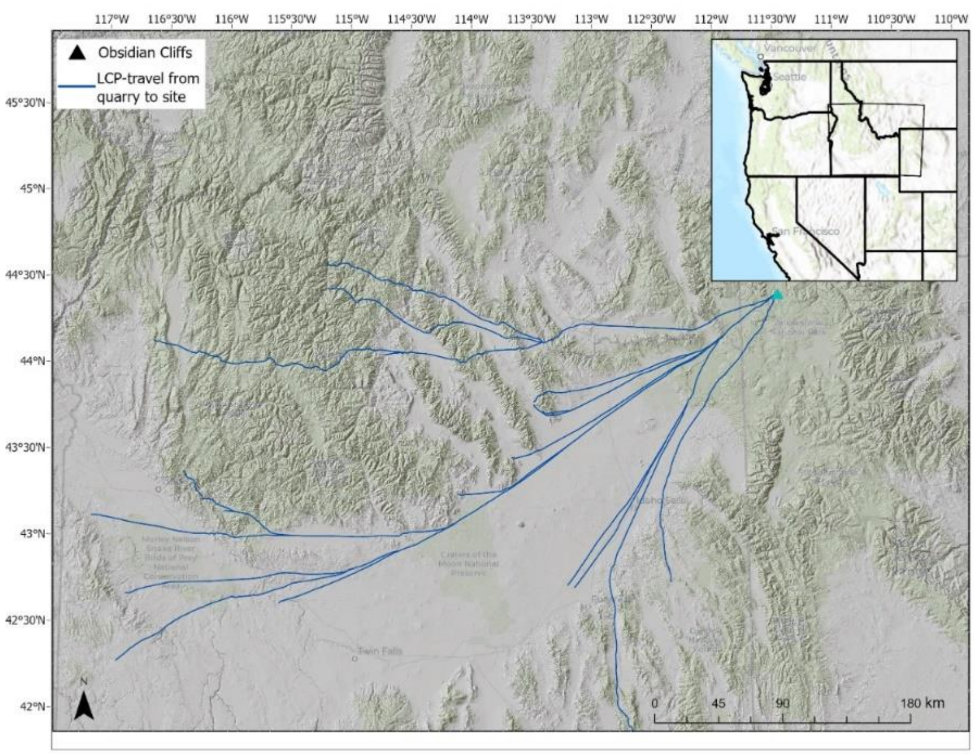

Figure 12. LCPs for Obsidian Cliff. Map Scale is 1:2,500,000.

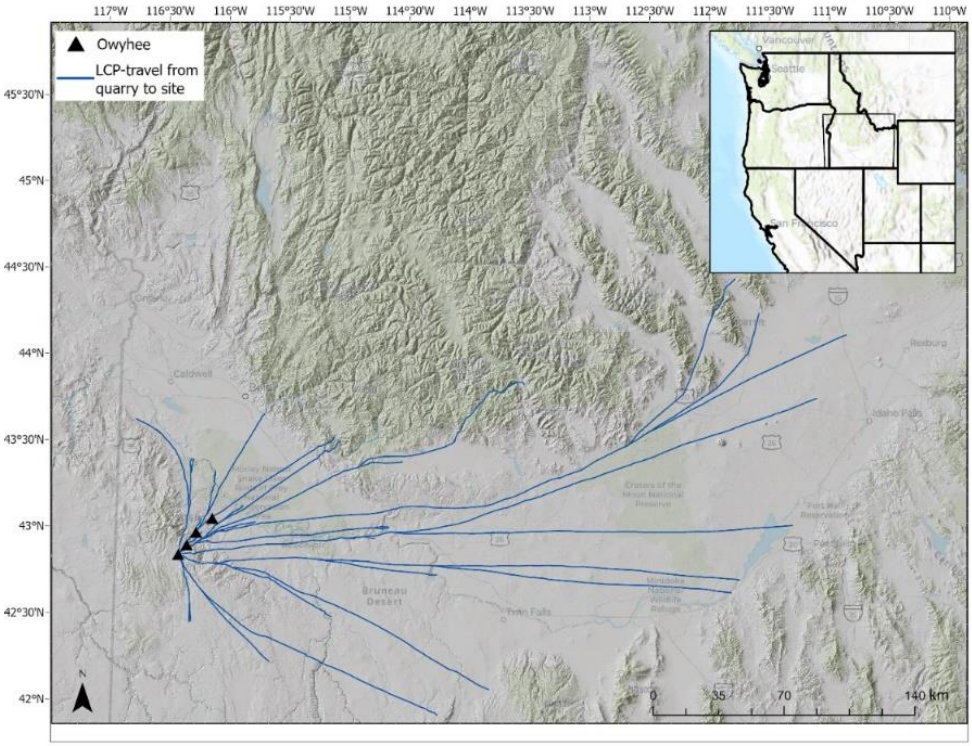

Figure 13. LCPs for Owyhee. Map Scale is 1:1,900,000.

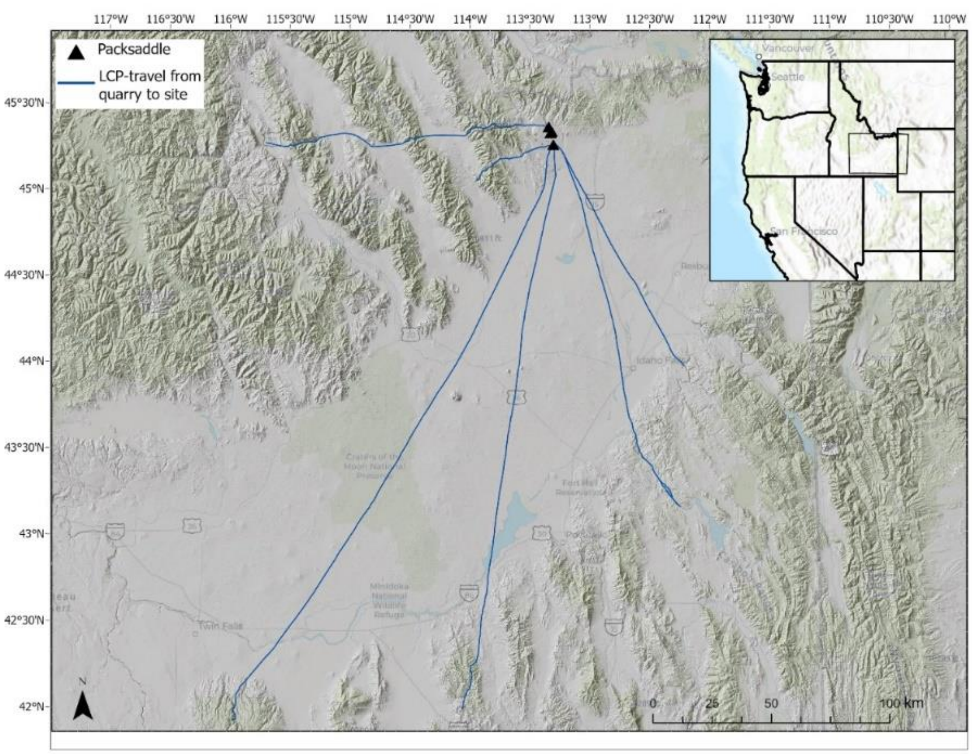

Figure 14. LCPs for Packsaddle. Map Scale is 1:1,500,000.

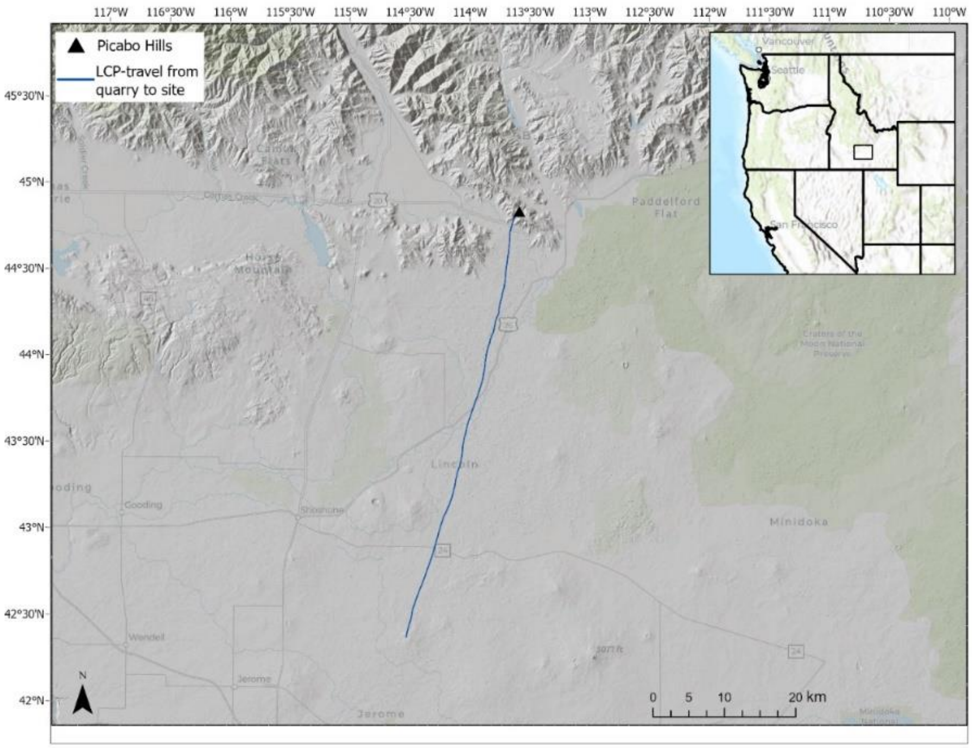

Figure 15. LCP for Picabo Hills. Map Scale is 1:499,000.

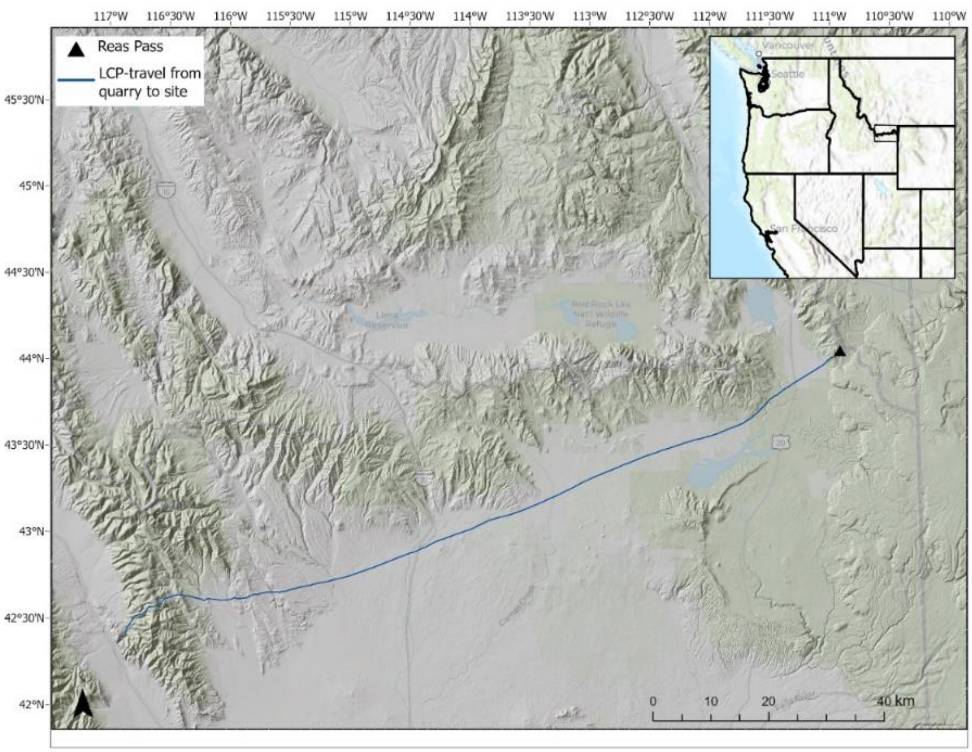

Figure 16. LCP for Reas Pass (subsource of Packsaddle) Map Scale is 1:614,400.

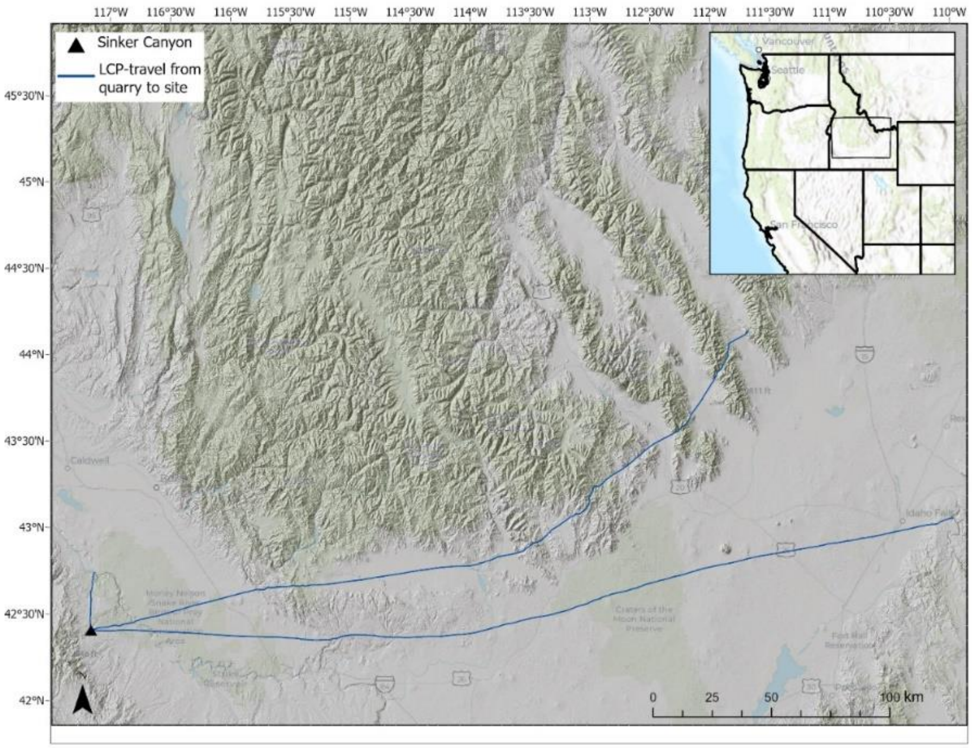

Figure 17. LCPs for Sinker Canyon. Map Scale is 1:1,500,000.

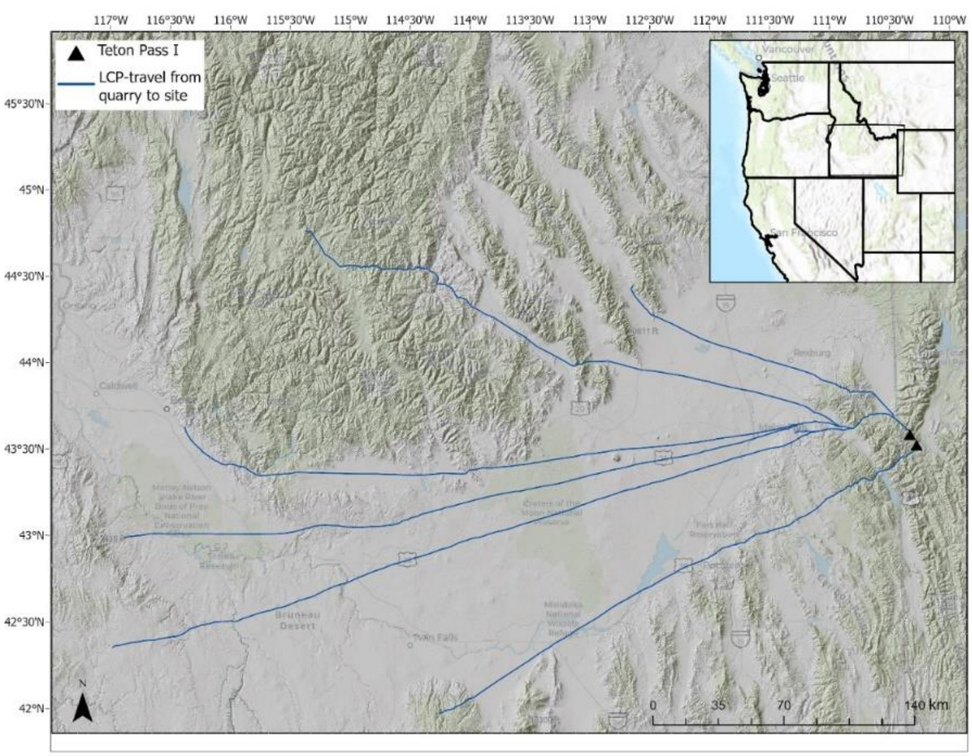

Figure 18. LCPs for Teton Pass I. Map Scale is 1:1,900,000.

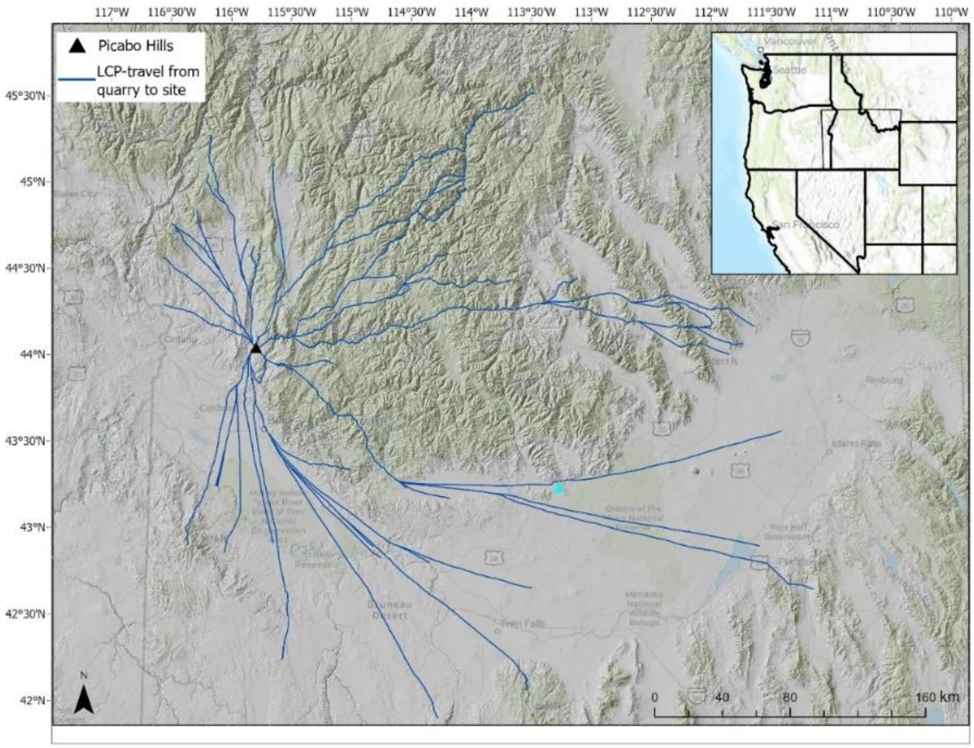

Figure 19. LCPs for Timber Butte. Map Scale is 1:2,100,000.

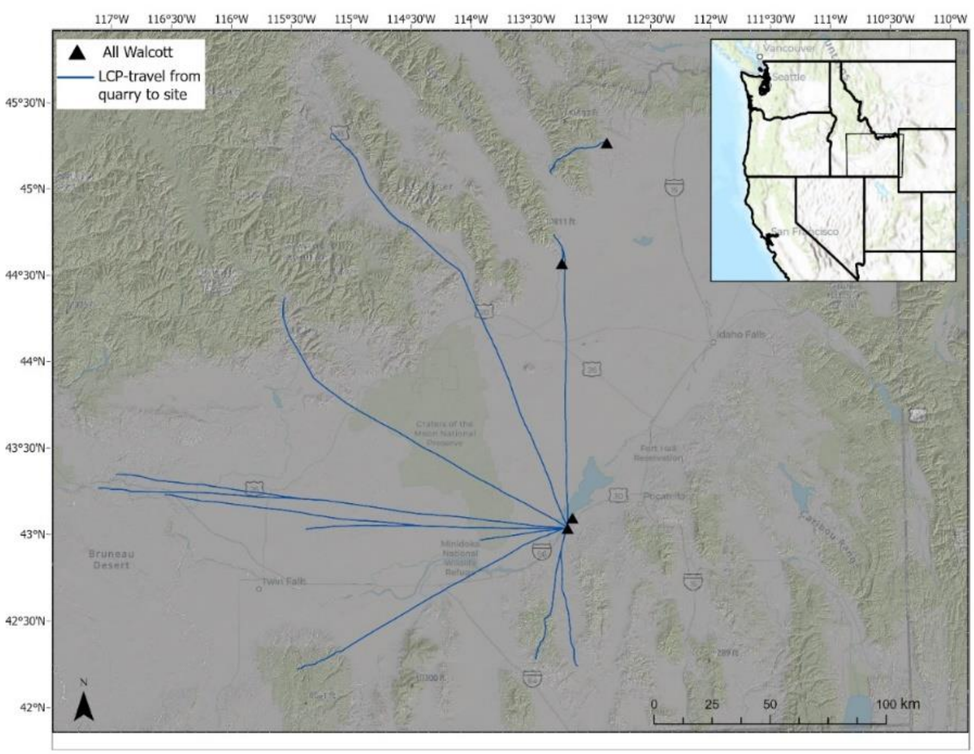

Figure 20. LCPs for Walcott. Map Scale is 1:1,900,000.

Appendix C

This series of maps represent travel from obsidian sources to archaeological sites. Each map represents LCPs for all sites in study. Note that generating LCPs for travel between a source and all sites in the study was not feasible in some cases.

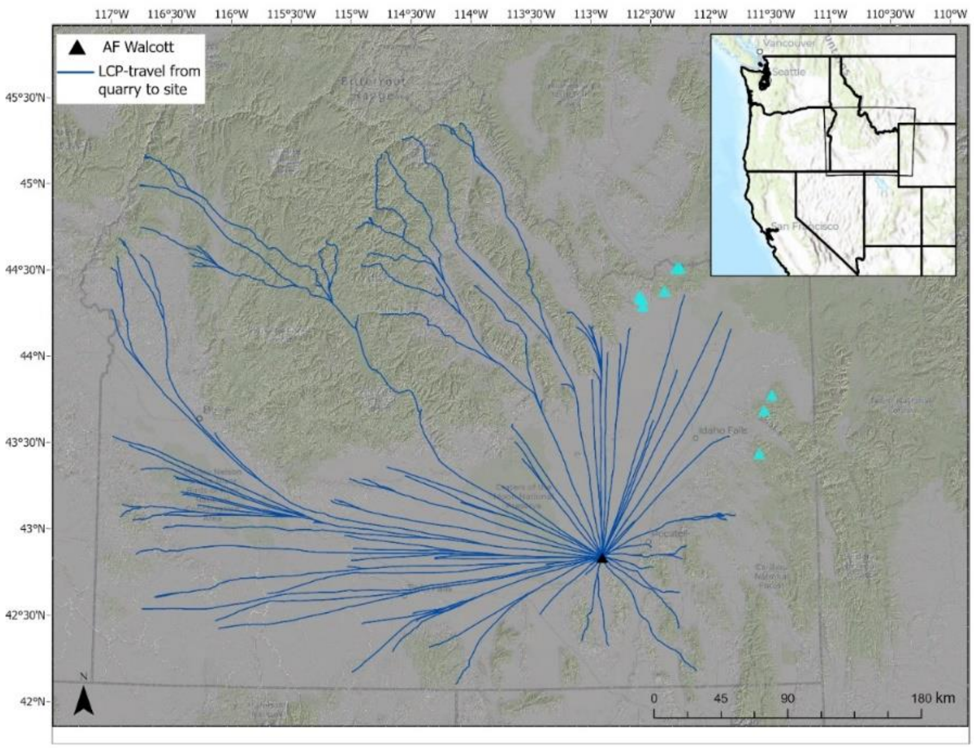

Figure 1. LCPs for American Falls Walcott. Map scale is 1:2,400,000.

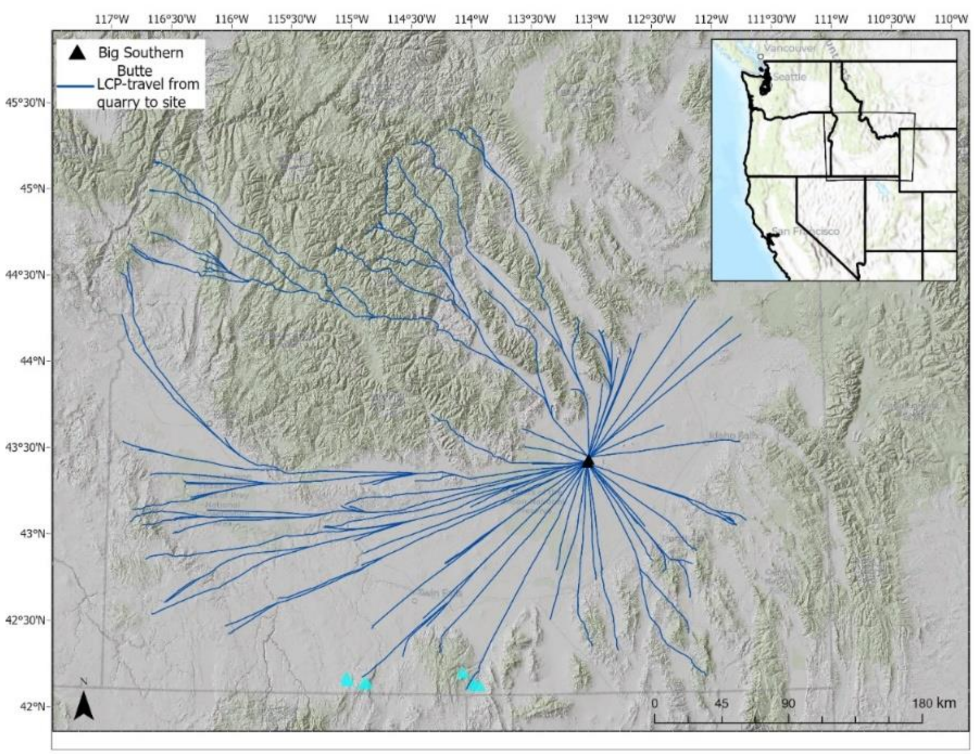

Figure 2. LCPs for Big Southern Butte. Map scale is 1:2,400,000.

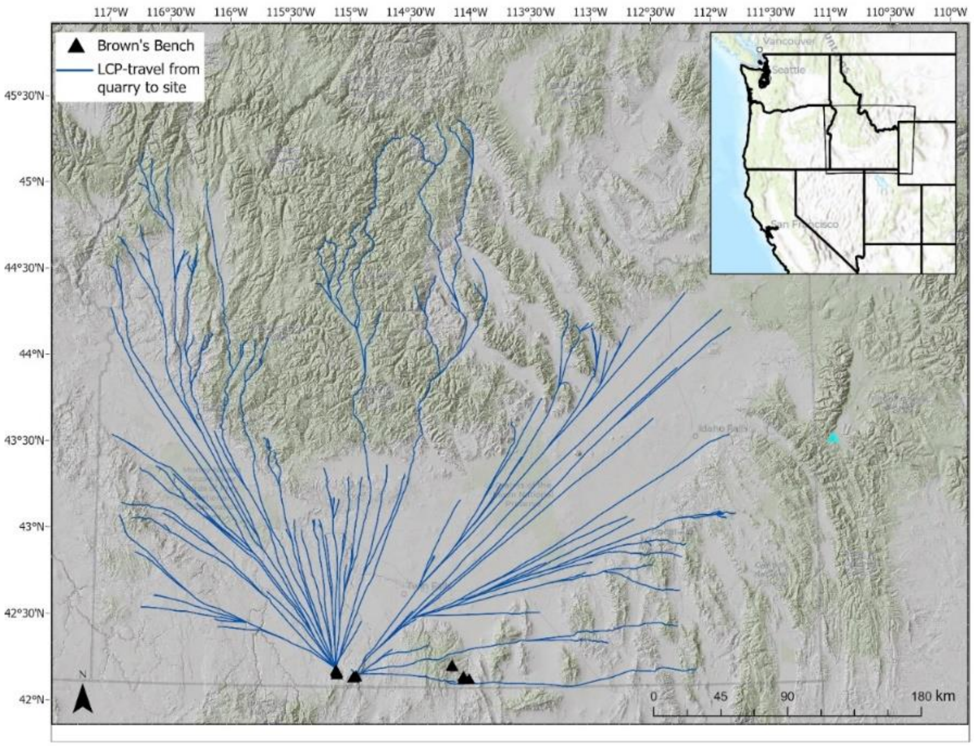

Figure 3. LCPs for Brown's Bench. Map scale is 1:2,400,000.

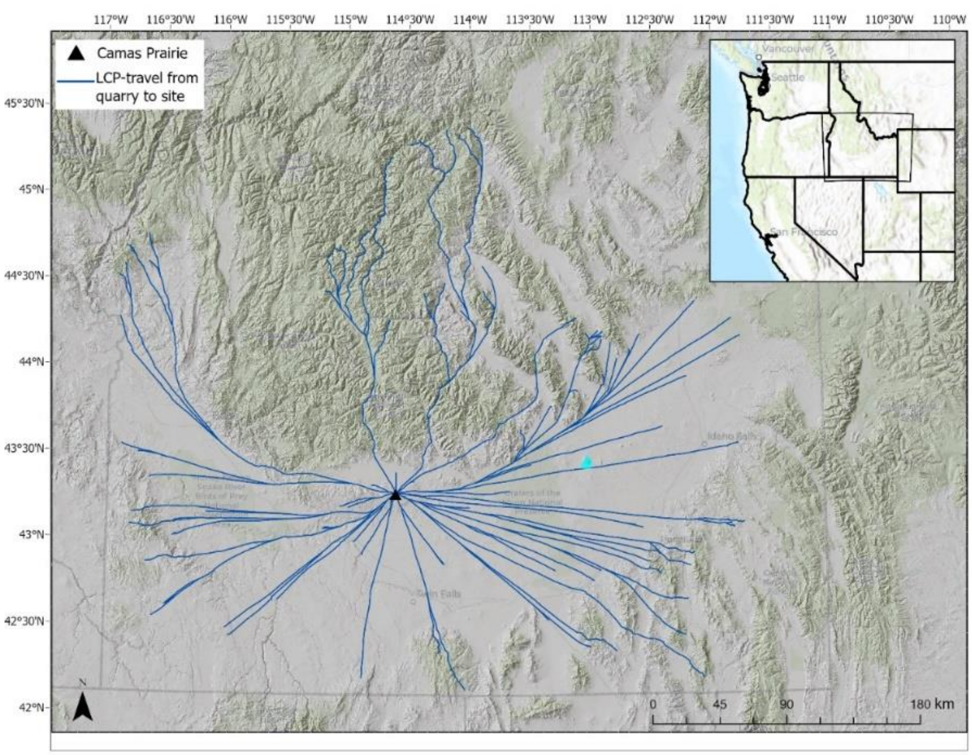

Figure 4. LCPs for Camas Prairie. Map scale is 1:2,400,000.

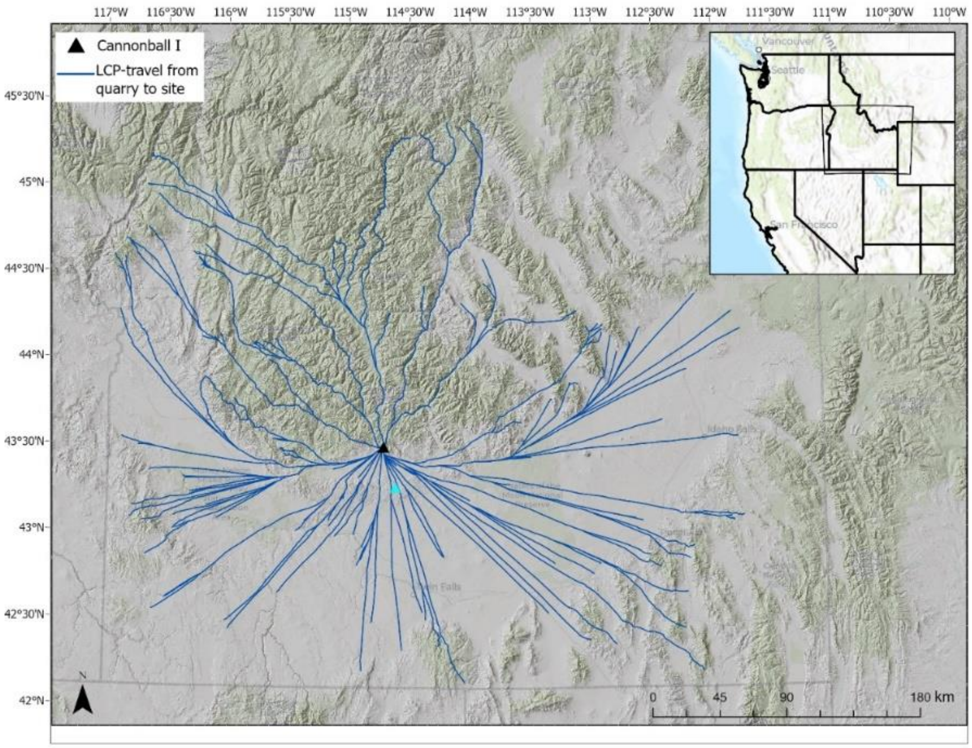

Figure 5. LCPs for Cannonball I. Map scale is 1:2,400,000.

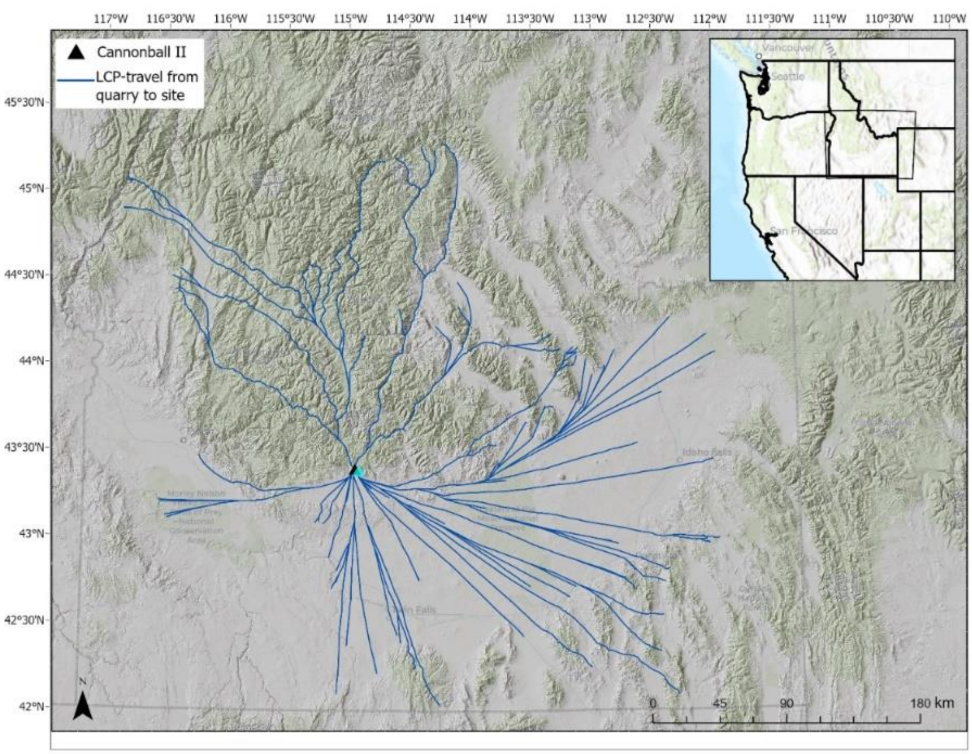

Figure 6. LCPs for Cannonball II. Map scale is 1:2,400,000.

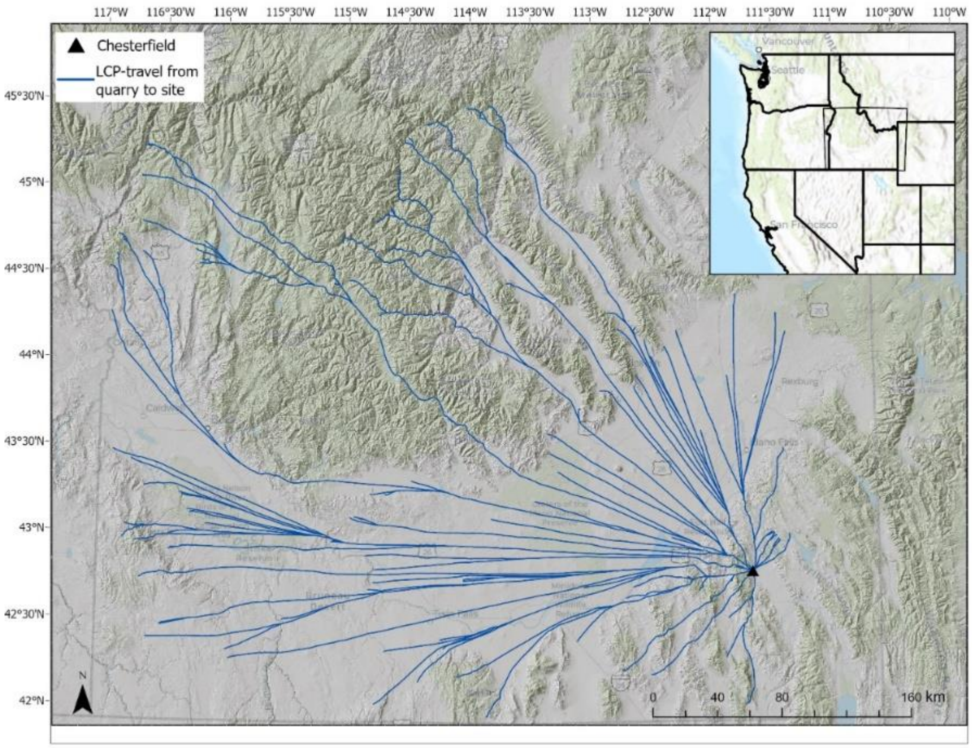

Figure 7. LCPs for Chesterfield. Map scale is 1:2,200,000.

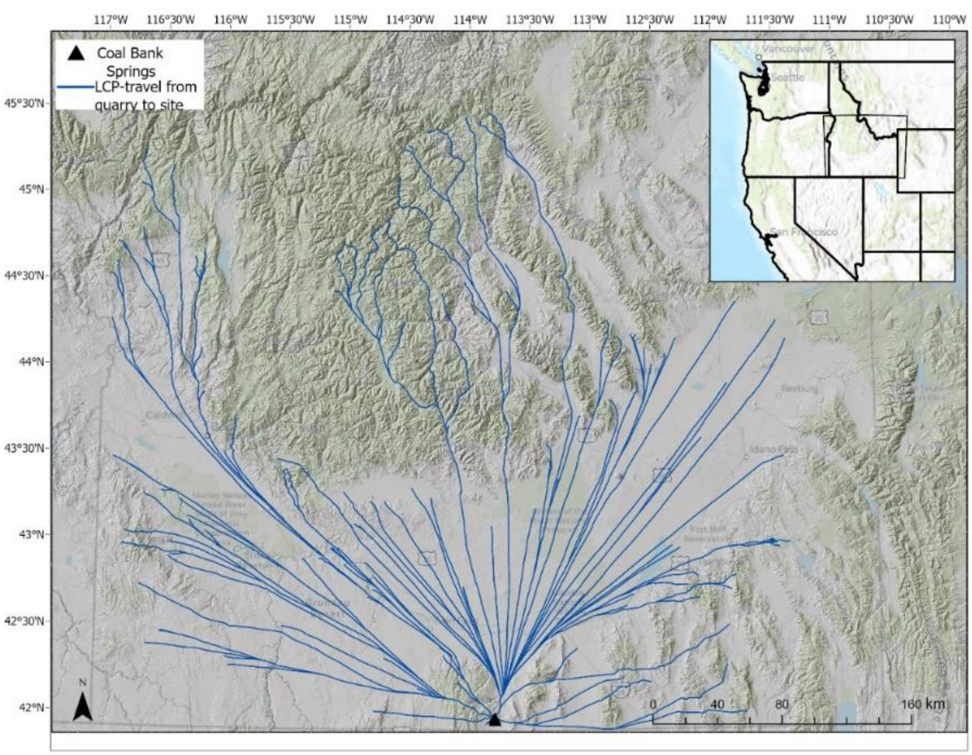

Figure 8. LCPs for Coal Bank Springs. Map scale is 1:2,200,000.

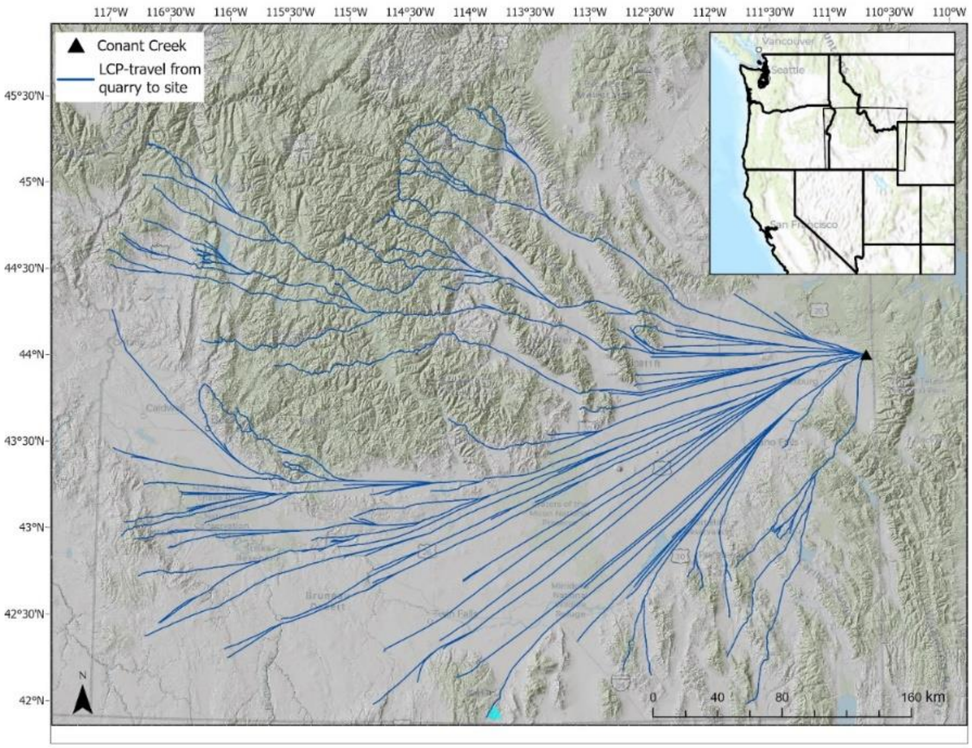

Figure 9. LCPs for Conant Creek. Map scale is 1:2,200,000.

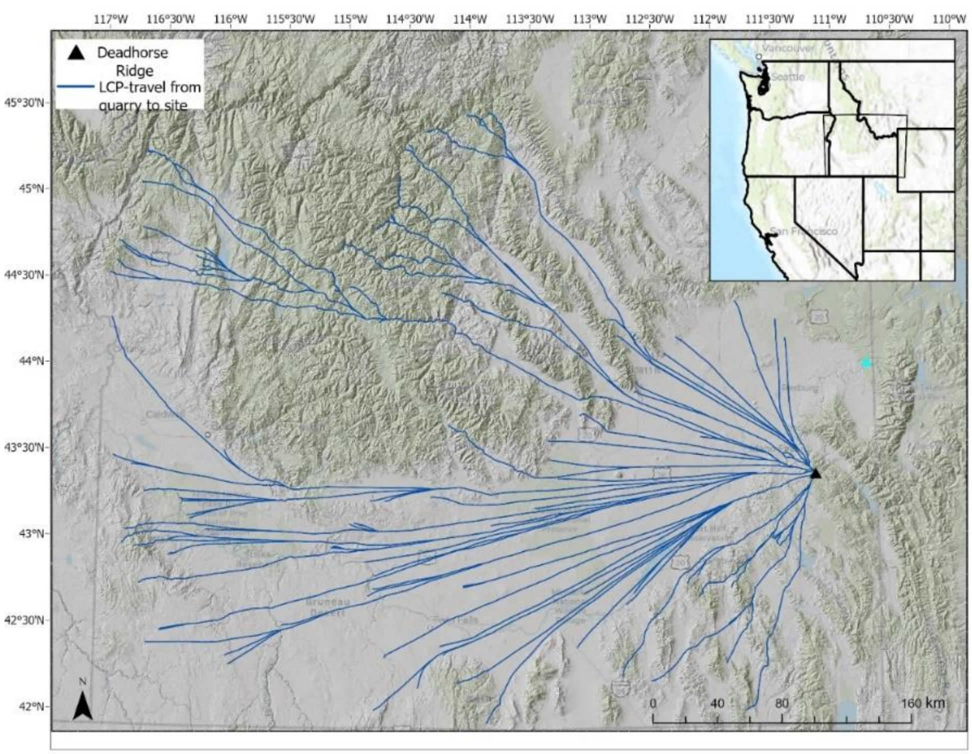

Figure 10. LCPs for Deadhorse Ridge (Packsaddle). Map scale is 1:2,200,000.

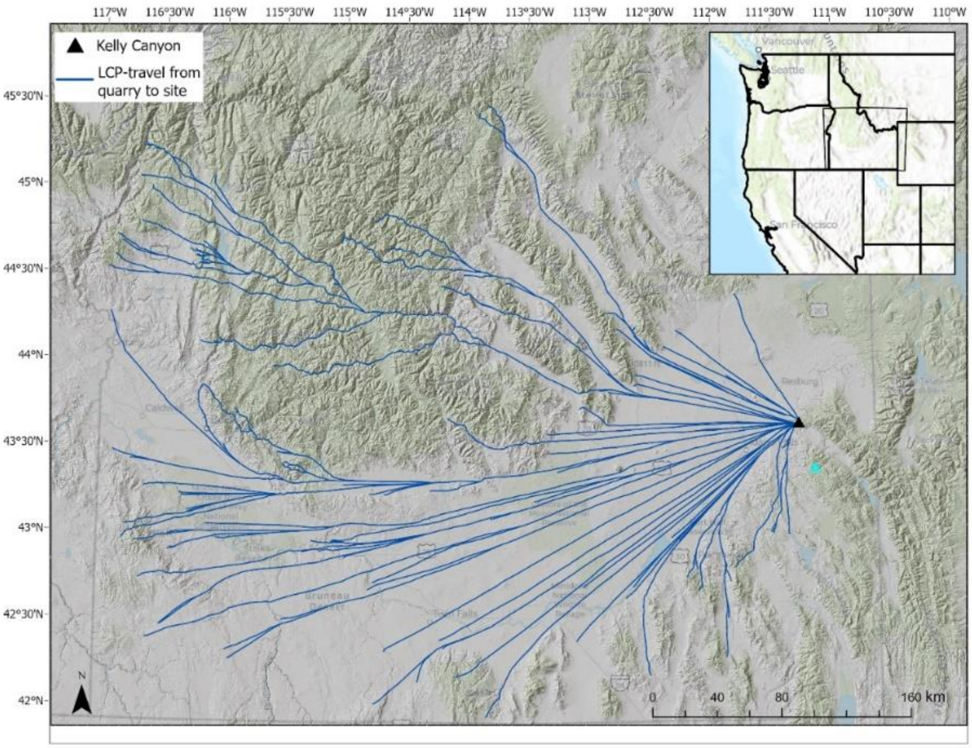

Figure 11. LCPs for Jordan Creek. Map scale is 1:2,200,000.

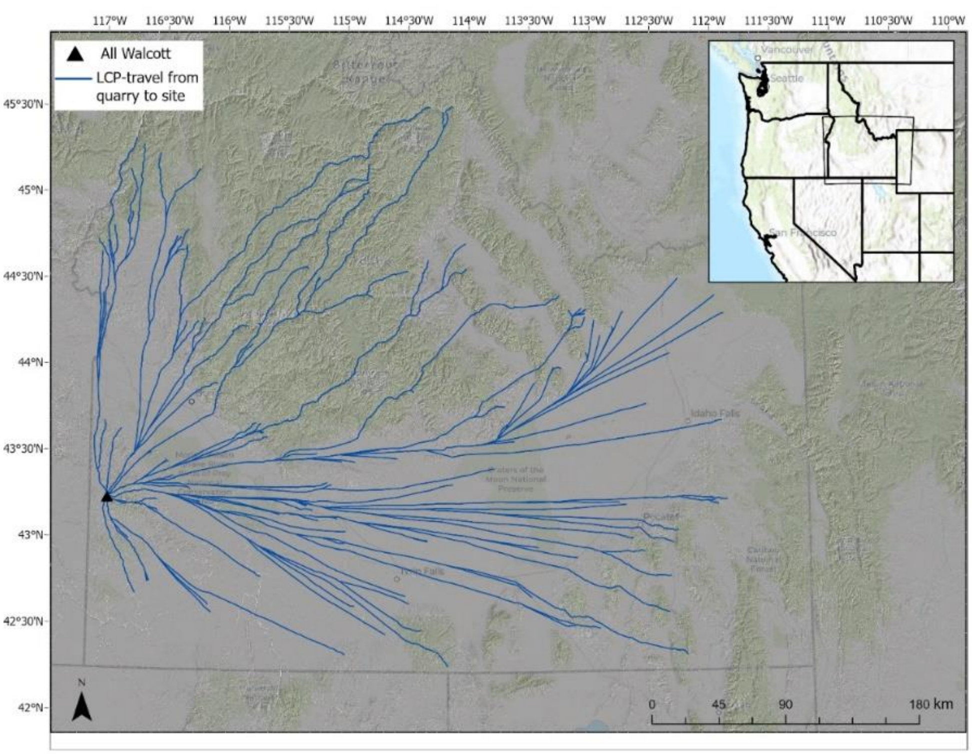

Figure 12. LCPs for Kelly Canyon. Map scale is 1:2,200,000.

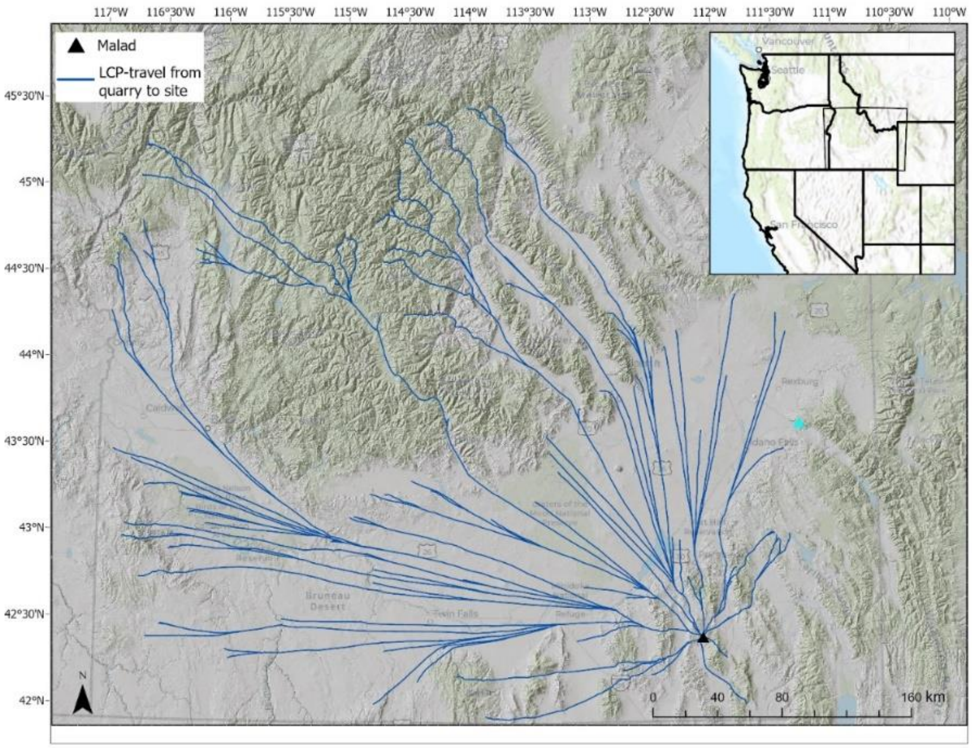

Figure 13. LCPs for Malad. Map scale is 1:2,200,000.

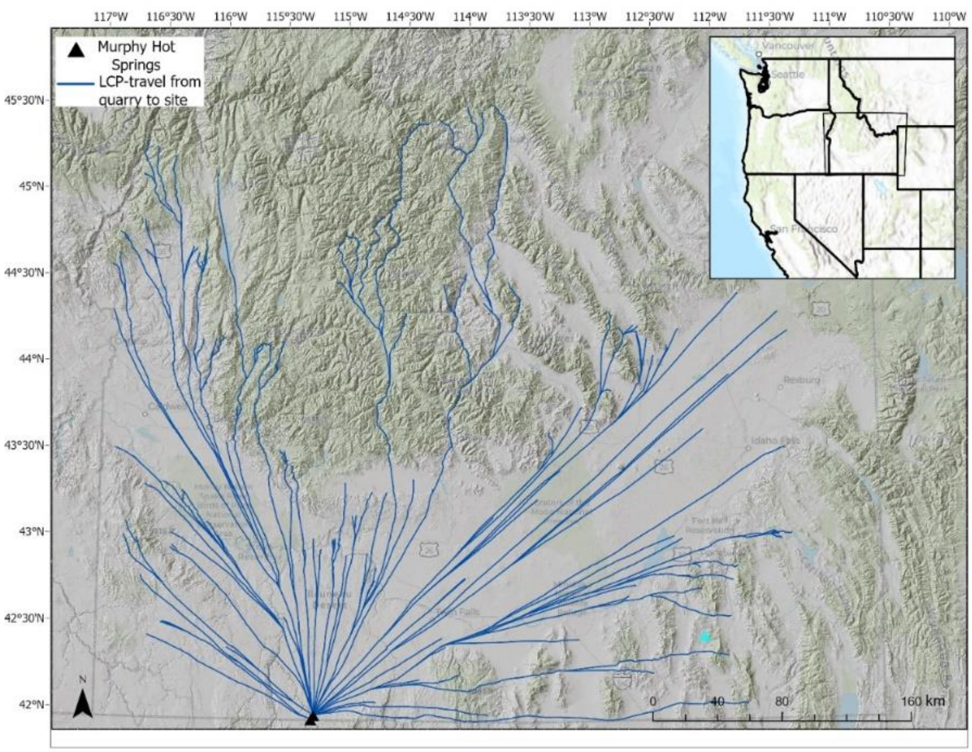

Figure 14. LCPs for Murphy Hot Springs. Map scale is 1:2,200,000.

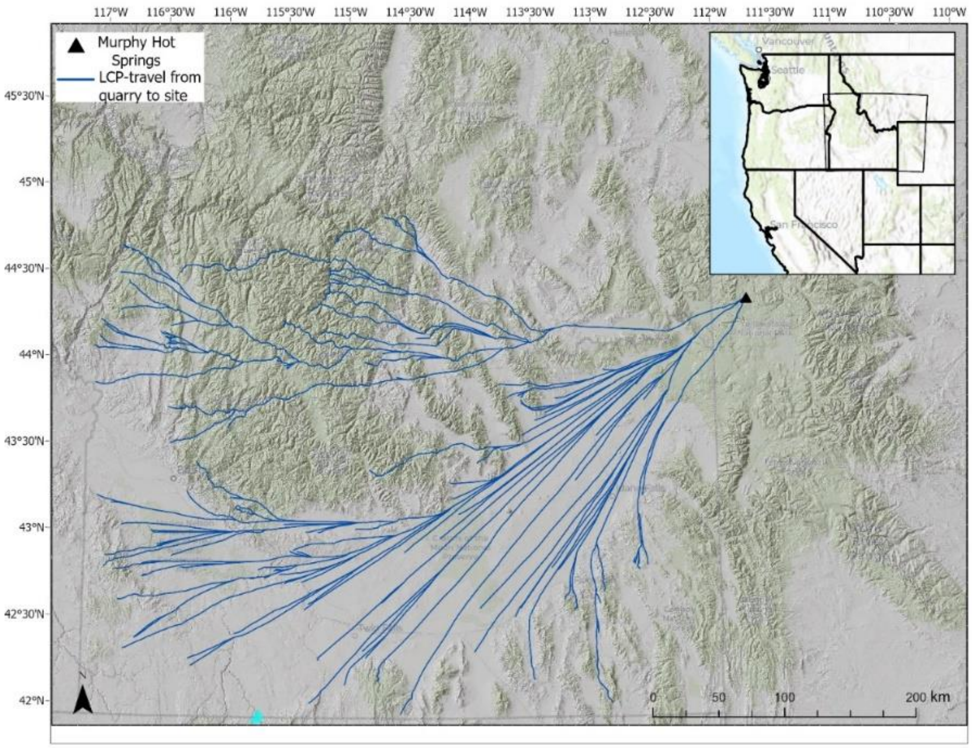

Figure 15. LCPs for Obsidian Cliff. Map scale is 1:2,700,000.

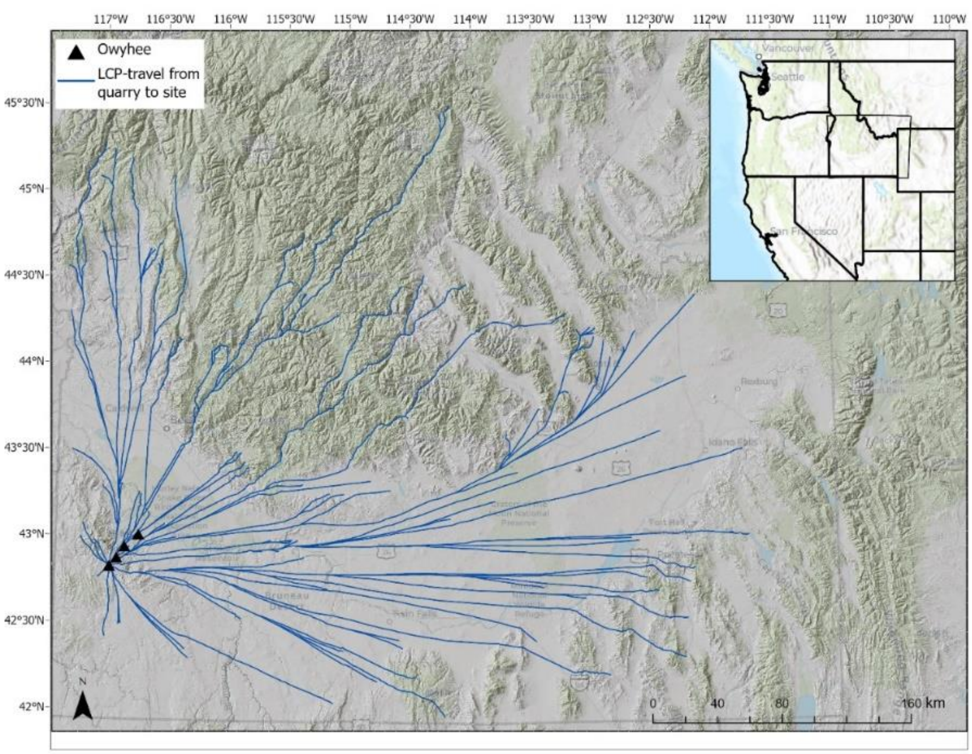

Figure 16. LCPs for Owyhee. Map scale is 1:2,200,000.

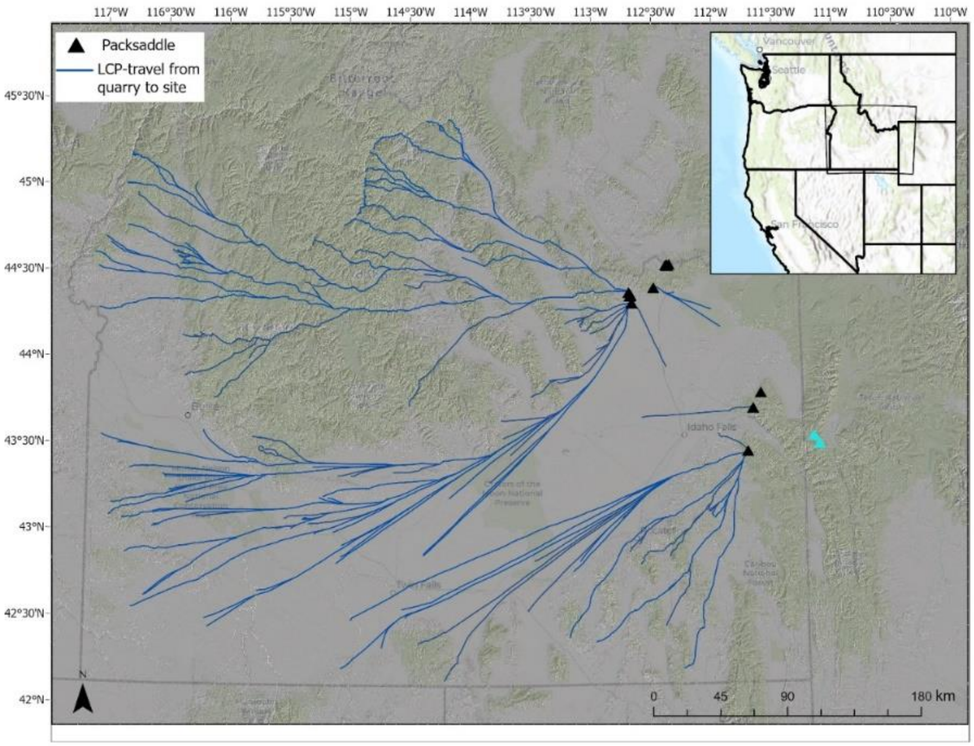

Figure 17. LCPs for Packsaddle. Map scale is 1:2,400,000.

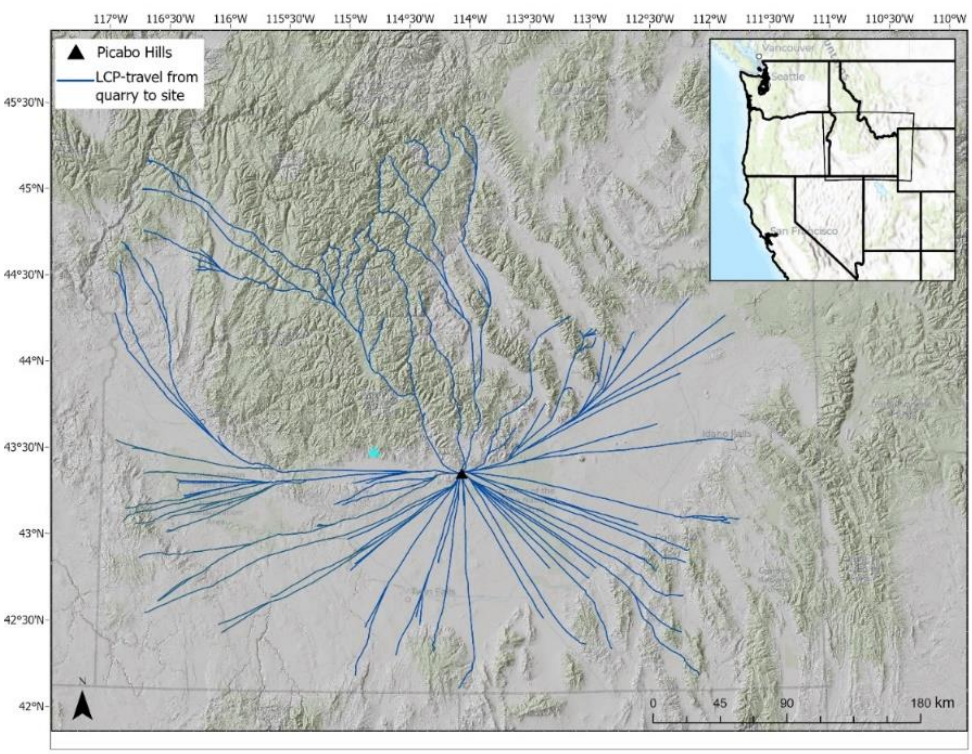

Figure 18. LCPs for Picabo Hills. Map scale is 1:2,400,000.

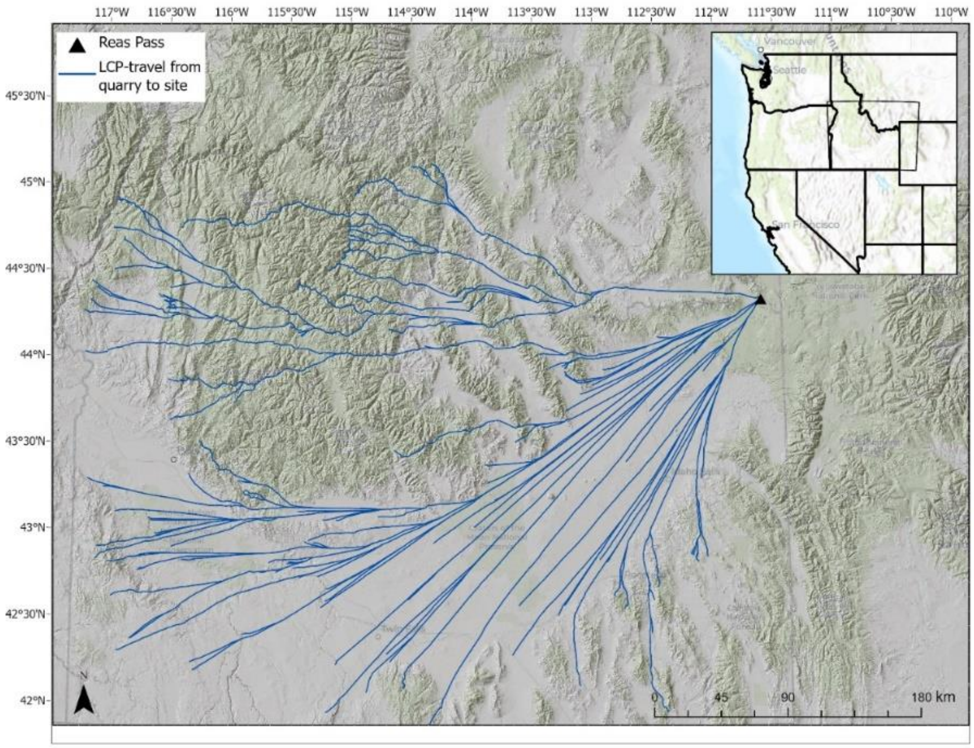

Figure 19. LCPs for Reas Pass (sub-source of Packsaddle). Map scale is 1:2,400,000.

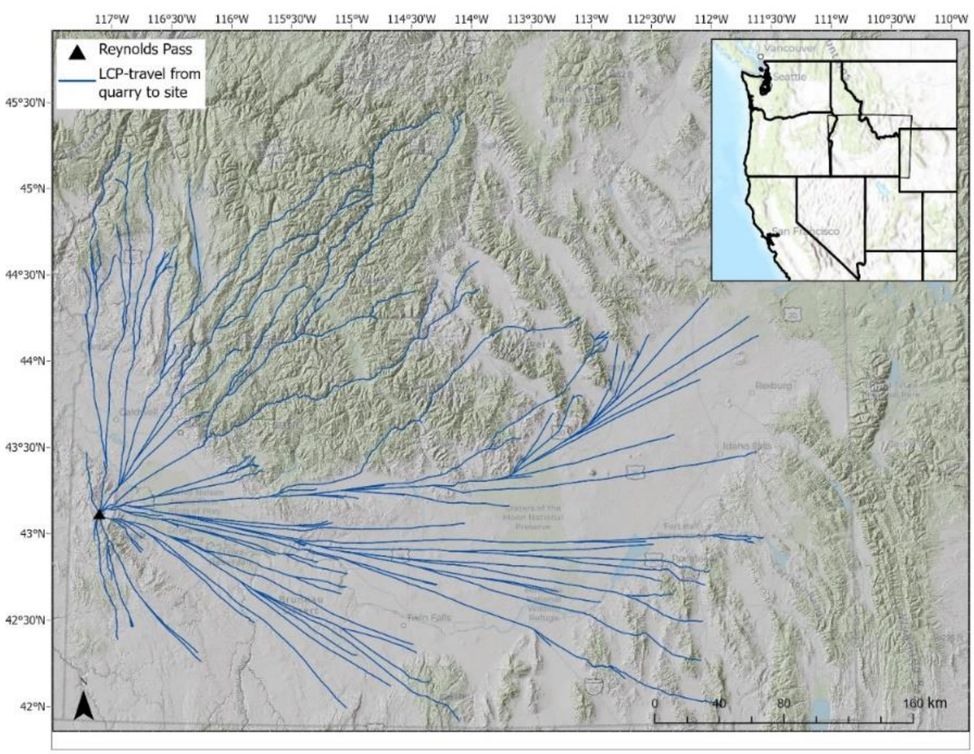

Figure 20. LCPs for Reynolds Pass. Map scale is 1:2,200,000.

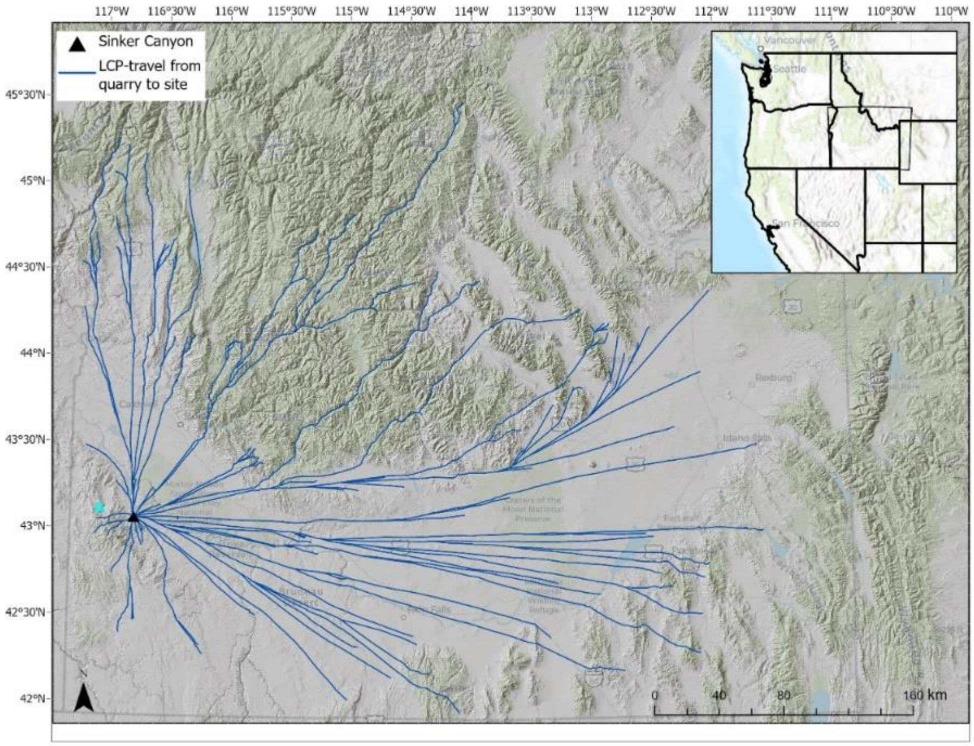

Figure 21. LCPs for Sinker Canyon. Map scale is 1:2,200,000.

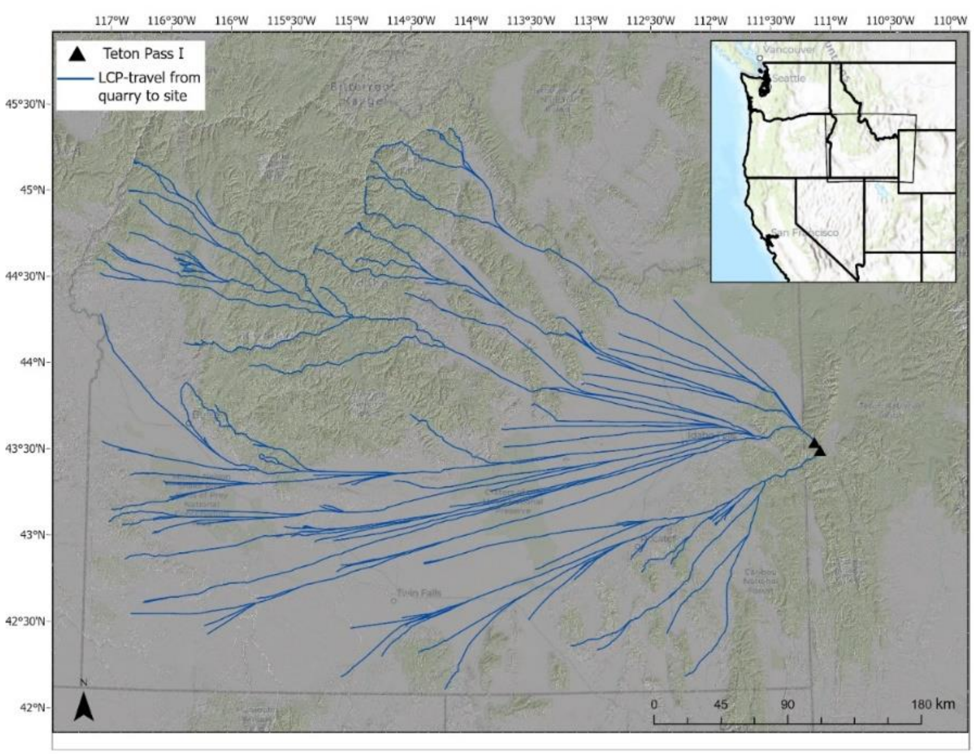

Figure 22. LCPs for Teton Pass I. Map scale is 1:2,390,000.

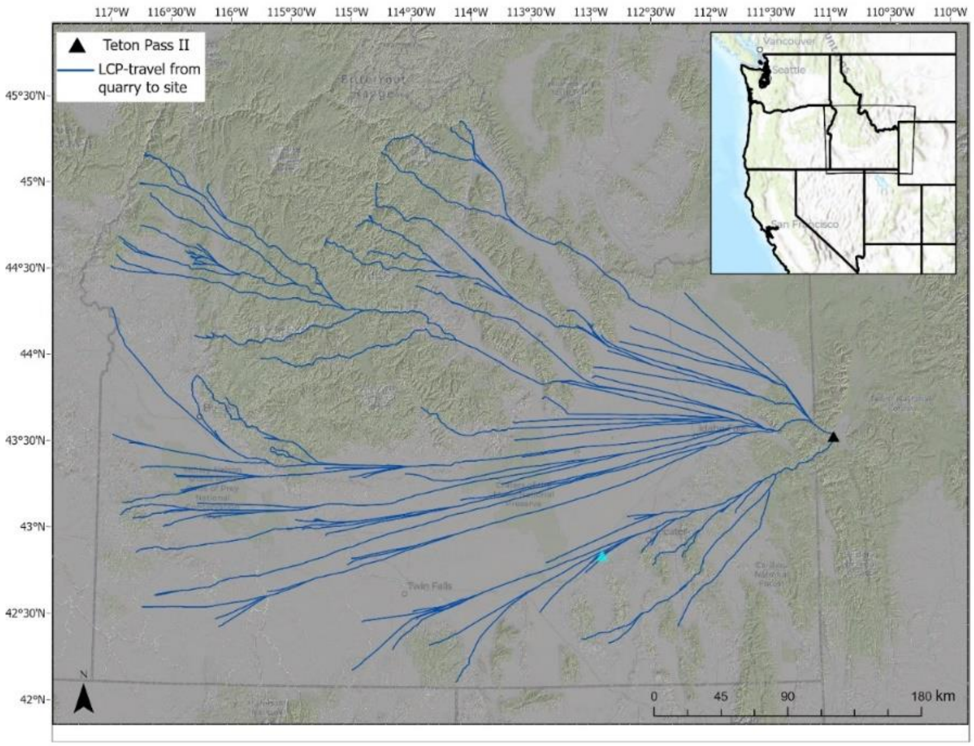

Figure 23. LCPs for Teton Pass II. Map scale is 1:2,400,000.

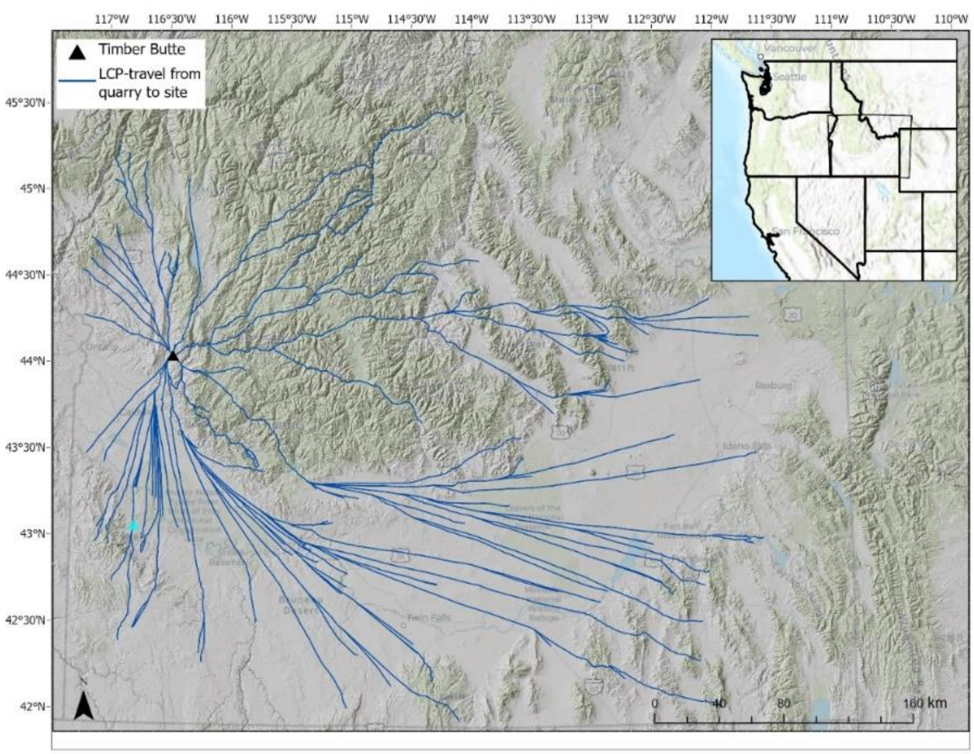

Figure 24. LCPs for Timber Butte. Map scale is 1:2,200,000.

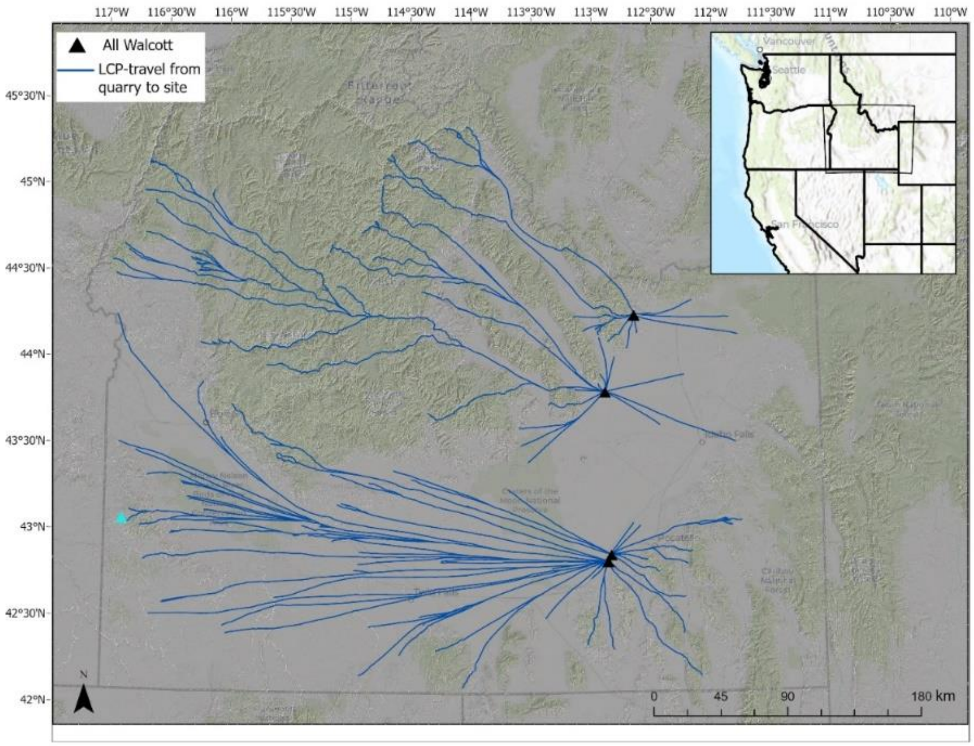

Figure 25. LCPs for Walcott. Map scale is 1:2,400,000.