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CALIFORNIA CREEK QUARRY: REGIONAL PERSEPCTIVES AND UAS MAPPING

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CALIFORNIA CREEK QUARRY: REGIONAL PERSEPCTIVES AND UAS MAPPING

By

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ABSTRACT

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Western Montana hosts an abundance of lithic deposits useful for precontact stone tool manufacturing. Lithic sources likely factored prominently into patterns of settlement, trade, subsistence and mobility for past populations in the region. The mining of these lithic resources results in a unique land use area, a prehistoric quarry. Prehistoric quarries in Western Montana have received very little research or spatial documentation. This may be due in part to their abundance and often overwhelming size and extent. Providing even basic spatial documentation for large quarries can be prohibitively time consuming and expensive. One such understudied quarry site is the California Creek chert quarry, a high elevation quarry site near present day Anaconda, MT. The goal of this study is to address some information gaps regarding this quarry and to assess its regional significance through two main approaches. The first approach will be to develop a regional context for the quarry in which to better understand how mining at the site factored into regional patterns of trade and subsistence. Ethnohistorical sources are particularly useful in developing this context in the absence of lithic sourcing. The second approach is to acquire high resolution spatial data aimed at measuring mining intensity for the site using UAS based remote sensing. These approaches provide baseline information from which to better understand the scale and regional significance of the quarry.

Chapter 1. Introduction

The diverse and complex geologic setting of Western Montana has resulted in several rich deposits of the raw materials needed for prehistoric stone tool manufacturing, including cryptocrystalline silicates (henceforth chert). Cherts were important to past peoples' technology and were extensively mined at various locations across Western Montana for at least the last 10,000 years. Some prehistoric quarries cover hundreds of acres and contain hundreds of quarry pits, representing an enormous amount of human labor involved in the mining process. Despite their apparent prominence for past populations, only a handful of quarry areas have received extensive research by archaeologists in Western Montana. This is likely due in part to the fact that there are an numerous quarries to research in the region and some are so large and extensive, that producing a thorough map of these complex sites can be prohibitively time consuming and expensive. One such understudied quarry site is the California Creek quarry near present day Anaconda, MT. This high elevation quarry site features hundreds of quarry pits and several tunnel like features concentrated in an area of roughly ninety acres. However, it has received relatively little attention after its initial documentation by Dr. Les Davis in 1988. The goal of this study is to address some of the information gaps regarding this quarry, primarily relating to how it may have factored into regional patterns of subsistence or trade and to measure how intensively it was mined by simple metrics like volume of material removed, number of quarry pits and areal extent. A combination of two main approaches are used to address these issues.

The first avenue of research will be to establish the regional context of the quarry in terms of its physiography, cultural setting, ecology and geology. These underlying factors all have influence over the broad regional patterns of subsistence, trade and tribal distribution that effect how people interacted with this lithic source. In addition, a brief ethnohistorical overview is provided to offer a more local scale picture of how specific groups may have used this quarry. The goal of developing this multi scale context is to provide insights into the quarry's overall significance and to provide foundational information for future researchers.

The second avenue of research will be to fill a gap in the initial documentation of the site by developing a detailed map of this extensive quarry and its many quarry pits. Providing a high resolution topographic map of the quarry provides a spatial record of the site useful for all subsequent research and interpretations. Unmanned Aerial Systems (UAS) is used as the platform to accomplish this task. Archaeologists have already successfully used this emerging technology for a variety of situations, such as mapping of large multi-feature archaeological landscapes (Meyer et al. 2016, Wechsler 2016), mapping of buried features with multispectral sensors (Rudolf et al 2014), site mitigation/salvage archaeology (Harrison Buck et al 2016), and site reconnaissance and discovery (Mark and Billo 2016). A common thread uniting these various applications is the efficiency and affordability of the UAS platform for high resolution mapping, especially when compared to traditional geodetic or satellite-based methods (Raeva et al 2016, Meyer et al 2016). Given its successful track record in other archaeological applications, UAS was considered to be the most efficient technology for producing high resolution spatial data for the California Creek Quarry.

The results of this two-pronged effort indicate that UAS is well suited to mapping large, topographically complex sites like quarries. By leveraging the data produced by the UAS with spatial analysis, it is possible to efficiently measure mining intensity at the California Creek quarry as defined by volume of material removed, total area of quarry pits and number of pits. The products of the UAS survey are also valuable resources for site managers or stakeholders as they clearly define site boundaries and provide a comprehensive spatial record of the site in its present condition. Finally, by establishing the regional context of the quarry, it is possible to at least begin to unravel how seasonal resource procurement strategies, mobility and trade impacted use of the site by both local and regional populations. The discussion will be organized into the chapters outlined below.

Chapter 2 aims to develop the regional context of California Creek quarry by discussing its environmental, cultural and geologic setting. Chapter 3 describes the site and summarizes previous archaeological work undertaken at the site and the adjacent areas, with a focus on work by Les Davis (1988) and Smith (1981). Chapter 4 provides a review of ethnohistorical data that offers clues as to how seasonality, mobility and trade impacted quarry use. Chapter 5 provides a methods and results section for the UAS survey. Finally, Chapter 6 provides general conclusions of the study.

Chapter 2 Environment and Geology

This chapter discusses the environmental, cultural and geologic setting of the California Creek quarry. These factors affect how past populations interacted with the quarry on both local and regional scales. This discussion is intended to provide baseline information relating to the quarry's significance as a lithic resource. A prominent theme developed here is that the quarry lies at the convergence of both cultural and ecological zones.

2.1 Physiography and Ecology

Viewed from a continental scale, the California Creek quarry is within the Northern Rockies physiographic province as defined by Fennemen (1931). Physiographic provinces areas with similar geomorphologic regimes and similarities between the composition and structure of their geology. The Northern Rockies province is characterized by its several distinct, non-linear mountain ranges that contain several minor crests running in a multitude of directions. Ranges in the region rarely reach above 10,000 ft and are separated by intermontane valleys of varying width. Some valleys are only two to five miles wide while others are much broader. The quarry itself lies in the south eastern portion of the Northern Rockies Province, and is therefore near to where the province converges with the Columbia Plateau, Basin and Range, Middle Rockies, Wyoming Basin and Great Plains physiographic provinces. Each of these physiographic provinces contain very different ecological settings as well, thus creating unique configurations of resources depended on by past populations.

When viewed on more localized spatial scales, the California Creek quarry is within a convergence zone of several ecoregions (Figure 2). The distributions of Montana Level 4 ecoregions surrounding the quarry illustrates this fact (Woods et al 1999). The quarry itself is within the northern reaches of the Big Hole ecoregion, defined as a low relief high elevation valley containing extensive meadows, wetlands, springs and swampy creeks. Sagebrush steppe dominates in the valley bottoms. The Big Hole ecoregion is bordered by the Pioneer-Anaconda Range ecoregion on its east and west side. The climax vegetation of this ecoregion is coniferous forests composed of subalpine fir and Douglas-Fir. The underlying geology is composed primarily of sedimentary and meta-sedimentary strata in the Anaconda Range, which contributes to its abundant chert deposits. This mountainous area straddles the continental divide and the glacially sculpted terrain contains numerous lakes and wetlands.

The convergence of several distinct ecoregions near the quarry creates an ecotonal setting containing a variety of floral and faunal resources in relatively close proximity. Bison, elk, moose, deer, bighorn sheep and many smaller mammal species can all be found in these ecoregions both currently and historically. Within each ecoregion, high variations in temperature, precipitation, solar radiation and soil occur over short distances. This setting provides habitats for numerous important floral species, including such staples as camas and bitterroot. For example, the Deep Creek-French Creek basin just south of the quarry contains one of the denser concentrations of camas east of the continental divide (Schwab 2012:32). The environmental conditions of the region surrounding the quarry were conducive to interaction among regional tribal groups due to the resource abundance it offered and may have implications for how quarry materials circulated after they were mined. Ethnohistorical accounts confirm this general pattern, which is discussed in more detail in Chapter 3.

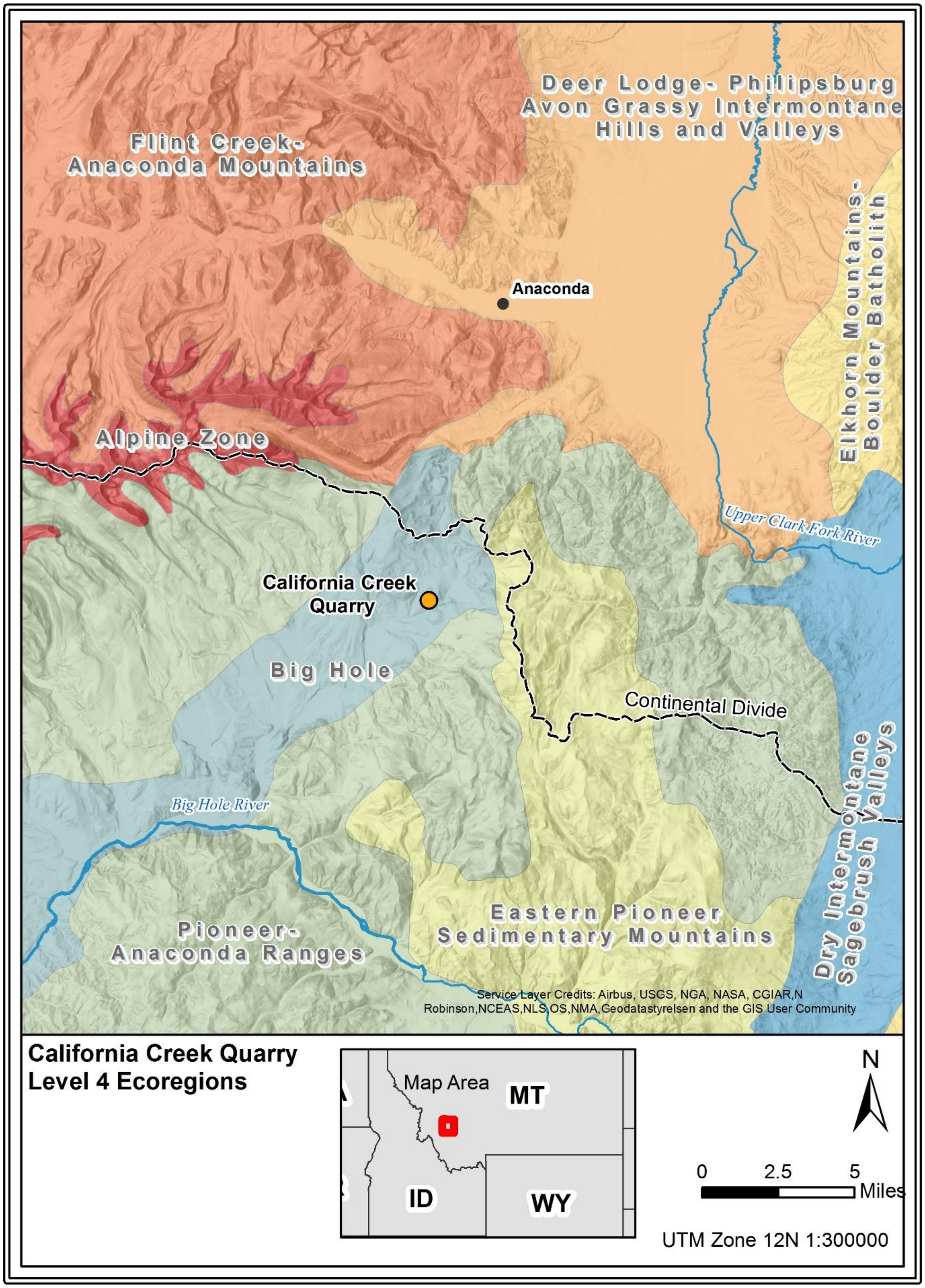

Figure 1 Level 4 Ecoregions surrounding the quarry

2.2 Cultural Context

Culture areas are defined as areas inhabited by diverse cultural groups who share more cultural traits with each other than with groups in bordering physiographic regions. These shared traits can be linguistic, or subsistence related (Deaver and Deaver 1986:8). This is not to suggest that environmental factors determined the cultural similarities, but simply to acknowledge that when viewed at appropriate spatial scales, resemblances in adaptive strategies exist among cultural groups inhabiting similar physiographic and ecological areas. As a general characterization, cultural groups on the Plateau are typically associated with deer, anadromous fish and camas; those in the Great Basin with broad-spectrum hunting and gathering, including special emphasis on smaller mammals and pine nuts; and Plains groups are linked with bison hunting and a reduced focus on plant resources (Deaver and Deaver 1986:8).

Culture areas have also been divided into subareas to reflect more localized patterns. Roll (1982) notes that the Plateau area that extends into Western Montana lacks the salmon typically associated with areas farther west, hence his designation for Western Montana as a Barrier Falls Subarea of the Plateau (Figure 2). The fact that the California Creek quarry lies at the convergence of these three culture areas suggests it may have been known to groups from all three. This creates a setting for interaction and potentially trade of lithic materials. Local ecological conditions in the valleys adjacent to California Creek provide further incentive for regional interaction by offering a relative resource abundance conducive to large gatherings, a phenomenon supported by ethnohistorical accounts reviewed in more detail in Chapter 3. Taken together, these conditions provide strong circumstantial evidence that materials from the California Creek quarry may have factored prominently into regional patterns of trade. However, lithic sourcing studies would be required to validate this occurrence.

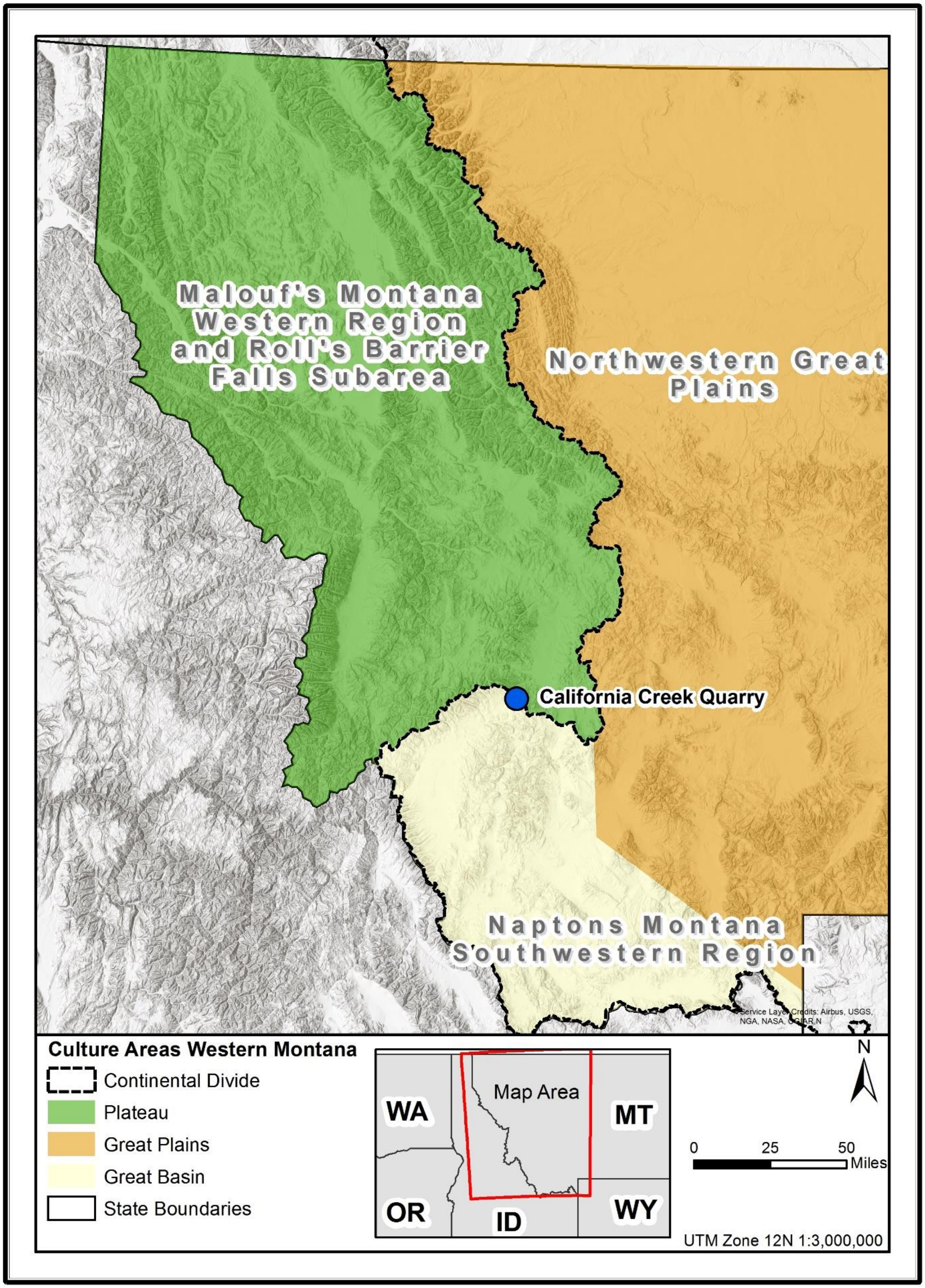

Figure 2 Culture areas and Subareas surrounding the quarry

2.2 Regional Geology and Quarries

When discussing cherts we are generally referring to cryptocrystalline silicates of many varieties that are sometimes also called jaspers, flints or chalcedony. The term chert has generally been used as a catch all term that describes a range of materials in archaeology. In regard to the linguistic ambiguity of the term chert and the range of materials it describes, we refer the reader to other literature that has addressed this topic already such as the *The Archaeologists Guide to Chert and Flint* by Barbara Luedtke (1992:9-10). We will use chert henceforth to refer to this wide variety of cryptocrystalline silicates for the sake of brevity.

The nature of how the chert formed at the California Creek quarry is related to both regional and local scale geologic events. Chert formation rarely occurs in a simple manner and tracing the exact sequence of events that led to any particular chert deposit is fraught with problems because its formation involves several steps that can occur at multiple scales. Chert can form through compaction, cementation, chemical alteration, replacement and recrystallization. All these events may have contributed to any given chert deposit to some degree and one process may erase the signs of another (Luedtke 1992:25).

Despite the complexities of chert formation, there are some general regional characteristics of the geology of Southwestern Montana that contribute to its abundance in the region. The first is that Southwest Montana contains large and extensive deposits of sedimentary and metasedimentary Paleozoic strata, including a notable collection of Cambrian and Devonian to Mississippian age limestones and dolomites that underlay several major Montana quarries (Roll et al 2000:C5). These units can contain chert through compaction and cementation that occur during their formation but are also more susceptible to replacement-based chert formation, particularly where they interact with volcanic strata and hydrothermal activity. The interaction of limestone and dolomite strata with volcanic units occurred frequently throughout Southwestern Montana. During the Mesozoic era western Montana was essentially the western margin of North America, therefore it was affected by the subduction of the Pacific plate by the North American plate (Alt and Hyndman 1986:11). This setting contributed to the formation of intrusive volcanic units such as the Boulder and Idaho Batholiths (Alt and Hyndman 1986:12). Later volcanic activity in the Tertiary period was responsible for the Lowland Creek volcanic formations, which are also widespread throughout southwestern Montana. The presence of hot volcanic-based water that accompanied these volcanic episodes is likely to have contributed significantly to regional chert formation.

This is especially true in zones where volcanic units were intruded into or were deposited in contact with the existing Paleozoic sedimentary limestone and dolomite formations. These formations are susceptible to karstic solution and likely contributed vast quantities of dissolved silica to hydrothermal waters where they interacted. The interaction of these sedimentary and volcanic units were then good candidates for replacement-based chert formation, as karstic cavities in sedimentary units became potential host areas for the precipitation of chert. Similar formation processes are responsible for the extensively studied Pennsylvania Jasper on the east coast (Luedtke 1992:30).

Like volcanism, metamorphism from orogenic processes can create high temperature and pressure regimes that modify sedimentary limestone or dolomite strata and contribute to chert formation through chemical alteration or recrystallization (Leudtke 1992:25). Given the abundance of faulting and orogenic processes leading to the formation of the Rocky Mountains, this is another prominent chert formation process widespread in Southwest Montana.

Clearly, the picture presented above is a simplification of a much more complex regional setting where chert formation was a result of several complex and overlapping processes. However, the general trends identified above do characterize the underlying geology of some of the better documented chert quarries in the region. The main trend is that chert quarries tend to occur where Paleozoic sedimentary limestones and dolomites, particularly Cambrian age units such as the Hasmark

Dolomite and the Silver Hill Formation, are adjacent to volcanic strata from the Tertiary period. While the Madison Limestone group is one of these Paleozoic strata, much less has been written about the chert bearing properties of their Cambrian counterparts. This general configuration of strata can be found at the Palmer Chert Quarries near Montana City (Herbort 1987, Stickney and Vuke 2017), the Eyebrow Chert quarry in the Flint Creek Valley (Roll et al 2000:C11, Lonn et al 2010), the Camp Baker Quarries on the Smith River (Roll 2000:C8, Reynolds and Brandt, 2005) and the California Creek quarry (Elliot 2017). However, this configuration of units is also widespread in areas that do not contain chert formations. Therefore, it is unlikely to have any significant predictive power.

In researching regional quarries, the author was made aware of a unique data set on Montana quarries compiled by Patrick Rennie, an archaeologist for the Montana DNRC. The data consist of the mapped locations of over 749 bedrock and surficial quarries in the state. The data was gathered through a search of archaeological site records housed at the State Historic Preservation Office, several Forest Service repositories, BLM records and through personal communications with regional archaeologists. Two hundred and forty-eight of these are chert quarries (Figure 3). Finally, Patrick has personally travelled to many of the quarry locations to collect samples of the lithic material found there, with a focus on gathering materials that represent the range of macroscopic characteristics found at each quarry (personal communication Patrick Rennie February 2018). Upon examining this unique collection of materials, two facts become abundantly clear.

First, the range of macroscopic characteristics in materials from any one quarry is immense, particularly in color variation (Figures 4 and 5). California Creek is no exception, it contains a variety of colors such as brown, red, caramel, orange, yellow and even black or white. From personal experience, it is very visually similar to Eyebrow Chert in color, luster and even texture. This brings us to the second lesson drawn from the collection. The overlap in macroscopic characteristics between materials from different quarries is significant, again notably in color. These facts make the identification of any quarry material’s source based on visual characteristics alone next to impossible, though it has cropped up frequently in past Montana archaeological literature. References to “Eyebrow” or “Avon” chert can be found in site forms and several early Archaeology of Montana articles. This is understandable given the lack of a comprehensive sample of lithic materials from many regional quarries at the time of those articles. It’s also tempting to do when some quarry’s appear to contain chert with some internal consistencies in color and texture, such as the Avon Chert.

Avon chert is indeed mostly white and lacks the color variation found at other quarries, but there are nonetheless several other quarries that contain lithic materials nearly identical to white chert found at the Avon quarry. Furthermore, the materials photographed below from the Avon quarry only represent materials from one concentration of quarry pits found in one portion of the quarry, other pit concentrations exist covering some 30km2 (Cameron 1984:60-79). Less consistently colored materials can be found at different quarry pit concentrations across the area (personal communication Patrick Rennie February 2018). This is instructive and makes clear the need for fingerprinting lithic materials with geologically based methods before assigning them a source. The materials in Patrick Rennie’s collection may prove useful for pursuing this line of research.

Many of the regional geologic characteristics that are conducive to chert formation are also found on more localized scales at the California Creek quarry. Recently, several 1:24,000 scale geologic maps have been produced for the California Creek quarry and adjacent areas. These maps offer detailed documentation of the geologic strata that host the chert at the quarry and demonstrate that this region has potentially far more extensive chert deposits than have been documented by archaeologists.

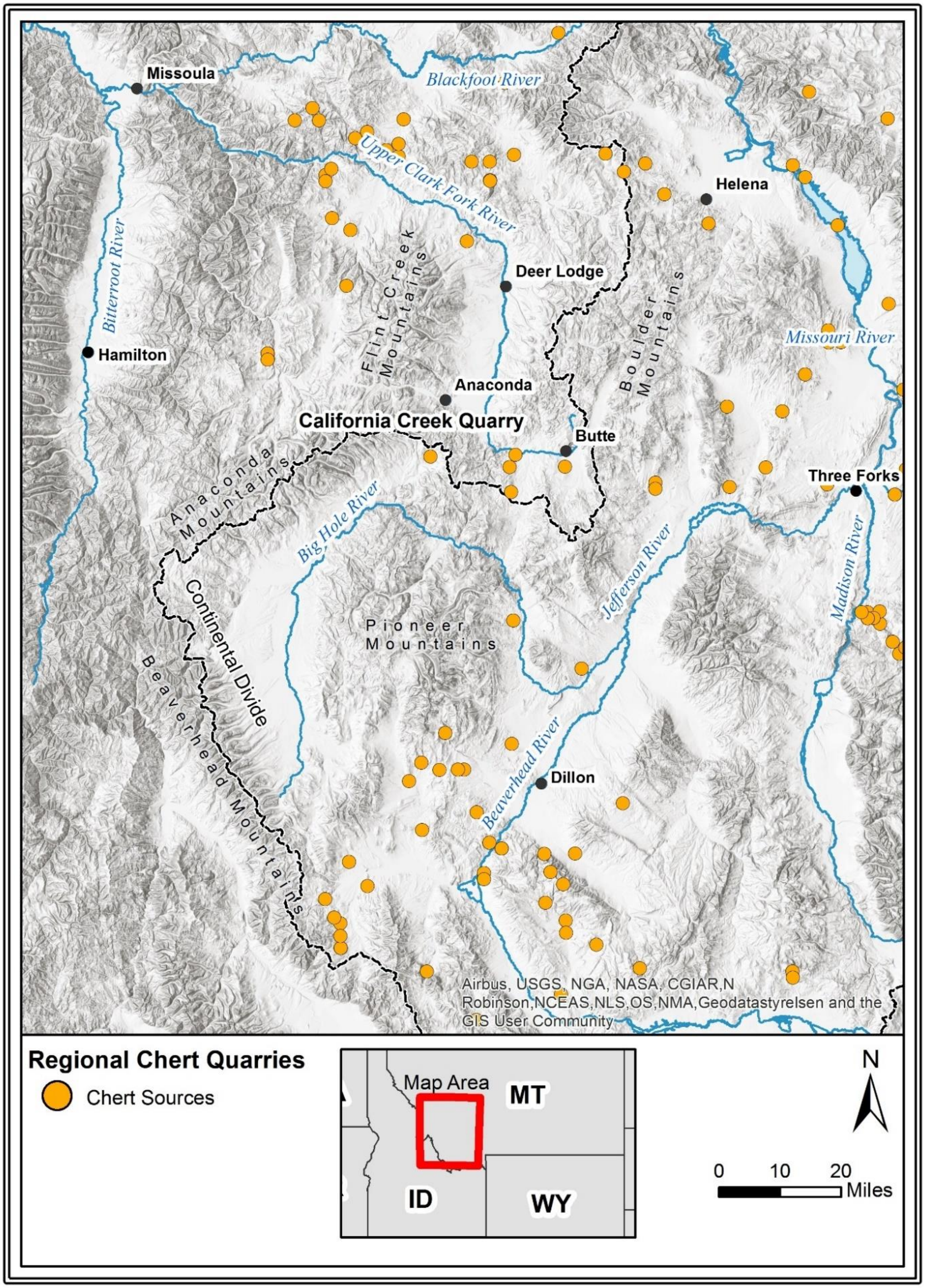

Figure 3 Location of primary and secondary chert source areas

Figure 4 Macroscopic variation within and between chert quarries in the region. From top to bottom: 1. Dry Creek Quarry 2. Lime Creek Quarry 3. Camp Baker Quarry 4. California Creek Quarry 5. Hope Creek Quarry

Figure 5 Macroscopic variation within and between chert quarries in the region. From top to bottom: 6. Van Auckerman Quarry 7. Avon Quarry 8. Palmer Quarry Complex 9. Logan Quarry 10. Everson Quarry

2.3 California Creek Geology

In 2017, a 1:24,000 scale geologic map of the Lincoln Gulch quadrangle was produced which covers the western half of the quarry. This map gives a more detailed description of the geologic unit hosting the chert. The map was compiled by C.G. Elliot at the Montana Bureau of Mines and Geology. The unit hosting the California Creek quarry was named the West Valley breccia (Unit Twv in Figure 6). The description provided is as follows: “Sedimentary and tectonic breccia characterized by large quartzite and carbonate blocks in an unsorted clastic matrix. Clasts include Proterozoic Swauger quartzite, Cambrian Flathead Formation quartzite, Hasmark Formation dolomite, dense black hornfels resembling Cretaceous Elkhorn Mountains Volcanics, caramel-colored chert, and gray rhyolite. Large blocks are brecciated and cemented with red and brown cryptocrystalline quartz. (Twv) is a mélange of tectonic and sedimentary breccias that extends along the Anaconda Detachment from the northwest end of the Deer Lodge Valley into the Big Hole Valley” (Elliot 2017). Previous geologists referred to this same unit as the West Valley chaos, an allusion to the difficulty encountered when attempting to classify and describe the unit (personal communication Colleen Elliot).

The difficulty of classifying this unit is further evidenced by the fact that the unit is described differently on the 1:24,000 scale quadrangle that covers the eastern half of the quarry. The Dickie Peak geologic map was done by Katie McDonald in 2011 and she describes the unit as follows (Unit Cbr in Figure 6): “Angular blocks of brecciated Hasmark and Flathead Formations. Age and origin is uncertain. Possibly a landslide deposit but a tectonic origin cannot be ruled out. Thickness unknown.” (McDonald 2011). The differing descriptions here capture the odd nature of this geologic unit, though the most recent description by Elliot seems more comprehensive. The fact that Elliot notes that the unit is widespread between the Deer Lodge and Big Hole valley certainly warrants future investigations, especially as new detailed geologic maps become available for the area surrounding the quarry. For example, several exposures of this same unit are found just to the west of the quarry in the Lower

Seymour Lake 1:24,000 topographic map quadrangle (Elliot 2015). Another prominent outcrop of this unit lies just south of the quarry on the other side of California Creek. It seems possible, given the regional and local geologic setting, that several additional chert bearing units exist in the area and have not been located due to the limited archaeological work conducted in this high elevation and densely forested area. This is certainly a worthy topic for future research.

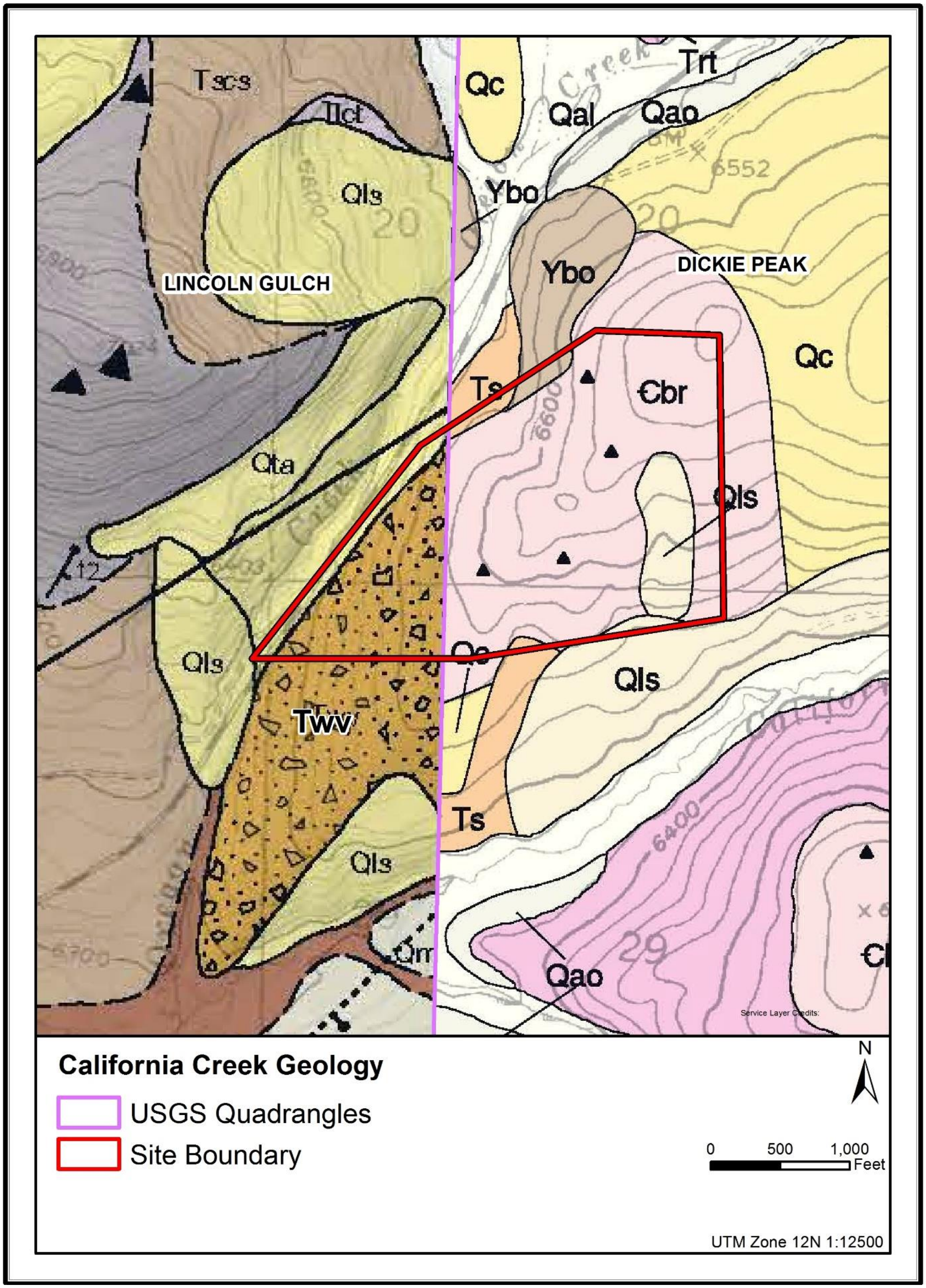

Figure 6 Geologic map of California Creek quarry

Chapter 3. California Creek Quarry

This chapter provides a basic site description for the quarry and some photos of typical features on site. In addition, previous archaeological work related to the quarry and surrounding area are summarized. While there have been no documented excavations have occurred at the quarry, excavations at sites in the vicinity provide proximal evidence of quarry chronology.

3.1 Site Description

The California Creek chert quarry is a National Register Nominated archaeological site (24DL0006). The California Creek quarry lies within the Mill Creek-Deep Creek drainages just outside of Anaconda, MT. The drainages straddle the Continental divide, and the quarry lies only a few miles south of the divide. The Deer Lodge Valley lies north of the site and is drained by the Upper Clark Fork River of the Columbia Watershed, while the Big Hole Valley borders the quarry to the south and is drained by the Big Hole River of the Missouri Watershed.

The quarry pits making up the site are found in several concentration areas on a ridgetop landform and extend down ridgelines that slope to the southwest and southeast (Figure 7). The area is relatively treeless due to clear cutting in the 1800's to provide fuel for the nearby Anaconda smelter. The area has also experienced natural forest fires since that event (Davis 1988: 5), and abundant fire altered chert found at the surface provides evidence of this. The chert deposit on site is extensive. Enormous quantities can be found in lenses within the bedrock and uncountable numbers of natural chert bearing cobbles cover the entire ninety acres of the site. As discussed previously, the chert on site features a large range of macroscopic characteristics and varies widely in color, texture, luster, translucence and structure. The primary colors observable on site are orange, red, magenta, yellow, caramel and dark brown. A lesser amount of material on site is completely white or black, though these colors are often interspersed in patches within the previously mentioned color range. There is considerable overlap between these colors and the boundaries between these color groups are gradational. Finally, some exotic lithic debitage and tools were noted on site made from materials such as obsidian, dacite and quartzite (Davis 1988:2).

The chert has been mined in various ways, resulting in a variety of different types of quarry pits. Three main types of quarry pits are evident. The first type consists of dense concentrations of shallow and ovoid shaped pits clustered in areas where the bedrock is close to the surface. These are the most common type of pits found on site and occur mostly in the northern reaches of the quarry at a hilltop that makes up the local high point. Similar types of pits extend from this northern high point down a southwest trending ridgeline (Figure 8). Bedrock debris, flaking debris and loose soils border these pits. Slope wash and aeolian deposition has accumulated in these pits after cessation of quarrying to varying degrees. The boundaries between these pits are overlapping and poorly defined, resulting in a hummocky terrain with nearly continuous pit features.

A second type of pit prevalent on site are more deeply excavated trench shaped pits found in the eastern slopes of the site. These areas have been affected by mass wasting, resulting in deeper and more developed soils in the area that permit deeper excavation. These pits likely targeted chert bearing cobbles that were already separated from the bedrock matrix through natural erosion and these cobbles litter the boundaries of these pits (Figure 9).

Finally, a third strategy was to tunnel into a few of the large bedrock outcrops occurring on site to a significant depth, most likely to mine particularly thick and high-quality lenses of chert (Figure 10). These bedrock outcrops occur primarily in the north west reaches of the site. Large quantities of discarded bedrock fragments litter the areas adjacent to these tunnel-like mining features. After cessation of mining, slopewash and possibly karstic erosion have obscured these tunnel like features. Their original depth and extent is hard to determine from their current state, but the enormous quantity of dislodged bedrock fragments near them indicates they may have been quite extensive at one time.

There are only two bedrock outcrops containing tunnel features but given the brecciated and metamorphosed state of the bedrock, they must have required enormous effort to excavate. Excavation of any type of pit on site would be helpful in discovering their true extent, though this would necessarily require tribal consultation and permitting that may be prohibitive.

Nearly the entire ninety acres of the site is covered with lithic debitage in all stages of reduction. During the 2017 field reconnaissance, two flakes of obsidian were noted on site. One dacite or basalt flake was also noted, suggesting the discard of materials from potentially distant sources. Similar exotic materials were noted by Les Davis in his field work. Exotic discard has been noted at other regional quarries in Montana and likely represents the presence of regional groups who have come to mine new materials for tool manufacturing and discarded old ones. Only one large preform biface was noted on site, though these would likely have been a primary product produced at the quarry. Taken together, the mining activity that occurred on site is extensive and the patterns found may reflect

Figure 7 Aerial overview of California Creek quarry, photo by Les Davis

Figure 8 Example of shallow ovoid pits excavated into the surface. The topography appears hummocky

Figure 9 Example of large and deeply excavated pit in areas with deeper soils and eroded cobbles

Figure 10 Deep tunnel like feature resulting from mining into a bedrock outcrop

It is worth noting that the area surrounding the quarry has seen significant historic mining activity, though mostly placer mining. However, there is a claim marker found within the California Creek that bears the name “Lost Dog #87”. This find prompted a search of mining records housed at the Montana BLM and the Montana Bureau of Mines and Geology to discover whether any modern hard rock mining occurred at the site. The BLM housed no records of hard rock mining at the site, however, records at the Montana Bureau of Mines and Geology indicated that a claim had been filed on a portion of the California Creek quarry by the Orvana Mineral Corporation in 1987. Those records indicate that the company did collect samples from the site in the form of roughly a hundred small (less than fist sized) samples of rock to test for mineral content and ore viability. However, the tests likely did not yield promising results as no follow up mining ever occurred on the site according to those records. Intensive field survey of the site both in 1988 and 2017 yielded no evidence of modern mining, and all quarry pits located were clearly prehistoric based on the lithic debitage surrounding them.

3.2 Previous Archaeological Work

There is relatively little previous archaeological literature concerned with the California Creek quarry. No quarry chronology has ever been firmly established as no excavation has ever occurred on or directly adjacent to the site to date. Instead, most of what is known about the site comes from diagnostic surface discoveries from two sources. The first source comes field work conducted by Dr. Les Davis in 1988, who originally recorded the site and produced a National Register nomination form for the site. The second source comes from a regional survey of the Deep Creek-French Creek basin, of which California Creek is a tributary. This reconnaissance level survey was conducted by Marc B. Smith in 1977 and 1978 prior to the acquisition of the Mt. Haggin Wildlife Management Area by the Montana Fish Wildlife and Parks. A few follow up excavations have occurred following this work, though they were not comprehensive in nature and do not provide significant contributions to quarry chronology (Fredlund 1993, Ferguson 2013).

Besides these sources, California Creek has seen little attention in Montana archaeology. For example, a search of the Montana State Historic Preservation Office's (SHPO) Cultural Resource Annotated Bibliography System (CRABS) revealed only two archaeological reports that mention the Smithsonian Number for the California Creek site (personal communication Damon Murdo: add date here). These two reports made only a passing reference to the quarry site and did not involve extensive archaeological work on the quarry. Therefore, the review of previous archaeological work is necessarily limited to work by Les Davis and Marc Smith. The archaeological time periods discussed below are based on chronologies developed by Frison for the Northwestern Great Plains.

Given the lack of any excavations that occurred at the site, the chronology of use at the quarry relies on the presence of temporally diagnostic surface discoveries at or near the site by Les Davis (1988) and Smith (1981). Successive surveys at the quarry by Davis yielded the discovery of six temporally diagnostic projectile points, estimated to range in age from 2,000 to 4,000 years before present and spanning the Middle and Late Plains Archaic periods (Davis 1988:2). The most common diagnostic points found at the quarry were corner notched dart points of the Pelican Lake complex of the Late Plains Archaic period. These points appear to be the most common type found at other Montana quarries as well, such as the Everson quarry (Davis 1981), Schmitt quarry (Davis 1987) and Palmer Quarry (Herbort 1981). The dominance of points from this period at quarry sites may reflect broader trends that occurred during the Late Archaic such as the intensification of bison hunting, increased mobility and population expansion (MacDonald 2012:95). It seems reasonable to suppose that these developments may have required more intensive quarrying activity to support increased hunting and growing populations. Middle period stemmed, indented based dart points of the Hanna complex were also noted on site, though they were all made from basalt or dacite rather than chert. The origin of this material is unknown, though the Cashman quarry known to contain basalt and dacite is not far distant.

As far as the mining technology used to extract the chert, hammerstones are typically credited with being the main mining tool for a variety of quarries (Davis, 1988, Roll et all 2000). However, there was a notable lack of these stones observed during field visits by Les Davis (1988:3). This may have been due to collecting by locals, as they seemed to be aware of the quarry's presence (Deer Lodge County History Group, 1975). But those same locals also reported a unique tactic used to mine chert on site, which may partially account for the lack of hammerstones. According to one account, "Their method was to build huge bonfires around an outcropping of the rock, and when the rock was very hot they dashed cold water on them, and in this process chunks of Jaspar (aka chert) would be popped off." (Deer Lodge County History Group, 1975:22). While the efficacy of this statement is unknown, it seems an odd report to fabricate and there is an archaeological precedent for the use of fire in chert mining as well.

Archaeological work conducted at the Palmer Quarry near Helena noted that bedrock surfaces in the quarry pits on site exhibited intense reddening and crazing of the surface of exposed bedrock, interpreted to be indicative of the use of fire (Herbort 1981:120). During site reconnaissance conducted at the California Creek quarry, several pits and bedrock outcrops seemed to exhibit an intense reddening of the bedrock surface as well. Using fire in mining may serve another purpose as well. It is common knowledge that chert was heat treated to improve its hardness and workability, an occurrence documented around the world. While no clear conclusions can be drawn about the use of fire as an aid to quarrying at the California Creek at this time, it may be a worthy topic for future research. More evidence of the quarry chronology comes from a survey of the Mt. Haggin Wildlife Management Area by Smith (1981).

During the summer of 1977 and 1978, Marc Smith surveyed a large portion of the Deep Creek-French Creek basin. California Creek is at tributary of this drainage basin and lies at the northern end of the area surveyed. Forty-two sites were documented as result of the survey, including sites classified as occupation, workshops, habitation and a driveline site (Smith 1981:77). In total, 1,331 artifacts were collected including forty projectile points, 230 bifaces, thirty four scrapers, four drills and a plethora of other tools (Smith 1981:52). No reference is made to where this material ended up after collection. Two intact hearth features were also noted as well as an abundance of FCR spread across many sites. The earliest diagnostic points found were from the Agate Basin Complex (10,500 to 9500 BP) and the Cody Complex (9500 – 8500 BP) (Smith 1981:75). Diagnostic points from the Early Archaic and Middle Archaic Period were by far the most common identified, containing points from the Bitterroot Phase (7000 – 3500 BP) and the McKean and Duncan-Hanna phase (4500 – 3000 BP) (Smith 1981:80). Smith attributes this occurrence to the fact that intermontane environments may have been favored by people during the Altithermal (aka hypsithermal) period. This generally hot and dry climatic episode caused harsh drought like conditions on the Great Plains, devastating the homogenous grassland ecosystems and thereby greatly reducing the population of two ancestral species of bison relied upon for subsistence by past populations (MacDonald 2012:59). The more heterogeneous ecologies of the Rocky Mountains were resilient against major droughts and provided a more stable and diversified resource base to exploit.

In 2005, David Ferguson of GCM service excavated one of the sites originally recorded by Smith. Two test pits were dug, and one large side or corner notched projectile point fragment was recovered. Ten pieces of fire cracked rock were also observed. No typology was assigned to the excavated point fragment and instead further testing was recommended (Ferguson 2013). In the Deer Lodge Valley north of the quarry, the Yellow Gopher site has also seen more recent excavations. Excavations at this yielded a teshoa, obsidian flakes and Intermountain Ceramic ware that were surmised to be indicative of a Late Prehistoric occupation associated with Shoshonean speakers known to be present in the valley (Fredlund 1993).

Despite the paucity of archaeological information regarding the quarry, these studies reveal that the quarry and surrounding region were extensively used by early and widely distributed cultural groups. The resource abundance surrounding the quarry, both lithic and biotic, likely played a role in the regions relevance to past populations for such a vast span of time. The prevalence of chert observed by Smith (1981) and by more recent excavations strongly suggests that the material came from the California Creek quarry. While it may be presumptive to attribute lithic materials found at these sites to the quarry in the absence of sourcing, the close proximity of these archaeological sites to the source area is suggestive. Ethnohistorical accounts provide further evidence of the unique setting of this region and the quarry's regional significance.

3.3. Ethnohistory

While the archaeological evidence indicates the quarry was likely used for at least the last 10,500 years, it has less to offer on topics such as how seasonality influenced mining and how important the quarry was to different ethnic groups on a regional level. To fill this gap, a brief ethnohistory section is presented below. The discussion will be limited to include only those aspects that have bearing on the

California Creek quarry and has a particular focus on the Deer Lodge Valley located just north of the quarry. For more complete coverage of this vast topic, the reader is referred comprehensive studies conducted by Stuart Chalfant (1974), James Teit (1930), Carling Malouf (1956), H.H. Turney-High (1937, 1941), J.B. Tyrell (1916), Schwab and Ryan (2012), Deaver and Deaver (1986) and Claude Schaefer (1935). The material covered below draws upon these sources, most prominently Chalfant and Schwab. A common theme that emerges from this body of literature is the importance of Traditional Ecological Knowledge (TEK) for guiding seasonal resource procurement strategies in the area. More specifically, this body of knowledge influenced subsistence strategies in the Deer Lodge Valley and provides insights into the how the quarry may have factored into broader land use patterns. A discussion of the seasonal round, as guided by TEK, serves to introduce the topic.

The seasonal round was a cyclical resource procurement strategy was guided by TEK of the numerous ecosystems surrounding the quarry (Figure 11). TEK had spiritual and utilitarian functions and was a product of generations of repeated observation, interaction, management and experimentation with ecosystems (Berkes et al 2000, Martinez et al 2006). This body of knowledge allowed hunter gatherers in Montana to thrive by embarking on seasonal movements meant to place peoples at dense resource emergence zones during their peak availability and preferred harvesting time. Well-established and efficient travel routes, constrained by the mountainous topography, facilitated these movements. Seasonal rounds were not static but responded to multi-temporal variations in resource abundance. They were designed to carefully cultivate ecosystem resilience by avoiding overharvesting of any resource (Schwab and Ryan 2012, Schaeffer 1974:52). The seasonal round also responded to the varying needs of the tribe, band, or family group participating in the movements, resulting in a myriad of potential routes. The seasonal round framework is useful for understanding the broader context in which the quarry and its surrounding environs factored into resource procurement strategies of both local and regional tribes.

Prior to and after the introduction of the horse, the Deer Lodge Valley was within the aboriginal territories of various bands of the Salish, the Pend Oreille and Kootenai tribes (Chalfant, 1974; Teit 1930, Malouf 1967:1). Their long-term residency in these areas is well established by archaeological evidence, oral traditions and place name studies (Knight 1989, Malouf 1974, Schwab and Durglo 2009, Salish-Pend d'Oreille Culture Committee 2005). According to Teit, in precontact times, the Flatheads and Pend d'Oreille occupied nearly all of present day Silver Bow, Deer Lodge, Beaverhead, Madison, Gallatin, Jefferson and Broadwater Counties (Teit 1930:268) and had headquarters at Anaconda (ibid:275).

The ancient connection of the western Tribes to chert is demonstrated in Salish oral history and the Tribe's mythological Coyote Stores. Oral traditions make references to Flint and his dog Grizzly Bear and how Coyote procured flint for the people and spread it throughout their western Montana homeland (Mourning Dove 1933, Sanders 1909). In the Tribes' Creations Stories, Coyote uses a flint knife regularly against his adversaries as he prepares the world for the coming of humans.

Following the introduction of the horse, Shoshone groups began expanding north from the Great Basin by the early 1600's (Malouf, 1968:10). Shortly after that, the Blackfoot and Crow began their rapid expansion from the northeastern Plains into these areas (Chalfant, 1974: 8, 79). These latter groups made temporary incursions into the area to raid horses from the Salish and Pend Oreille, though the Shoshone were at time also militarily aligned with Salish groups as well. While the Salish and Pend d'Oreille were likely long term permanent residents of the Deer Lodge Valley, there are abundant accounts that support the fact that regional groups were familiar with the area as well. This can be attributed in part to the fact that the Deer Lodge Valley was at the intersection of several ancient trail routes used by these various tribal groups. In fact, the Salish place name for the Deer Lodge and Flint Creek Valleys is translated to "Many Trails" (Salish Pend d'Orielle Culture Committee 2005:68). Groups from the Great Basin could enter the valley through Gibbons Pass and the Big Hole Valley. From the Big Hole Valley, Mill Creek pass leads directly to the Deer Lodge Valley and also passes right by the California

Creek quarry. Groups coming from the Plateau could use the Nez Perce Trail and Skalkaho Pass to enter the area, crossing through what is now Philipsburg and the Georgetown Lake area. Finally, the Deer Lodge Valley is in the Upper Clark Fork river drainage which served as one of the primary thoroughfares for Plains groups entering the Rockies (Figure 12). Each of these groups would have interacted with the Deer Lodge Valley at different times of years, guided by different seasonal rounds.

The Deer Lodge valley was considered prime wintering grounds due to its yearlong abundance of elk and deer, the exceptionally mild winters there and the presence of mineral hot springs with prized healing properties (Malouf, 1974; Stevens, 1855:344). Deer and other game animals congregated in the valley due to a unique feature in the valley, a volcanic mound. The mound is located near a hot spring

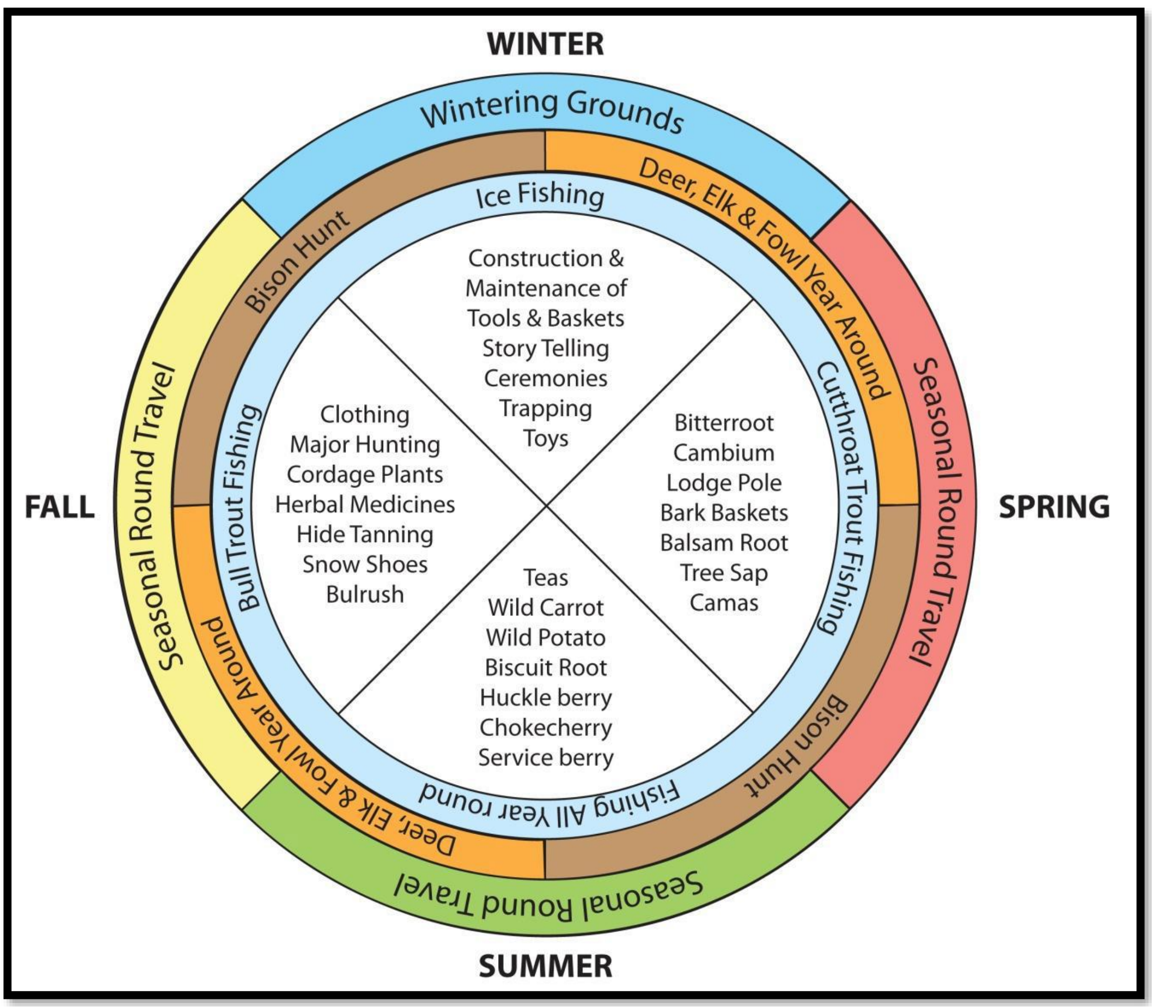

Figure 11 Seasonal model of tribal resource procurement, primarily for Salish groups, used with permission by Tim Ryan

found on Warm Springs creek, and the soils surrounding this mound provided a natural salt lick attractive for deer. This volcanic mound feature was called the Deer's Lodge, since during winter it looks like a tipi/lodge with smoke coming out and typically had deer nearby (Speck 1933:4). The warm waters also allowed grass to grow nearby year-round, an additional attraction to deer and useful feed for the horses tribal people maintained. Bison could also be found in the Deer Lodge valley in precontact times, making it one of the few areas they existed west of the continental divide (Chalfant 1974:51).

During the early spring, seasonal movements would have taken Salish and Pend d'Oreille groups out of their various wintering grounds in search a primary floral resource, bitterroot and camas. Groups wintering in the Deer Lodge Valley did not need to go far, as areas around modern day Anaconda were valued for the abundant, large, and high quality bitterroot (Schwab and Ryan, 2012:23, Salish Pend d'Oreille Culture Committee 2005:68). Camas was the next main staple sought in a seasonal round, and it is typically ready just after the bitterroot. Camas patches were located around the Anaconda area, as well as in the Deep Creek French Creek drainage just south of the California Creek quarry ibid:32). The dense concentration of camas in the Deep Creek Drainage is unusual as it is in a relatively high elevation area (5500 to 7000ft) and is one of the only a handful found in the notably drier regions east of the continental divide. Its high elevation position means it becomes ready for harvest later then camas found in the lower elevation valleys, allowing groups to extend the camas harvests into the early summer.

Finally, bison hunting played a large role in determining the path of the seasonal round. Here again, the Deer Lodge Valley was of unique importance. The valley was a staging ground for the Fall buffalo hunt due to its location as a convergence of several regional trails and its easy access to several passes into buffalo country east of the divide. Several tribes gathered here from distant regions for this hunt. In 1925, Granville Stuart noted the presence of a combined village of Nez Perce, Yakima, Coeur d'Alenes, Pend Oreille and Bitterroot Salish who had gathered in the Deer Lodge Valley to spend the fall and winter hunting bison on the eastern plains (Stuart 1925:157). The gathering provided an opportunity for socializing and trade, and their large numbers protected them from potential Blackfoot harassment. Shoshone and Bannock also gathered in the Deer Lodge Valley for the annual fall Bison hunt (DeVoto 1947:88). One account noted a particularly large gathering of Western Tribes that occurred in late August of 1854. An estimated 6000 members of the Shoshone, Salish, Nez Perce and various Pacific Northwest tribes were reported to have gathered in the Deer Lodge Valley for the fall buffalo hunt. This gathering was reported to have occurred every three years (Wilson 1988:14).

The gathering of regional tribes is not likely confined to the historic contact period, as one account indicates. In April of 1862, the Salish Chief Victor was upset from recent raids by the Shoshone and Bannock who had stolen horses from his band. He asked Granville Stuart to keep the Shoshone and Bannock out of this place following the incident. In response, Stuart (1925:204) makes a note about territoriality concerning the region, saying: “As Deer Lodge valley and the valleys of the Big Hole, Beaverhead and Jefferson has been, from times immemorial, a neutral ground for the Snakes, Bannocks, Nez Perce, Pend d’Oreilles, Flathead, Spokane, Coeur d’Alene and Kootenai, it looks like the old chief is too arbitrary in insisting that the Snakes and Bannocks should be forbidden to spend the winter and hunt there same as all the others..” In other words, the Deer Lodge Valley had long been recognized as a neutral hunting ground by both local and regional inhabitants.

From this abbreviated ethnohistory discussion, two main trends emerge that have interpretive power for understanding the quarry. The first deals with the seasonality of quarry use and the second with how the quarry may have been utilized by regional tribes. Given the large gathering of regional tribes in the Deer Lodge Valley for the fall buffalo hunt, fall mining for lithic materials would likely have been a necessity. The proximity of the California Creek quarry to this gathering ground makes it a prime candidate to fill this need. Furthermore, the quarry lies adjacent to a well-established trail route connecting the Deer Lodge Valley with the buffalo hunting grounds in the Big Hole Valley, via the Mill

Creek-Deep Creek drainages. Another factor relating to seasonality is that the high elevation location of the area would have limited the seasonal window for use. Mining on site would have been difficult or impossible during all but the late summer months, as high annual snowfalls persisting well into the spring are common. Frozen ground does not lend itself to excavations, even with more modern metal tools. Finally, the quarry may have also been used in the early summer months by peoples harvesting the high elevation camas patches that abound in the Deep Creek French Creek drainage. This may also explain the abundance of FCR and hearth features noted by Smith in his archaeological reconnaissance of the area, though this conclusion is tentative and would require further work to validate

Finally, the large gathering of regional groups in the Deer Lodge Valley would have created an ideal setting for trade of various goods. Lithic materials may have been particularly valuable trade commodities during the fall buffalo hunt. It is impossible to tell for how long the Deer Lodge Valley functioned as a gathering place for regional groups, but the ecological, lithic and physiographic factors that encourage it have been in place for thousands of years. Unfortunately, in the absence of lithic sourcing, it's impossible to verify with certainty whether California Creek chert was widely dispersed after its procurement. This is certainly an area worth of future research, though the evidence presented here makes its likely that materials from California Creek were or regional importance.

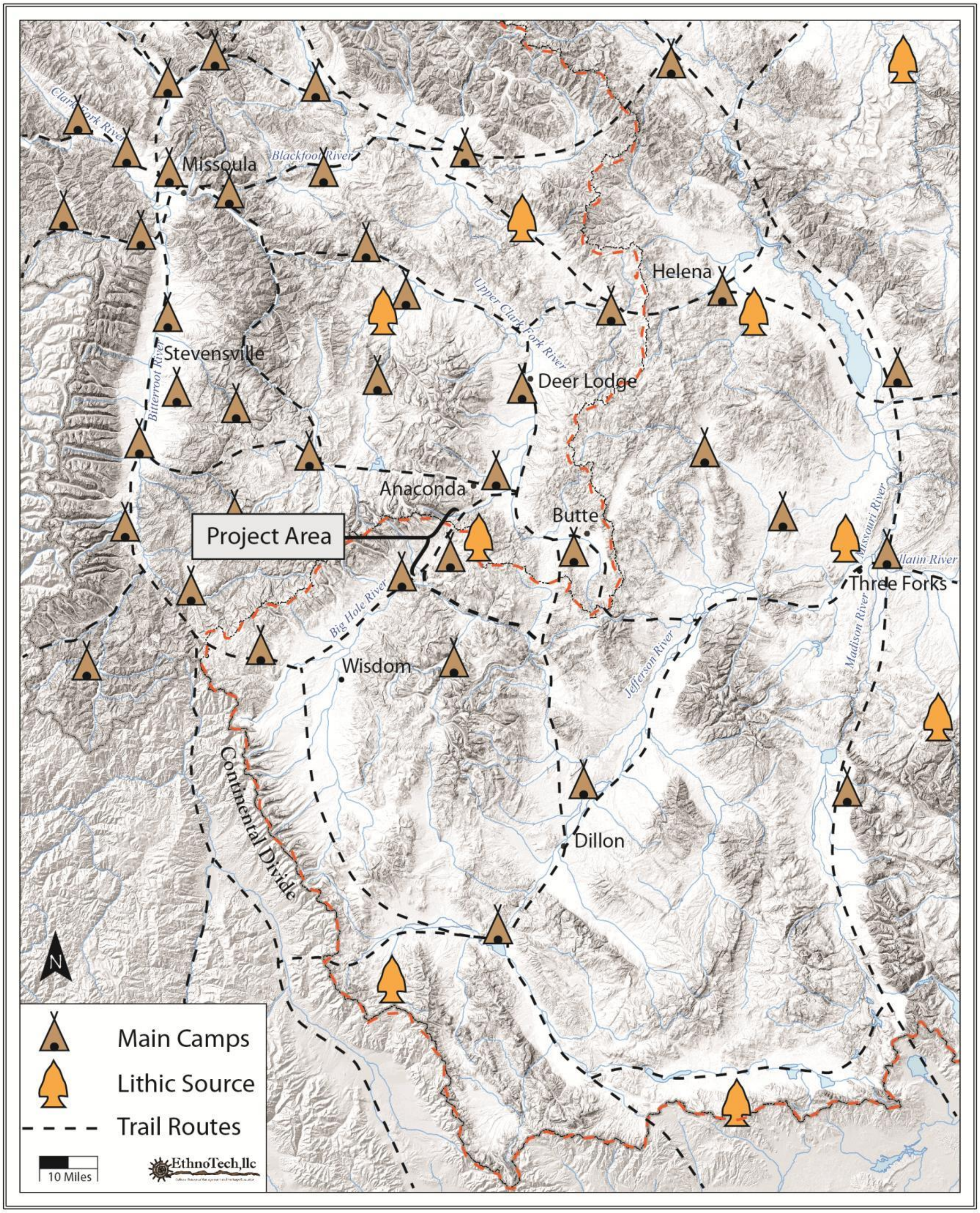

Figure 12 Regional travel corridors, lithic sources and camps. Adapted from Malouf (1980) and used with permission from Tim Ryan

Chapter 4. UAS Mapping

Having established a regional context in which to better understand how the California Creek quarry may have factored into subsistence and trade, the next main component of this study was to map the quarry site itself. Understanding the spatial aspects of the California Creek quarry provides a foundation upon which to base future research and interpretations of the site. The spatial data gathered can help to measure mining intensity at the site through simple metrics like volume of material removed, number of quarry pits and total area of mining activity. Furthermore, providing an accurate record and detailed map of the quarry and its features in their current state is a useful management tool for the preservation and conservation of this site. Using more traditional means to produce high resolution spatial data for the site can be prohibitively time consuming and expensive (Raeva et al 2016). It would likely have required the purchase or rental of survey grade geodetic systems such as a total station, which can cost tens of thousands of dollars. The price for UAS technology has plummeted in recent years, offering a new and much more affordable platform for site documentation. Therefore, this technology was used as an efficient and affordable means to gather high resolution spatial data on the California Creek quarry. The UAS survey undertaken at the site will be discussed in terms of its three main phases.

The first component is flight planning. This phase is crucial to any UAS mission and heavily influences the results achievable. Planning includes obtaining all legal certifications (e.g. FAA part 107 license) and landowner permissions. This project was no exception and all relevant permissions and certifications were obtained prior to this undertaking. The second phase is flight execution. This phase relies heavily on specific software developed for UAS mapping and necessarily includes some discussion of these software. The third phase is image processing which converts the raw UAS images into spatial products such as orthophotos, 3D products and digital terrain models. Again, software is a crucial component of this phase and is discussed in some detail. A brief discussion of the UAV hardware used for this survey serves as an introduction.

4.1 Hardware

The UAS survey of the California Creek quarry was conducted using a recreational grade drone, the DJI Inspire 1 Pro equipped with the Zenmuse X5 camera. Recreational grade drones typically have a lower payload capacity, lower battery life and flight time, less accurate onboard GPS's and lower resolution cameras compared to industrial grade drones. Despite these limitations, they are an order of magnitude less expensive than industrial grade drones-two to four thousand dollars instead of twenty to forty thousand dollars. Also, they are still capable of producing centimeter grade spatial resolution products when flown to certain specifications, which are elaborated on below.

The Inspire 1 pro is a rotor wing drone meaning it has four rotors fixed around a central mast. Rotor wing drones offers the advantage of being relatively easy to control given their ability to hover and self-stabilize, so they are great for new pilots like this author. The Zenmuse X5 camera produces 16 megapixel photos and 4K video recordings, providing more than adequate pixel resolution for high grade mapping applications.

The Inspire 1 Pro costs around four thousand dollars including accessories consisting of five extra batteries, an extra charging unit and the upgraded Zenmuse X5 camera. This cost is minimal when one considers that the traditional means of creating high resolution digital terrain models usually requires geodetic survey equipment including GNSS and RTK capable total stations, costing at least 10,000 dollars and potentially much more (Raeva et al 2016). The final piece of hardware required is a smart phone or tablet so that one can run the software necessary to assist the remote pilot in UAV flight. Once the hardware is chosen the next-and perhaps most important-step is to plan out the UAS survey.

4.2 Flight Planning

Flight planning is a crucial part of any UAS survey. The decisions made during this phase of a UAS survey will constrain the results that can be achieved. While planning a UAS survey, it's helpful to reflect upon some central questions to guide the process. The primary questions to consider during this phase are as follows and they will serve as a guide for the following discussion:

- What kind of terrain are you mapping and what challenges can that introduce?
- Are you better served conducting several small flights or can you do one large flight?
- What is the target spatial resolution you hope to achieve for the final products?
- How can you conduct your flight to minimize shadows in your images, which can lead to errors when generating final products?
- Are there any FAA restrictions on the airspace you are operating in?
- What software do you plan to use to aid in the UAS survey?

These questions are helpful to keep in mind throughout the planning process. The first step in the planning process for this UAS survey was field reconnaissance. Several visits were made to the site to assess terrain, obstacles and outline the boundaries of the core concentration of mining activity on the site. As a result, 95 acres of land were identified to be surveyed. The terrain on site had significant variations in elevation across short distances. These factors contributed to the decision to break up the UAS survey into several smaller flights, which limited total flight time in a day and made it possible to maintain visual line of sight with the UAV during survey. In total, six flights were undertaken to map the quarry (Figure 6).

The next step was to define the target spatial resolution of the final products from the UAS survey. Spatial resolution is measured as the Ground Sampling Distance (GSD), expressed by how many centimeters of the actual ground surface will be included in each pixel of the photos captured.

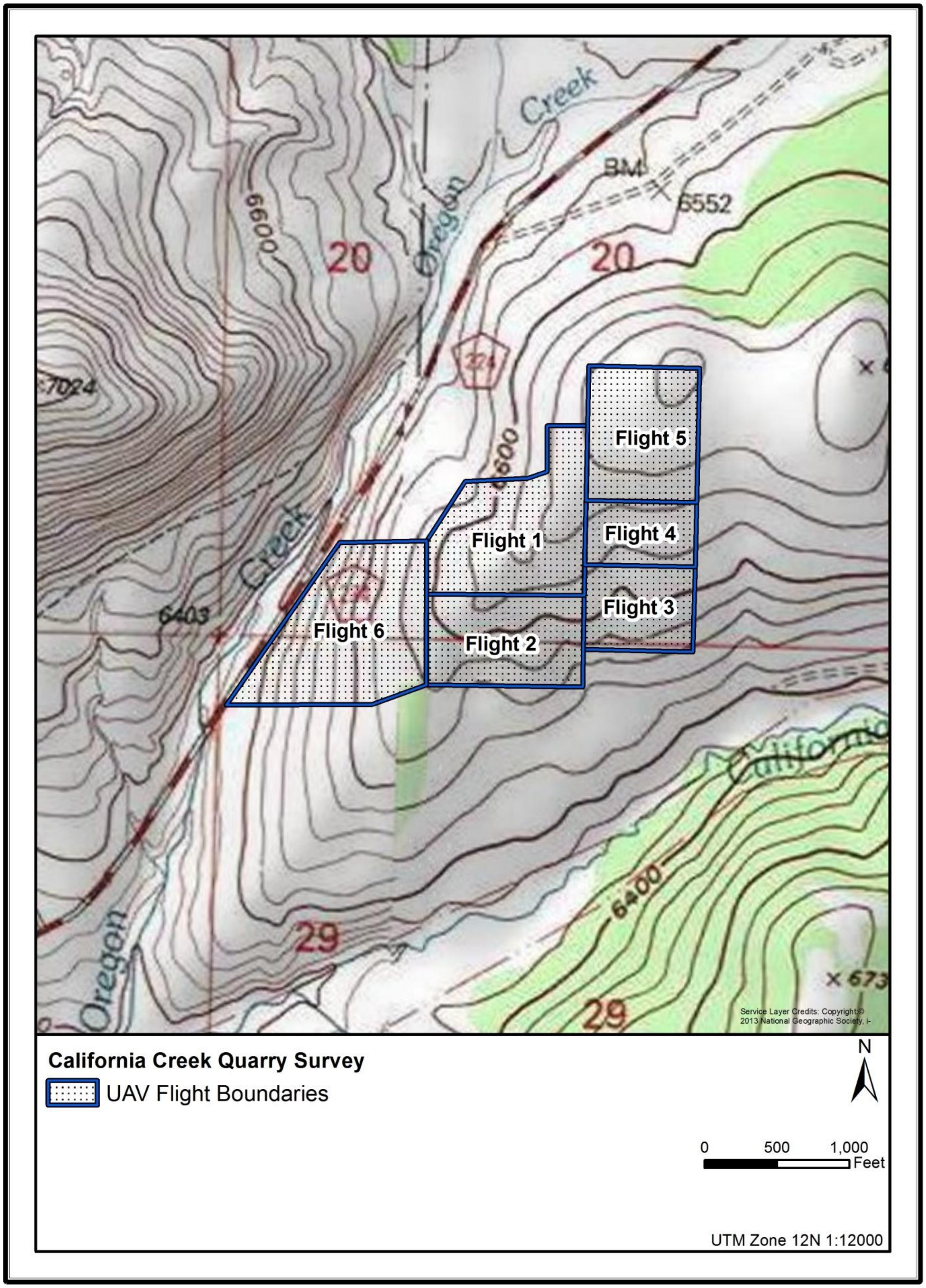

Figure 13 UAV flight boundaries numbered sequentially from earliest to latest flight

GSD can be calculated by the equations given below (Tscharf 2015). The target GSD for this project was 2cm. Given the specs of the Zenmuse X5 camera used for survey, a sixty-meter flight height was required to yield the desired GSD.

1. Pixel Size = Sensor Width (mm)/ Image Width (px)

*2. GSD = Pixel Size (mm/px) * Elevation Above Ground (m)/Focal Length (mm)*

1. Pixel Size: 0.0051mm/px = (23.5mm sensor width/4608px image width)

*2. 20mm GSD = (0.0051mm/px*60,000mm)/ 15mm focal length*

The next set of factors to consider is how much image overlap is required for you mission, as overlap also influences the quality of the final products you can produce. Image overlap measures how much overlap there is in the amount of ground captured between any two images. Its typically broken down into frontlap and sidelap and is measured in percent. Frontlap refers to the amount of overlap between two consecutive images taken along the same flight line, while sidelap refers to the amount of overlap between two images in adjacent flight lines. Figure 14 below shows the actual flight path of the UAV and the location at which it took photos, represented by the points. Frontlap and sidelap are marked within the flight path to illustrate the difference between them. Overlap can be adjusted within a software package that is used for flight planning and autonomous flight. The amount of overlap required depends on whether you are attempting to create 2D product or 3D products with the captured images. For 3D products, its recommended to have a frontlap and sidelap between 80-90%. For 2D products, 60-70% is recommended (Greenwood 2015:39). captured images.

Another factor to consider is how to limit shadows in the images captured, as make it more difficult for the computer programs to stich the images together into various products during post processing (Gutierrez et al 2016:10). Therefore, its best to concentrate flight time around solar noon when shadows are naturally minimized. This limits the time of ideal flight conditions on any given day, which was another reason to break up the UAS survey into several smaller flights.

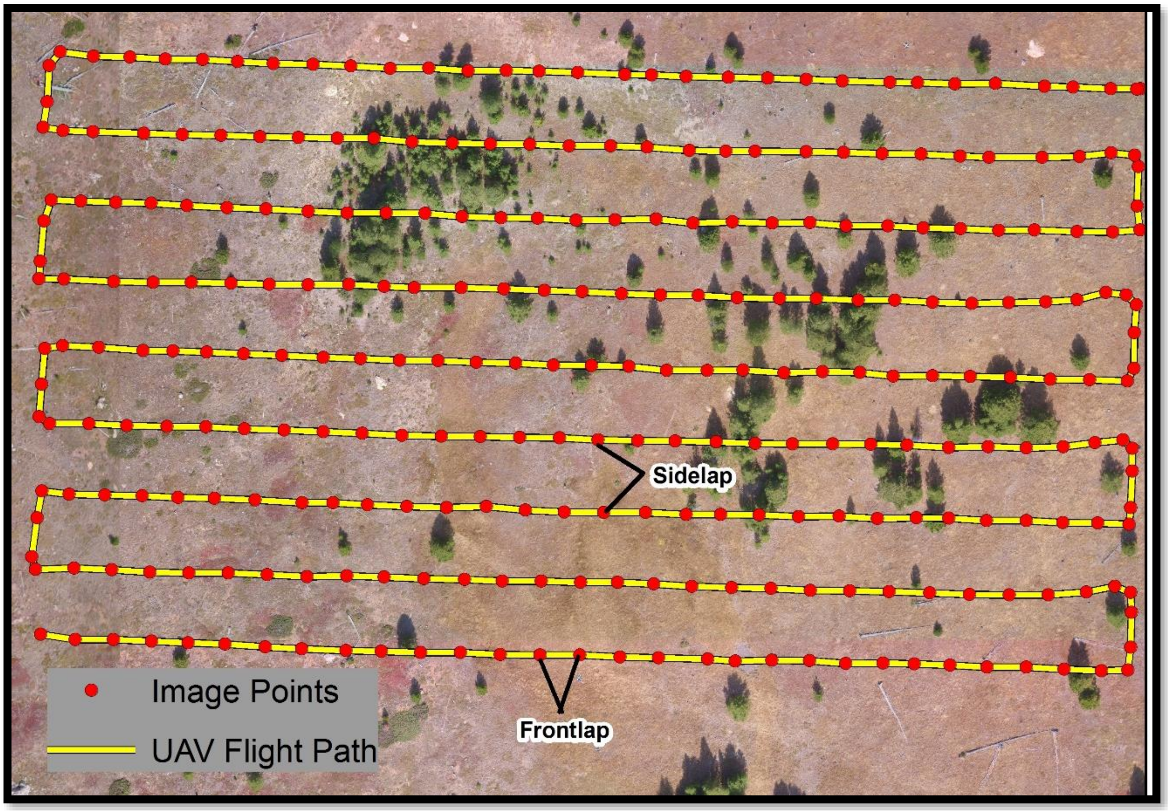

Figure 14 Actual flight lines of the during survey including frontlap and sidelap indicators

Ideally, one would fly during a cloudy day which would allow a much larger window of good lighting conditions for flight time. Unfortunately, these days were rare during the time of this undertaking. Conducting several small flights also had advantages that would only become obvious during flight execution, which is discussed in more detail in the flight execution section below. Having addressed many of the guiding questions outlined above and setting a target GSD, the next step is to design each flight in a flight planning software package.

There are several software packages have been developed specifically for flight planning and each will autonomously pilot the UAV to fly the mission specified. For this case study, the free application DroneDeploy was chosen as the primary flight planning software. DroneDeploy has an online interface for flight planning and a mobile application that's used to execute the flight in the field. It also allows users to download any flight plan to a mobile device so it can be flown without internet connection, which was necessary for this project. Lastly, DroneDeploy allows users to use GIS derived shapefiles as your flight boundary during flight planning. This feature offers the advantage of being able to plan multiple overlapping flights in a GIS environment where you can reference any geographic data that may be helpful for flight planning. This feature was crucial for this UAS survey, since several GPS points were collected during field reconnaissance that helped define the area that needed to be flown. Planning multiple flights in GIS is preferable to relying solely on DroneDeploys' online interface because you cannot reference other flight boundaries while designing a new one in DroneDeploy. This leaves one to guess on where the previous flight boundaries were and makes designing multiple overlapping flights for a single continuous area difficult.

To recap, the plan for California Creek quarry UAS survey was designed with the following specifications. The 95-acre site was surveyed in a total of six separate flights, each roughly taking two hours to complete after factoring in battery swaps. The flights all were conducted with 85% frontlap and sidelap and were flown at sixty meters (200ft) above ground level. The flights were all flown within a few hours surrounding solar noon in order to minimize shadows. With the plans in place, the next step was to execute them.

4.3 Flight Execution

The California Creek quarry UAS survey was conducted from August 2017 through November 2017. Prior to beginning each flight there were a few setup procedures undertaken in the field that helped to ensure successful data collection. They will be discussed below in hopes they may be helpful for newer pilots and those unfamiliar with the software packages used.

The DJI Go application is published by the Inspire 1 Pro manufacturer and is useful for setting up the UAV and camera before switching to autonomous flight software like DroneDeploy. Some settings to be aware of before flying include checking the IMU calibration, the camera exposure and compass calibration. IMU calibration will calibrate the barometer on the UAV, which the UAV uses to judge its height above the ground. Having an accurate IMU reading is necessary for the UAV to be able to maintain a consistent height above ground during its autonomous flight. A second crucial setting to check in DJI Go is the camera exposure. For example, in sunny conditions the pilot can set the camera exposure to “Sunny” so that the white balance in each photo is correct and you avoid white washed photos. It was the experience of this author that automatic camera settings in DroneDeploy were prone to errors and manually setting the exposure in DJI Go was preferable. Compass calibration is important to do so that the UAV can orient itself more accurately during autonomous flight.

The second important setup process prior to flight is to set up Ground Control Points (GCP’s) within the flight boundary. GCP’s are a target within the mapping area that has known coordinates and acts as a datum point for other locations within the mapping area. The GCP’s ensure that the final products from the UAS survey will be more internally consistent, correctly georeferenced and have a higher spatial accuracy. They are especially useful for achieving higher spatial accuracy when using recreational grade drones with limited onboard GPS accuracy (Greenwood 2015:43), as was the case with this survey. GCP’s also help in the post processing phase by providing a spectrally distinct feature that the computer can use to tie together different photos. This is helpful in homogenous terrain, such as grasslands, where there are potentially very few spectrally distinct features. To gain maximum benefit from GCP’s, their location must be recorded with a submeter accuracy GPS unit and they must be widely distributed within the mapping area. For this survey, a Trimble GeoXH 2008 GPS receiver capable sub-meter accuracy was used to record the location of the GCP’s. A minimum of three GCP’s are required for image processing, but more can be beneficial especially for larger area surveys. Four to six GCP’s were used for each flight in this UAS survey, varying depending on the acres covered. GCP’s can take considerable time to setup for larger acreage sites like California Creek. It often took a few hours to set these up in the steep mountainous terrain, so planning ahead was key so as not to miss the window of ideal lighting conditions surrounding solar noon.

Once all setup procedures are complete and GCP's were in place, it was time to let DroneDeploy autonomously pilot the UAV for data collection. During flight the remote pilot should maintain visual line of sight with the UAV and monitor the DroneDeploy application for errors. Some common errors encountered were the improper focusing of the camera by DroneDepoly, the freezing of the application and the random cessation of data collection. Though infrequent, these occurrences can potentially ruin the data captured. One must monitor the live feed and running count of the images being taken that are displayed in the app to catch these issues early on. It was the experience of this author that If the live feed looks blurry, then the photos being captured are likely blurry as well. If the image counter stops or the app freezes, you likely are no longer collecting data. Monitoring the app for these issues is important for catching these errors early on and all were fixed by restarting the application.

By far the most consistent error encountered during the UAS survey on DroneDeploy was related to restarting a flight after swapping batteries on the UAV. Swapping batteries is necessary for any flight lasting over roughly fifteen minutes due to battery life limitations on the Inspire 1 Pro. All six flights conducted required at least three battery swaps, some required as many as five. On several occasions, DroneDeploy failed to restart the flight as the correct point at which it left off after replacing the battery. The cause of this issue is unknown, but its worth noting that at the time of writing DroneDeploy has received several updates and upgrades to functionality that may have already addressed this issue.

A potentially significant limitation of DroneDeploy is that it does not adjust the height of the UAV to compensate for elevation changes in the terrain. Given the steeply sloping mountainous terrain at the California Creek quarry, this became an issue. Having the UAV height above ground change during a flight will introduce variance into the GSD and photo overlap within a given flight, in turn affecting the spatial resolution achievable from the flight.

There are software packages that do alter flight height in response to terrain, such as Map Pilot. The “terrain following” feature of this app was tested during one UAV flight. This feature adjusts the flight height in response to changes in elevating of the underlying terrain. To do this, the software calculates the elevation profile of the area to be surveyed using 30m resolution digital elevation models (DEM’s). However, the relatively poor spatial resolution of these DEM’s means the software can only adjust flight height in response to very generalized changes in elevation. It does a relatively poor job at adjusting flight height for areas containing steep slopes and drastic changes in elevation across short distance, as was the case at California Creek.

After testing the feature, it was found to have potential as well as limitations. It certainly can mitigate variance in GSD within a flight by compensating for terrain, but its better suited to gently sloping terrain. The benefits of this feature were also offset by the many errors encountered while using Map Pilot. For example, the app incorrectly focused the camera during terrain following flights resulting in blurry photos. Similar to DroneDeploy, Map Pilot also frequently restarted missions at the wrong point after a battery swap. At the time of writing, these issues were recognized and apparently fixed in a recent update of Map Pilot. However, this author found DroneDeploy to be a more intuitive and flexible product for autonomous flight. The errors introduced from variable terrain were mitigated by breaking UAS survey up into six components. The changes in elevation within these six subareas were relatively minor and resulted in a more consistent GSD and overlap during UAS flight. In all, each of the six missions were successful in capturing the data needed to create the desired spatial products.

4.4 Post Processing

Phase three consists of generating spatial products from the raw UAV imagery. For this project, ESRI’s Drone2Map software was used. The software is image-based 2D and 3D reconstruction software that has its origins in the field of image processing and photogrammetry (Hartley and Zisserman, 2004, Verahoven 2012). Drone2Map uses the same processing engine as Pix4D, popular image processing software, but it can generate ESRI specific products such as 3D scene layers. Drone2Map can also create orthomosaics, digital surface models, digital terrain models and 3D point clouds. All these products were generated for the six flights and each flight was processed separately within Drone2Map. The total time taken to process all six flights was over three weeks with the computer running full time. The process is very computationally complex and demanding even on high end computers. In total, 3214 pictures were captured and used in the image processing.

Within Drone2Map, there are several settings one can choose from that affect the results. I will refer the reader to ESRI's website to see a full explanation of what the settings are and what they do (ESRI 2017). The short version is that there are three main steps: initial processing, densification, and product generation. I chose to have the maximum available quality settings turned on for the initial and densification steps. On product generation you can also set quality, which was set to maximum, but there was one further setting that was crucial to producing a high quality digital surface and terrain model. Drone2Map offers a "surface smoothing" option with sharp, medium and smooth settings. I had the most success with the "Smooth" setting which filtered out much of the noise present in the digital terrain model and resulted in the best possible representation of terrain. After I had processed each of the six flights, I chose to mosaic the 2D products together into one large orthomosaic and digital terrain model. Similar success was achieved in generating the 3D products from the UAV imagery.

Chapter 5 Results and Analysis

In general, each of the six flights returned satisfactory products that met the goal outlined in the flight planning phase. The spatial products produced, particularly the digital terrain model, capture the extent of mining on site in striking detail. The orthophoto and 3D scene layer convey a sense of the terrain, vegetation and rocky outcrops within the quarry and document its present condition for future researchers. Taken together, these products provide an excellent record of the site produced with relatively minimal time and money.

5.1 Spatial Accuracy

The GSD obtained by each survey varied from 1.2 cm per pixel to 2.3cm per pixel, which was within the range of values targeted. The variation in final GSD was most likely due to the varying terrain and the fact that some flights contained higher relief within their boundaries than others. The flights that had the highest relief within their boundaries generally returned the higher GSD. The "terrain following" feature discussed in the second phase could mitigate this issue, though it has limitations already discussed. Despite a small variation in GSD, breaking up the UAS survey into several smaller flights helped to maintain a more consistent GSD.

Another measure of the accuracy of the products is the root mean square (RMS) error, which Drone2Map calculates to measure error in the XYZ dimensions of the GCP's. Each of the six flights contained minimal RMS error in the X and Y dimensions, with none exceeding thirteen centimeters. The RMS error in the Z dimension was more substantial for some flights with the highest being 10m in error. This was due to the fact that the IMU was not calibrated prior to each flight, making it so the UAV had an inaccurate reading of its height above ground compared to the GCP's.   Additionally, the Inspire 1 Pro contains only a recreational grade GPS with an accuracy range of (+-)5 meters in the horizontal and (+-)10 meters in the vertical dimension. Therefore, having an RMS error in the Z dimension of 10 meters is not unexpected. The GCP's surveyed with sub meter accurate GPS helped to minimize these inconsistencies during the post processing phase and the digital terrain models or 3D scene layers contained internally consistent elevation values with no major anomalies.

5.2 Spatial Products

The spatial product that is most useful for visualizing the complex mining topography on site is the digital terrain model (Figures 16, 17 and 18). Drone2Map produces these products by first creating a digital surface model (DSM), then modifying it to expose the underlying terrain. A digital surface model is a high-resolution representation of the terrain its surficial features including small trees and shrubs. To create a DTM, the DSM is resampled to filter out sparse surface vegetation and expose the underlying terrain (Figure 17).

The DTM gives an exceptionally detailed view of the scale of the mining that took place on site. The DTM captures the complex topography of this archaeological landscape and reveals some patterns associated with quarrying activity. The high resolution orthophoto of the site also returned excellent results and serves as a useful reference when analyzing the patterns seen in the DTM. Finally, the 3D products generated provide a unique way to visualize the terrain on site. One such layer is the 3D scene layer that can be viewed in ArcScene, a product similar to Google Earth that allows users to zoom and pan into 3D scenes (Figure 15) . This scene layer conveys a sense of setting and scale of the California Creek quarry and may prove to be useful for site managers as a record of the sites current condition.

5.3 Limitations

There are some limitations involved with the UAS method. The main limitation for this purpose is the inability of the UAV camera to capture terrain data in areas obscured by dense vegetation. A few quarry pits were obscured by dense aspen groves. However, the majority of quarry pits were not obscured by vegetation and were adequately captured with the UAS data. UAS based LIDAR is a potential way to solve this issue for other surveys in areas with dense vegetation. LIDAR can penetrate vegetation and expose the underlying terrain, but its prohibitively expensive for UAV's at the time of writing and requires expensive customized software to support.

A second limitation is that some of the flights produced orthophotos that contained blurry sections, likely due to motion blur in the original photos and inaccurate GPS readings from the UAV itself. The blurry orthophoto issue was rectified because there were several overlapping flights, making it possible to take pieces from one orthophoto that was not blurred and mosaic that piece in where another orthophoto did look blurry. The results were that the final orthophoto contained hardly any blurry sections and its final resolution was exceptional at 2cm.

Ultimately, this undertaking was successful in demonstrating the utility of low-cost UAS based remote sensing. The products generated convey the scale and mining intensity found on site in an intuitive visual form. This method can provide the baseline information for future archaeological work at the site and can be leveraged to measure mining intensity, discussed below.

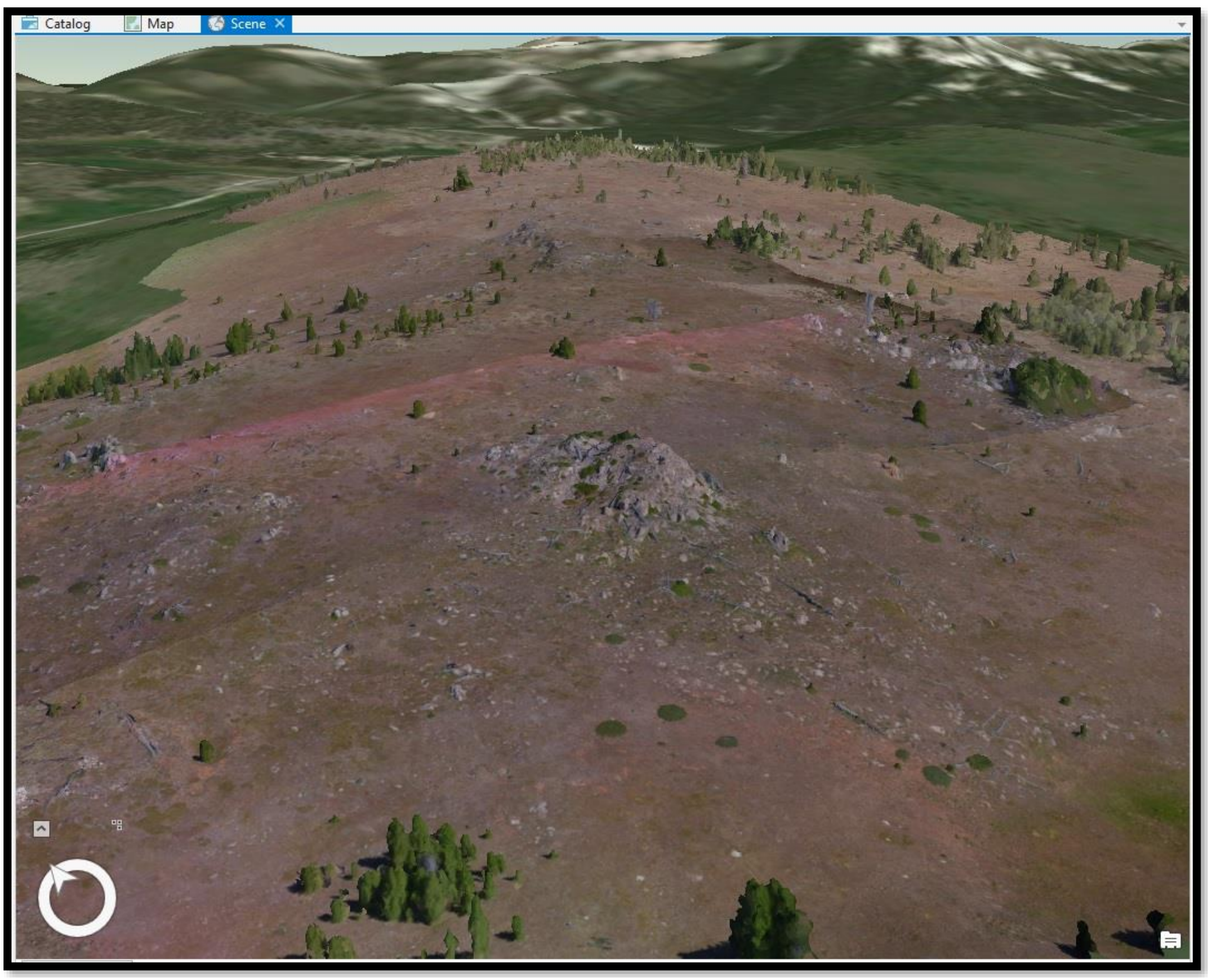

Figure 15 Example of 3D scene layer viewed in ArcScene

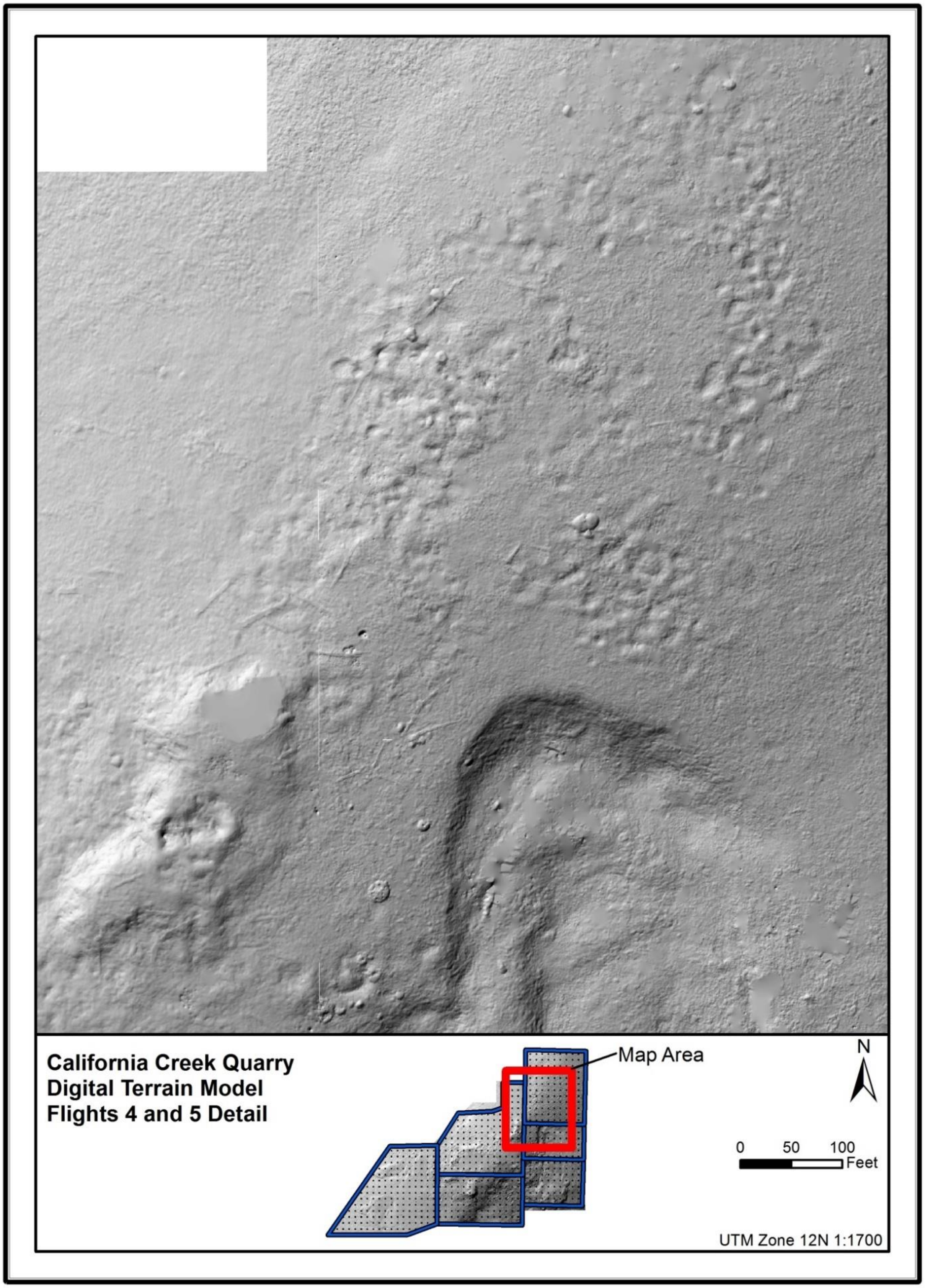

Figure 16 Detailed view of quarry pits from the DTM

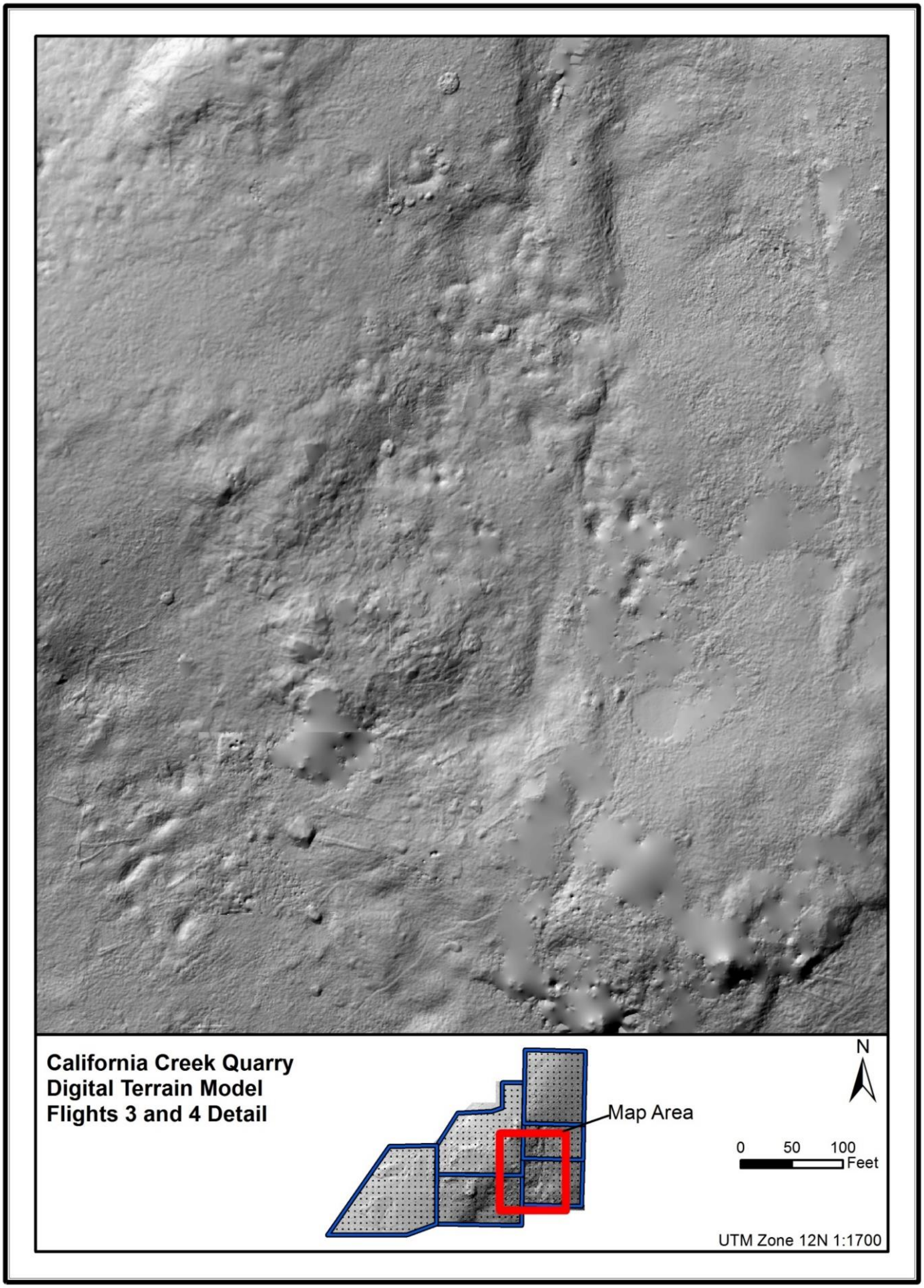

Figure 17 Detailed view of quarry pits from the DTM. Areas with flat and featureless terrain are errors resulting from the presence of dense vegetation

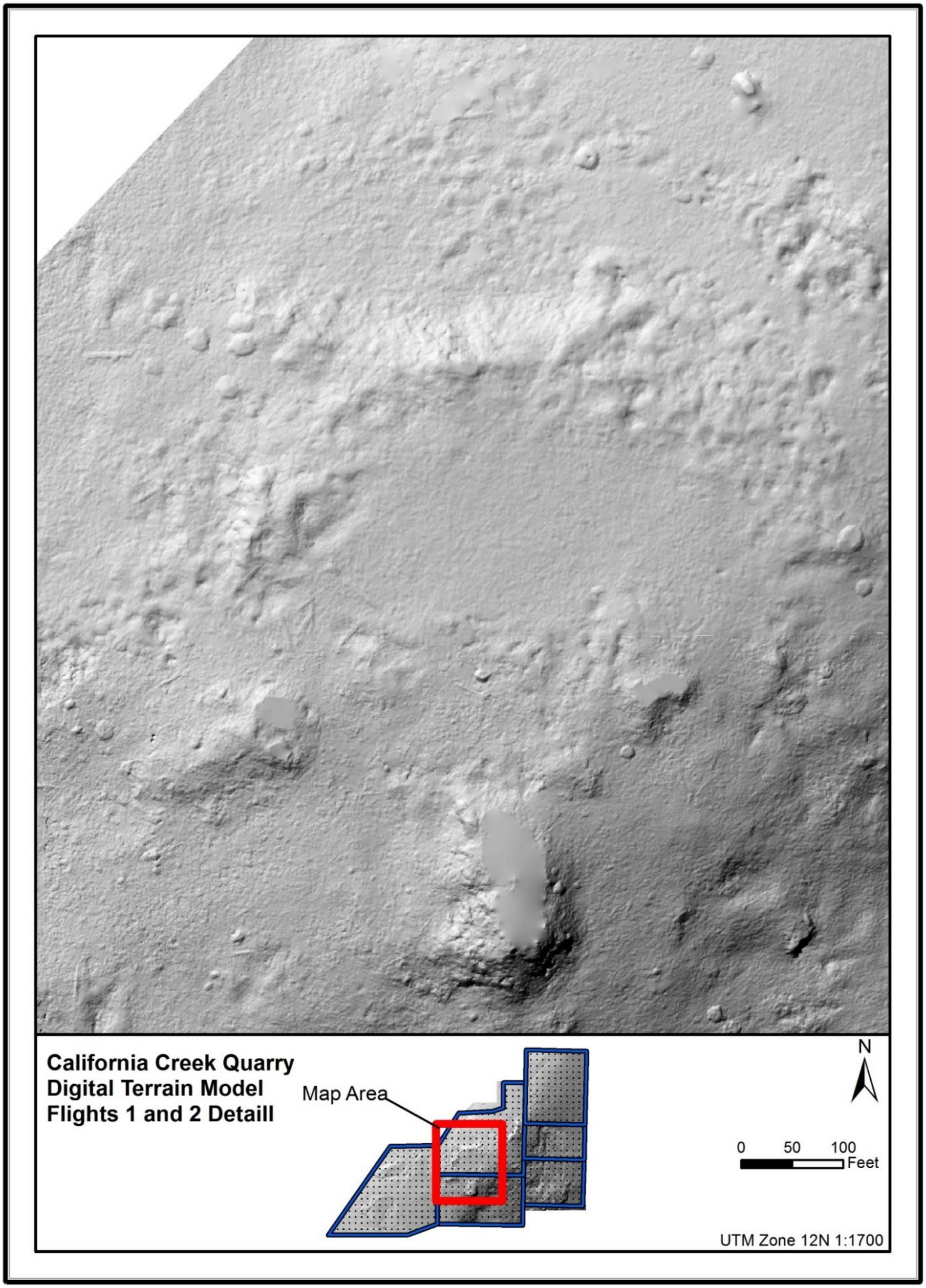

Figure 18 Detailed view of quarry pits from the DTM

5.4 Mining Intensity and Spatial Analysis

Using spatial analysis techniques to leverage the DTM allowed for the accurate and efficient measurements of mining intensity on site through to be obtained. The volume measurement is particularly useful, as archaeologists have developed equations that can translate volume of material removed into the number of person hours it would have taken to remove the material. This provides a useful metric for determining how much time was spent mining on site based on average caloric expenditures needed to remove a set unit of material. The spatial analysis based techniques used to perform these measurements involve two main steps.

The first step is to artificially fill in all quarry pits on site using a "Fill" tool in the Spatial Analyst tools of ArcDesktop. This tool was originally developed for hydrological modeling and it essentially fills all closed depressions within a DTM prior to extracting drainage information from the DTM. A closed depression essentially describes a quarry pit, so this process identifies and artificially fills the quarry pits on site. Each is filled as if water had been added to them to just below the point where they would overflow. The result is shown below (Figure 19). The tool proved remarkably accurate at recognizing and filling the quarry pits on site. The next step is to perform a 'Cut Fill' operation.

A cut fill operation subtracts one DTM from another. In this case, the tool was used to subtract the filled DTM from the original non-filled DEM. The output from this operation is a raster surface, or grid of cells, where each cell value is determined based on changes in elevation between the two DTMs. Essentially, the result is a measurement of the volume and area of material that was added in order to artificially fill the quarry pits. The output contains a table of these measurements, including the volume and surface area of all areas that contained cuts and fills between the two inputs. This process is a very quick and accurate way to measure the volume and area of hundreds of quarry pits on site with a few clicks. The only other way to do this would be to hand measure the volume of each pit individually using ArcPro or Drone2Map. That process involves drawing a polygon around each pit individually and then

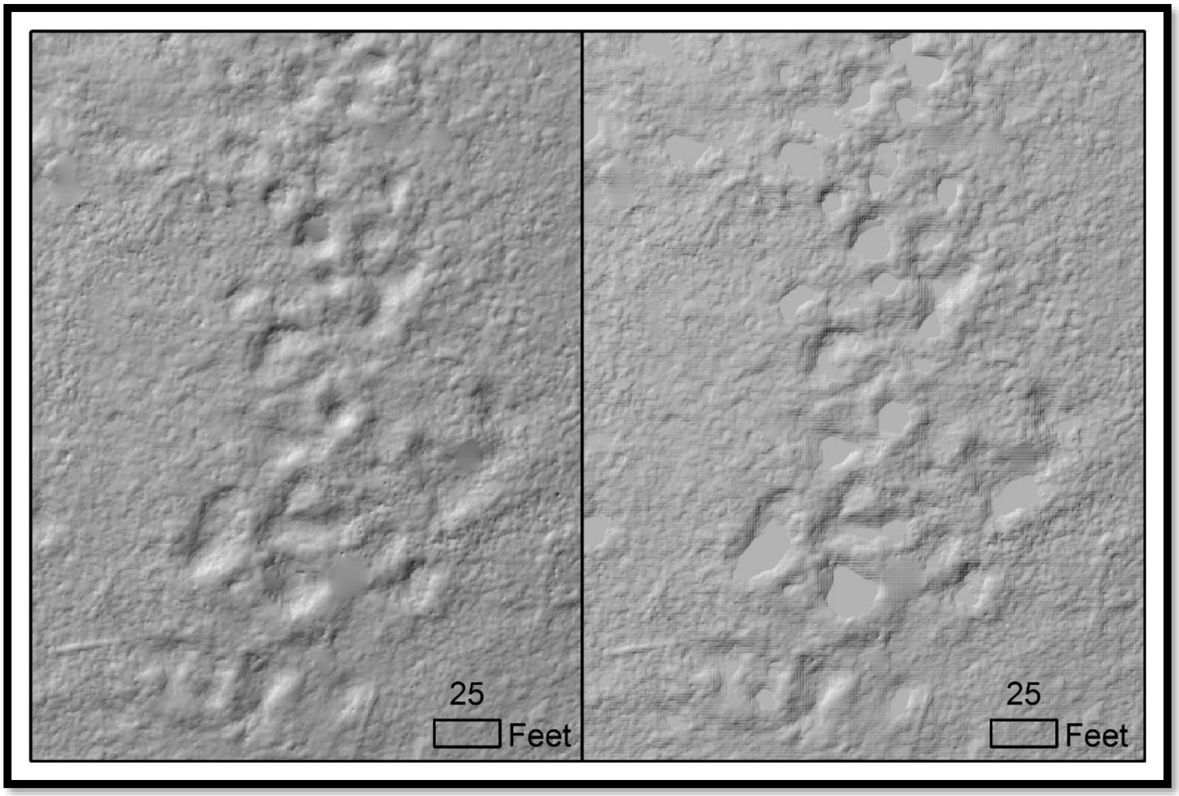

Figure 19 Left image is before fill, right image is after fill

running a volume calculation. Clearly, the cut fill method is far more efficient especially when there are hundreds of pits to measure.

There are a few limitations, however, and not every pit was perfectly captured by the fill and cut fill operations. In particular, a few pits are located on hillslopes and their downhill edge is not higher than the pits deepest point. Pits located on hillslope have a half bowl shaped geometry and making it impossible to calculate their true volume with this method. However, these instances were rare and many pits on hillslopes had a downhill edge that was higher than the pits deepest point. Visual inspection of the modeling results indicate that over 95% of the pits were accounted for during this process. To verify the accuracy of the volume calculation ten pits were selected, and their volume was measured by drawing a polygon around the pit in ArcGIS Pro and calculating the volume contained within the polygon. When this volume was compared to that obtained through the cut fill operation, it was found that the difference between these measurements was minimal and there was never a difference between the two that exceeded 0.01 cubic meters for all ten pits compared. A second limitation is that its unknown how the quarry pits have changed in volume since their initial excavation. It seems likely that many are far shallower than they were originally and have been partially filled in by slopewash and aeolian deposition. Tunnel like pits are also difficult to measure with this data, as these pits on site were either filled in by debris or their subsurface component could not be represented by the 2D DTM at all. It's likely that the volume of material removed from these tunnels like areas was significant, though it would be impossible to measure without re-excavating them. Finally, in one case a natural closed depression was lumped together with quarry pits. This closed depression was a result of karstic subsidence where a spring upwelling occurred. Comparing the results of the fill process to the orthophoto made this anomaly clear and it was removed from the total volume calculation. Cumulatively, it's likely that the volume of the pits measured today is reliable for present conditions but likely underestimates the actual volume of material removed from the quarry site.

The results of the volume calculation show that 487 cubic meters of material have been removed from the California Creek quarry. In addition, 550 pits were documented covering a combined area of 3,865 square meters. The full results are included in a table in Appendix 1 below. Originally, Les Davis estimated that only 120 pits were present on site. The difficulty in defining the boundary of any given quarry pit on site likely contributed to the disparity here, but the level of spatial documentation provided by this data also contributes to the higher count. There are also some notable trends relating to the volume of the pits on site. The first is that many of the pits are relatively small in area and volume, the vast majority of which are under 1 cubic meter in volume. This reflects the general observation that most pits are shallow and ovoid shaped and occur in areas where the bedrock is close to the surface. A second trend is that of the larger volume pits, generally 5 cubic meters in volume and above, most are concentrated in the southeastern portion of the site. This reflects the observed trend that these pits tend to be concentrated in areas with deeper soils conducive to deeper excavations.

Finally, some of the largest pits on site also contain tunnel features. Cumulatively, the data reaffirms the general observations gathered during field reconnaissance.

Archaeologists have calculated that it takes a person one day to remove one cubic meter of material from a quarry area, so mining activity at the quarry represent 487 person days' worth of effort. This calculation is useful but also limited in scope. It cannot account for the differing mining techniques potentially used at the site (e.g. fire) or the tunnel features and effort taken to excavate those. Furthermore, it's likely that the quarry pits in their modern form have been partially filled in by slopewash and aeolian deposition, which may lead to an underestimate of the amount of person days of effort expended at the quarry. Regardless, the calculation of volume and its translation to person day so effort provides a general framework for comparing mining intensity at the numerous quarries found in Montana. In addition, this method of volume calculation is far more accurate than those provided in other studies, such as those by Ahler at the Knife River Flint quarry (Ahler et al 1986). In that study, he notes that other researchers have estimated the volume of material removed from quarries with little to no justification of the methods used to calculate it (Ahler et al 1986:18). This issue begs revisiting, especially since the KRF quarries now have LIDAR coverage. Using cut fill technique outlined here on the LIDAR data could provide a far more accurate accounting of the volume, area and total number of quarry pits found at the KRF quarries and many others for that matter, albeit with some of the same caveats listed above.

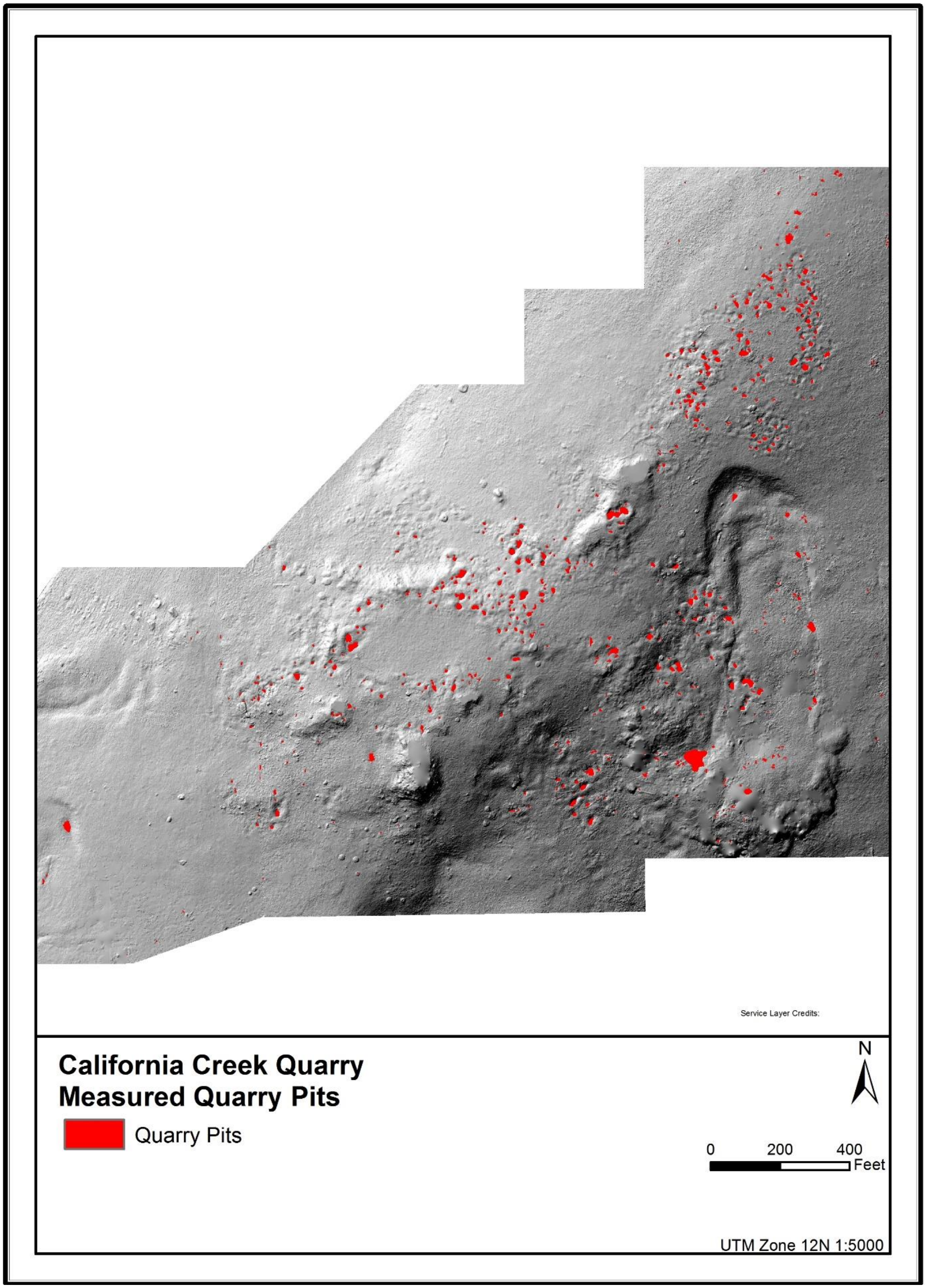

Figure 20 Final output with measured quarry pits highlighted

Chapter 6 Conclusions

Based on the evidence presented here, its clear that the California Creek factored prominently into the regional subsistence strategies of past populations for at least the last 10,500 years. Several factors contribute to this conclusion. The first is related to the nature of the geologic chert deposit itself. The deposit features an enormous quantity of high quality chert material covering an area of nearly 100 acres. Ongoing geologic mapping indicates that the geologic unit responsible for this quarry is potentially widespread and warrants further investigation. The second is that the quarry occupies an area where several physiographic provinces converge. These provinces influence the regional distribution of important resources like salmon and bison, thereby influencing the territorial boundaries of regional tribes who exploited them. Diverse groups inhabiting the Great Basin, Columbia Plateau and Great Plains would all likely have been familiar with the quarry since its near to where these cultural regions converge. A second factor contributing to the significance of the quarry is its proximity to the Deer Lodge Valley.

The Deer Lodge Valley contains a yearlong abundance of deer, numerous hot springs with prized healing properties and is at the convergence of several regional travel corridors. The resource abundance of the valley and its location provided a natural setting for trade, socialization and communal hunting; all of which is reflected in ethnohistorical data. Perhaps most important, large communal fall buffalo hunts were staged from the Deer Lodge Valley and would have likely required abundant lithic tools to facilitate. This was likely a crucial factor in determining the seasonal use of the quarry. The high elevation camas population surrounding the quarry would have offered additional incentives for quarry use in the early summer months. Given the abundance of biotic and geologic resources surrounding the quarry, its most likely that mining at the California Creek was embedded into other subsistence activities rather than being 'disembedded' (Binford 1979). However, this does not preclude its importance as a potentially significant trade commodity. The regional significance of the quarry warrants a more complete documentation of the site than has been conducted to date, which was accomplished through the use of UAS survey.

The UAS based remote sensing of the California Creek quarry produced high resolution spatial products that capture the scale and extent of the prehistoric mining that took place on site. Compared to traditional methods for producing such products, the UAS based survey was both an efficient and relatively low-cost solution. The methods demonstrated here can be easily applied by a beginner UAS pilots with recreational grade hardware and require minimal time. The data produced from the UAS survey can be leveraged through relatively simple methods of spatial analysis to produce robust measurements of mining intensity on site, which are in turn useful for understanding the amount of effort expended in mining at the site. The UAS methods can be further refined as UAS technology continues to advance and new tools become more affordable, such as UAS based LIDAR. Furthermore, the Cut Fill method for volume measurement has the potential to more accurately measure mining intensity at a variety of quarries in any setting. Whether the DTM data used is derived through UAS, plane-based LIDAR or other methods, this method offers a simple and efficient way to produce a relatively complicated calculation.

The data produced from this UAS survey can serve as baseline data upon which to base future research at the quarry, including potential excavations or further research regarding mining technology used at the quarry. One potential application of this method going forward would be to use it for a regional comparison of mining intensity. The low-cost UAS method is well suited to providing the baseline data needed for such a comparison, and areas featuring high mining intensity (e.g. volume of material removed) may be indicative of regional significance. Finally, the most important area for future research regarding the California Creek quarry would be to test whether the chert mined here can be sourced. Linking material from this quarry to archaeological assemblages in region is the best way to validate the regional significance of this source.

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APPENDIX 1. Table of the Volume and Area of Quarry Pits

Quarry Pit Number	VOLUME (m3)	AREA (m2)
1	0.05	3.57
2	0.05	3.13
3	0.05	1.16
4	0.05	1.81
5	0.05	0.81
6	0.05	1.98
7	0.05	1.79
8	0.06	1.91
9	0.06	0.74
10	0.06	2.90
11	0.06	1.57
12	0.06	1.21
13	0.06	1.63
14	0.06	2.44
15	0.06	1.83
16	0.06	2.80
17	0.06	1.42
18	0.06	1.63
19	0.06	1.09
20	0.06	1.44
21	0.06	1.61
22	0.06	1.61
23	0.06	1.90
24	0.06	2.15
25	0.06	4.38
26	0.06	1.80
27	0.06	1.53
28	0.06	1.14
29	0.06	1.67
30	0.06	3.67
31	0.06	1.41
32	0.06	3.27
33	0.06	0.95
34	0.06	1.11
35	0.06	1.27
36	0.06	3.01
37	0.06	2.81
38	0.06	3.63
39	0.06	1.07

Quarry Pit Number	VOLUME (m3)	AREA (m2)
40	0.06	2.24
41	0.06	0.98
42	0.06	1.67
43	0.06	1.37
44	0.06	2.00
45	0.06	1.45
46	0.06	1.72
47	0.06	3.99
48	0.06	1.34
49	0.06	1.50
50	0.06	2.40
51	0.06	1.67
52	0.06	2.46
53	0.06	1.91
54	0.06	1.33
55	0.06	1.58
56	0.06	1.69
57	0.06	2.01
58	0.06	3.65
59	0.06	2.27
60	0.06	2.62
61	0.06	3.32
62	0.06	2.11
63	0.06	2.72
64	0.06	2.10
65	0.06	1.69
66	0.06	2.21
67	0.06	1.66
68	0.06	2.38
69	0.07	3.62
70	0.07	2.17
71	0.07	3.47
72	0.07	1.45
73	0.07	2.24
74	0.07	2.63
75	0.07	1.56
76	0.07	2.28
77	0.07	2.94
78	0.07	1.38
79	0.07	0.64

Quarry Pit Number	VOLUME (m3)	AREA (m2)
80	0.07	1.07
81	0.07	2.84
82	0.07	1.74
83	0.07	2.59
84	0.07	2.16
85	0.07	3.51
86	0.07	1.50
87	0.07	3.06
88	0.07	0.71
89	0.07	2.56
90	0.07	1.36
91	0.07	1.40
92	0.07	2.02
93	0.07	1.45
94	0.07	2.25
95	0.07	2.62
96	0.07	1.48
97	0.07	2.07
98	0.07	3.30
99	0.07	1.63
100	0.07	3.02
101	0.07	1.98
102	0.07	3.11
103	0.07	1.83
104	0.07	3.12
105	0.07	1.21
106	0.07	2.72
107	0.07	1.84
108	0.07	2.44
109	0.07	2.51
110	0.07	0.59
111	0.08	2.06
112	0.08	2.50
113	0.08	3.73
114	0.08	2.19
115	0.08	3.20
116	0.08	3.31
117	0.08	0.99
118	0.08	2.25
119	0.08	2.49

Quarry Pit Number	VOLUME (m3)	AREA (m2)
120	0.08	2.49
121	0.08	1.33
122	0.08	2.65
123	0.08	1.31
124	0.08	0.99
125	0.08	4.05
126	0.08	3.78
127	0.08	0.78
128	0.08	2.30
129	0.08	1.55
130	0.08	2.75
131	0.08	2.34
132	0.08	1.02
133	0.08	0.78
134	0.08	1.98
135	0.08	2.10
136	0.08	2.56
137	0.08	2.76
138	0.08	2.00
139	0.08	2.44
140	0.08	4.06
141	0.08	2.86
142	0.08	2.19
143	0.08	3.41
144	0.08	3.05
145	0.08	3.29
146	0.09	1.98
147	0.09	2.28
148	0.09	1.41
149	0.09	2.07
150	0.09	1.57
151	0.09	1.93
152	0.09	0.62
153	0.09	1.82
154	0.09	0.79
155	0.09	2.00
156	0.09	0.97
157	0.09	2.71
158	0.09	1.51
159	0.09	1.50

Quarry Pit Number	VOLUME (m3)	AREA (m2)
160	0.09	3.39
161	0.09	4.07
162	0.09	1.99
163	0.10	3.60
164	0.10	2.28
165	0.10	2.19
166	0.10	3.01
167	0.10	1.01
168	0.10	1.89
169	0.10	3.00
170	0.10	2.40
171	0.10	2.74
172	0.10	1.70
173	0.10	2.31
174	0.10	1.82
175	0.10	4.09
176	0.10	1.28
177	0.10	1.83
178	0.10	2.43
179	0.10	1.90
180	0.10	3.11
181	0.10	2.15
182	0.10	3.15
183	0.10	2.10
184	0.10	3.66
185	0.10	1.94
186	0.10	3.29
187	0.10	3.57
188	0.11	2.99
189	0.11	2.21
190	0.11	2.85
191	0.11	3.04
192	0.11	2.64
193	0.11	2.01
194	0.11	2.53
195	0.11	2.73
196	0.11	2.88
197	0.11	3.45
198	0.11	4.50
199	0.11	1.67

Quarry Pit Number	VOLUME (m3)	AREA (m2)
200	0.11	5.48
201	0.11	2.29
202	0.11	0.87
203	0.11	2.57
204	0.11	0.90
205	0.12	1.91
206	0.12	0.75
207	0.12	3.62
208	0.12	2.52
209	0.12	6.55
210	0.12	4.43
211	0.12	1.75
212	0.12	2.36
213	0.12	1.12
214	0.12	3.46
215	0.12	1.95
216	0.12	3.91
217	0.12	2.72
218	0.12	4.23
219	0.12	2.21
220	0.12	1.30
221	0.12	1.27
222	0.12	3.92
223	0.12	1.63
224	0.13	2.72
225	0.13	3.05
226	0.13	3.18
227	0.13	2.61
228	0.13	2.52
229	0.13	0.90
230	0.13	3.05
231	0.13	4.16
232	0.13	3.47
233	0.13	2.46
234	0.13	3.59
235	0.13	1.53
236	0.13	3.59
237	0.13	3.41
238	0.14	1.72
239	0.14	3.47

Quarry Pit Number	VOLUME (m3)	AREA (m2)
240	0.14	3.85
241	0.14	4.60
242	0.14	3.94
243	0.14	5.11
244	0.14	8.94
245	0.14	1.38
246	0.14	1.44
247	0.14	3.60
248	0.14	4.23
249	0.15	4.45
250	0.15	4.24
251	0.15	3.90
252	0.15	5.65
253	0.15	4.41
254	0.15	3.89
255	0.15	3.47
256	0.15	5.14
257	0.16	6.71
258	0.16	1.96
259	0.16	4.74
260	0.16	2.33
261	0.16	3.76
262	0.16	2.73
263	0.16	10.00
264	0.16	8.01
265	0.16	3.33
266	0.16	2.90
267	0.16	1.19
268	0.16	4.56
269	0.16	5.84
270	0.17	7.81
271	0.17	1.58
272	0.17	7.62
273	0.17	5.26
274	0.17	2.59
275	0.17	3.25
276	0.17	1.77
277	0.17	5.19
278	0.17	2.87
279	0.17	6.21

Quarry Pit Number	VOLUME (m3)	AREA (m2)
280	0.17	2.68
281	0.17	4.06
282	0.17	3.79
283	0.17	6.02
284	0.18	6.32
285	0.18	6.79
286	0.18	4.19
287	0.18	1.01
288	0.18	2.51
289	0.18	5.35
290	0.19	2.66
291	0.19	2.61
292	0.19	4.44
293	0.19	3.66
294	0.19	8.19
295	0.19	3.25
296	0.19	3.44
297	0.19	2.28
298	0.19	3.10
299	0.19	4.10
300	0.19	3.61
301	0.19	2.33
302	0.20	3.08
303	0.20	3.89
304	0.20	5.33
305	0.20	3.97
306	0.20	4.47
307	0.20	5.51
308	0.20	2.31
309	0.20	3.60
310	0.21	3.83
311	0.21	5.81
312	0.21	5.11
313	0.21	7.40
314	0.21	2.84
315	0.21	1.85
316	0.21	2.11
317	0.22	2.75
318	0.22	4.73
319	0.22	12.26

Quarry Pit Number	VOLUME (m3)	AREA (m2)
320	0.22	4.15
321	0.23	4.80
322	0.23	4.04
323	0.23	1.35
324	0.24	4.49
325	0.24	4.88
326	0.24	4.79
327	0.25	3.90
328	0.25	3.97
329	0.25	5.17
330	0.25	3.04
331	0.25	5.73
332	0.25	4.51
333	0.26	5.15
334	0.27	5.51
335	0.27	3.31
336	0.27	3.51
337	0.27	6.03
338	0.28	5.84
339	0.28	4.23
340	0.28	3.70
341	0.28	6.35
342	0.28	3.66
343	0.29	6.67
344	0.29	2.89
345	0.29	2.21
346	0.29	4.67
347	0.30	4.83
348	0.30	3.34
349	0.31	6.69
350	0.31	6.87
351	0.31	4.79
352	0.31	13.26
353	0.31	8.58
354	0.32	4.96
355	0.33	4.90
356	0.33	5.13
357	0.34	5.84
358	0.34	5.61
359	0.34	7.24

Quarry Pit Number	VOLUME (m3)	AREA (m2)
360	0.34	5.92
361	0.35	4.55
362	0.35	5.90
363	0.36	7.88
364	0.36	5.04
365	0.36	6.55
366	0.36	4.46
367	0.36	5.82
368	0.37	5.04
369	0.37	3.58
370	0.38	5.93
371	0.38	4.90
372	0.38	6.61
373	0.38	6.77
374	0.38	9.20
375	0.38	6.53
376	0.38	8.47
377	0.39	2.64
378	0.39	11.04
379	0.40	6.18
380	0.40	7.98
381	0.41	5.60
382	0.41	7.69
383	0.41	4.58
384	0.41	6.09
385	0.41	5.47
386	0.42	5.74
387	0.42	5.63
388	0.42	6.33
389	0.42	4.34
390	0.42	2.56
391	0.42	8.03
392	0.43	5.09
393	0.43	8.88
394	0.44	4.74
395	0.45	6.99
396	0.46	8.67
397	0.46	7.66
398	0.48	6.27
399	0.48	7.42

Quarry Pit Number	VOLUME (m3)	AREA (m2)
400	0.48	4.62
401	0.48	6.11
402	0.49	8.04
403	0.49	15.42
404	0.50	8.81
405	0.50	6.69
406	0.51	5.72
407	0.51	7.87
408	0.51	8.06
409	0.52	10.80
410	0.52	4.70
411	0.53	4.45
412	0.54	7.45
413	0.56	5.20
414	0.56	7.89
415	0.57	7.50
416	0.57	3.90
417	0.57	9.28
418	0.59	6.29
419	0.59	8.51
420	0.60	6.01
421	0.62	12.13
422	0.62	4.81
423	0.63	7.00
424	0.63	4.58
425	0.63	5.04
426	0.64	11.11
427	0.65	7.63
428	0.66	5.95
429	0.67	8.27
430	0.68	10.87
431	0.68	9.44
432	0.68	8.52
433	0.68	3.40
434	0.69	8.92
435	0.70	7.00
436	0.71	11.46
437	0.72	12.54
438	0.72	9.03
439	0.73	8.93

Quarry Pit Number	VOLUME (m3)	AREA (m2)
440	0.73	5.86
441	0.74	8.86
442	0.78	12.18
443	0.79	8.90
444	0.79	9.29
446	0.79	10.43
447	0.80	10.30
448	0.81	6.07
449	0.81	13.05
450	0.83	17.05
451	0.83	17.19
452	0.84	9.70
453	0.85	8.61
454	0.85	10.00
455	0.86	13.82
456	0.90	6.09
457	0.90	15.49
458	0.90	9.74
459	0.91	12.09
460	0.91	13.96
461	0.93	10.50
462	0.96	17.85
463	0.97	8.57
464	0.97	17.64
465	0.97	11.06
466	0.98	9.91
467	0.98	8.59
468	0.99	9.86
469	1.00	16.40
470	1.01	9.15
471	1.01	9.25
472	1.04	6.93
473	1.05	19.66
474	1.06	7.66
475	1.06	6.66
476	1.08	8.53
477	1.13	13.24
478	1.16	11.85
479	1.24	11.79
480	1.31	10.32

Quarry Pit Number	VOLUME (m3)	AREA (m2)
481	1.32	13.00
482	1.36	18.36
483	1.37	25.63
484	1.39	4.62
485	1.39	15.47
486	1.39	8.59
487	1.41	11.70
488	1.43	28.04
489	1.54	5.69
490	1.55	15.09
491	1.59	11.69
492	1.60	20.32
493	1.61	15.18
494	1.62	8.92
495	1.73	14.96
496	1.74	24.31
497	1.74	19.03
498	1.76	15.40
499	1.81	12.28
500	1.92	13.08
501	1.95	16.15
502	2.02	4.91
503	2.04	24.09
504	2.10	11.13
505	2.10	11.57
506	2.12	10.37
507	2.19	14.20
508	2.24	17.11
509	2.25	13.96
510	2.34	12.61
511	2.38	13.48
512	2.40	17.27
513	2.44	11.21
514	2.57	9.84
515	2.58	19.85
516	2.83	44.46
517	2.85	18.93
518	2.88	17.48
519	2.96	20.87
520	2.96	28.32

Quarry Pit Number	VOLUME (m3)	AREA (m2)
521	3.17	17.51
522	3.19	22.22
523	3.24	16.17
524	3.48	17.23
525	3.58	21.30
526	3.74	24.91
527	3.79	26.76
528	3.96	18.44
529	4.25	22.09
530	4.54	35.05
531	4.73	23.69
532	4.76	19.30
533	4.94	24.82
534	5.26	20.17
535	5.28	24.76
536	5.41	33.80
537	5.47	21.03
538	5.77	29.81
539	6.03	31.08
540	6.66	39.43
541	6.93	46.61
542	7.76	39.81
543	7.91	44.86
544	8.02	22.17
545	8.17	32.24
546	8.71	42.25
547	8.91	33.97
548	10.16	49.46
549	24.71	90.85
550	102.38	241.34
Total	**487.02 m3**	**3865.67 m2**